University of Zurich[UZH]

Comparing Hand-Held Augmented and Virtual Reality for the On-Site Assessment of Construction Projects

GEO 511 Master's Thesis

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Abstract

Switzerland's major cities have been dealing with a persisting housing crisis and increased resistance towards densification, exemplified by a surge in building appeals. This thesis investigates the role that hand-held Augmented Reality (AR) and Virtual Reality (VR) could play in urban planning and the established public participation process of construction projects. The study's empirical component focuses on participants' responses to on-site visualizations of a hypothetical construction project. By conducting a between-subject (AR vs. VR) experimental study (n = 42), this research examines how different Extended Reality (XR) technologies influence public perception of such projects and the motivation to file an appeal against them. The results find little to no evidence of diverging perception or appeal behavior between the two conditions. The loss of green spaces and aesthetic utility are found to play a much more important role in the decision to appeal. This research not only sheds light on the impact of XR visualization tools on public engagement but also demonstrates the feasibility of integrating such technologies into the current urban planning framework under real-world conditions. Ultimately, this thesis contributes to the broader discussion surrounding the use of innovative technological interventions to promote more inclusive and effective urban planning practices, enhancing the way cities handle public participation and the development of its built environment.

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Acronyms

M mean 29–31, 33, 36–39, 41, 43, 44

SD standard deviation 29–31, 33, 36–39, 41, 43, 44

p p-value 33, 36–39, 41–44

r correlation 39, 41–44

AR augmented reality 9–11, 13–19, 24, 25, 27–30, 32, 33, 36–39, 41–47, 49, 64

CAD computer-aided design 30

CAVE cave automatic virtual environment 15

CI confidence interval 31, 33, 36–39, 41, 43, 44

GIS geographic information systems 28, 30

GNSS global navigation satellite system 17, 24

H0 null hypothesis 31–33

HA alternative hypothesis 31

HHD hand-held display 9–11, 14–18, 23, 33, 39, 42, 44, 45, 47

HMD head-mounted display 10, 14–17, 23, 47

ICT information and communications technologies 9

LOD level of detail 17, 25, 27, 45

MR mixed reality 13, 14

NIMBY "not in my backyard" 12, 13

VPS visual positioning system 25, 44

VR virtual reality 9–11, 13–19, 24, 25, 27–30, 32, 33, 36–39, 41–47, 49, 64

XR extended reality 6, 9–13, 15–18, 21, 24, 25, 28, 39, 41, 42, 44, 46, 47, 49

Chapter 1

Introduction

1.1 Motivation

Switzerland and, more acutely so, major Swiss cities like Geneva or Zurich have been dealing with a serious housing problem for several years already (Credit Suisse AG, 2023; Marty, 2024; Raiffeisen Gruppe, 2023; Stadt Zürich, 2023b; Statistisches Amt, Kanton Zürich, 2023; Zürcher Kantonalbank, 2023). Accordingly, the last few years have seen a lively media discussion surrounding this topic (Fleury, 2023; Herdt & Jonkman, 2022; Martel, 2023; Sarasin, 2023; Vontobel, 2023). While the symptom is generally very similar across the country—difficulty to find accommodation, rent increases, etc.—the underlying causes of the problem may vary. Geneva, for example, has seen a surge in housing supply in recent years (Curti, 2023; Pirszela, 2022), yet it's vacancy rate has not increased significantly and remains at a low 0.4% (Office cantonal de la statistique, 2024a, 2024b), suggesting that a surge in demand may be causing the problem. Zurich, on the other hand, has seen a sinking construction rate, accompanied by a dwindling number of construction permits being issued. In this case, there seems to be a supply-side problem. As of 2023, the city has less than 0.06% of its housing units vacant (Stadt Zürich, 2023c), demonstrating the severity of the situation.

In the case of Zurich, one part of the puzzle seems to be the high number of appeals against building permits. It has possibly the highest number of appeals against construction permits in the country, with 7 out of every 10 permits being appealed (Metzler, 2023). At the cantonal level, the number of appeals filed has also steadily increased since 2018, reaching an all-time high of 1012 appeals in the last report for the year 2022 (Baurekursgericht, Kanton Zürich, 2023). The high level of resistance could be caused by the lack of concern for housing affordability and social issues in densification efforts that have been reported in academic literature (Debrunner et al., 2020; Gerber & Debrunner, 2022; Hersperger et al., 2014).

While these statistics pose a challenge for developers and urban planners, as well as home seekers, construction appeals are an important tool for residents to take part in the decision-making process of their neighborhood. Citizen participation in urban planning has been a constant demand since at least the 1960's, with thinkers like Jane Jacobs (1961), Henri Lefebvre (1967) and Sherry Arnstein (1969) reorienting the discipline from a top-down functionalist approach to a more human-centered and inclusive one.

This participative approach towards urban planning has gained momentum, at least since the 1990's (Hersperger et al., 2014) and in Zurich, recent and current projects, such as the citizen participation projects "Stadtidee" (City Idea) (Stadt Zürich, 2023a), "Euses Züri" (Our Zurich) (Stadt Zürich, 2021) and "Züri wie neu" (Zurich like new) (Stadt Zürich, 2024b) are evidence of this new paradigm. However, all these projects come from the public sector in partnership with NGOs. Private developers, on the other hand, seem less invested in public participation and, instead, aim at bypassing or manipulating such processes (Debrunner et al., 2020; Gerber & Debrunner, 2022). So, while housing supply remains a problem, building appeals remain a crucial tool of control for the citizenry and, as such, should not be weakened.

Nevertheless, there is room for innovation. Developments in information and communications technologies (ICT) are creating new opportunities in digital forms of participatory processes in what is called e-participation (Chassin & Ingensand, 2022; Fegert et al., 2020; Scherer & Wimmer, 2011). The establishment of new geospatial services, such as Cesium ion (2024b), 3D city models (Stadt Zürich, 2023d) or Google's Photorealistic 3D Tiles (2024d), as well as developments XR technologies, like the introduction of new virtual reality (VR) headsets (Apple Inc., 2023; Meta Platforms, Inc., 2023) and augmented reality (AR) software (Google LLC, 2023c), provide fertile ground for new ways to expand citizen participation, while also dealing with the housing problem.

1.2 Research Goals

In this thesis, I investigate how XR affects our understanding of construction projects both to expand our knowledge of the technology and to facilitate its gainful use as a tool for participatory urban planning. To achieve this goal, I developed and conducted a user experiment to study whether and how AR and VR in the form of a hand-held display (HHD) differ from each other in how they influence our perception of development projects. The experiment leaned on current practices in the Swiss construction approval process, focusing on the on-site assessment of a fictive proposed building.

When applying for a construction permit, developers are required to publicize the planned buildings by mounting a framework at the construction site. This framework usually consists of construction poles that are used to demarcate the volume of the planned structures (see Figure 1.1). In this manner, residents are easily informed about incoming changes in their neighborhood and can get a rough idea of what will eventually be built. This announcement of the intention to building something is also the critical step where affected people have the right to demand the construction documents and later appeal against a positive decision by the authorities.

Given that these building frameworks are not very intuitive (Boos et al., 2023) nor necessarily precise (Collenberg, 2023), I want to innovate on this rustic form of visualization with the use of hand-held AR and VR. A better visualization of the projects with XR technologies could help alleviate the current situation by creating an easier venue through which neighbors get involved (Fienitz & Siebert, 2023). Furthermore,

Figure 1.1: Swiss construction framework consisting of construction poles (Unternährer, 2012).

XR has the potential to open urban planning up to other novel forms of e-participation (Fegert et al., 2020).

Also, there has been–to the best of my knowledge–no studies comparing AR and VR as HHDs. Instead, most experimental studies either do only one form of XR (Boos et al., 2023; Chassin & Ingensand, 2022; Jansen et al., 2023; Saßmannshausen et al., 2021; J. P. van Leeuwen et al., 2018) or compare them using different forms of hardware, e.g., VR in a head-mounted display (HMD) and AR in a HHD (Fegert et al., 2020; Huang et al., 2019; J.-H. Kim et al., 2023; Tai, 2023). As a secondary goal, this study aims at testing the feasibility and the limits of hand-held AR and VR with the technologies currently available in the market.

1.3 Research Questions

The research questions delineated below are what will guide this thesis and are derived from the goals stated in the last section. Moreover, the hypotheses articulated for each question will serve to test the outcome of the experimental study. They are inferred from the literature discussed in Chapter 2.

Research Question 1. *Does the selection of hand-held AR vs. VR as a tool for the on-site visualization of construction projects affect the user's perception of the project?*

Hypothesis 1. *AR will give a better understanding of the construction project than VR.*

Hypothesis 2. *AR will generate more confidence in the visualization than VR.*

Research Question 2. *Does the use of AR vs. VR affect the decision to file a building appeal against a development project?*

Hypothesis 3. *AR will diminish the number of appeals compared to VR.*

Research Question 3. *How feasible is the use of HHD AR and VR as a tool for the on-site visualization of building projects under current consumer-grade state-of-the-art technology?*

Hypothesis 4. *AR and VR will generate the same level of engagement.*

1.4 Thesis Outline

This thesis is divided into five further chapters. After this introduction, Chapter 2 dives into the theoretical background and literature review of the the two main topics of this thesis: Urban planning and XR. The experiment of the thesis is explained in detail in Chapter 3. With the use of statistical data analysis, the results are reported in Chapter 4. It is then followed with a discussion in Chapter 5, where the insights and implications of the experimental results are reviewed and put into context. Chapter 6 ends the thesis with a summary of the research and a highlight of what has been accomplished.

Chapter 2

Theoretical Background

This chapter explores the theoretical background that forms the backbone of this thesis. A literature review of the two main topics of this thesis, Urban Planning and XR, is done. The topics are first reviewed separately and later combined.

2.1 Urban Planning

2.1.1 The Swiss Context

With the first revision of the national spatial planning law in 2014, Switzerland committed itself to curbing urban sprawl (the encroachment of the built environment onto the natural environment) and, instead, focus on the densification of its existing urban centers (Bundesamt für Raumentwicklung, 2014). This change in policy has sparked the interest of Swiss academics to study inwards densification (Debrunner et al., 2020; Gerber & Debrunner, 2022; Wicki & Kaufmann, 2022; Wicki et al., 2022), but the same process is also being studied in other countries (Bauer & Duschinger, 2024; Herdt & Jonkman, 2022; Honey-Rosés & Zapata, 2021).

One major challenge that Wicki and Kaufmann (2022) and Wicki et al. (2022) found with this new paradigm is the ”not in my backyard” (NIMBY) phenomenon. This refers to the phenomenon in which residents accept change (in this case densification) on broad terms, but decrease their support the closer it occurs to their residence. However, acceptance is also project-specific and strongly affected by the perceived benefits and detriments of the project. Housing costs and amenities were common denominators influencing the acceptance of densification in their study on the canton of Zurich (Wicki & Kaufmann, 2022) and on six metropolises across Western Europe and the United States (Wicki et al., 2022). Furthermore, access to transportation was found to be a very important factor in Wicki and Kaufmann (2022), as well as the inclusion of public participation practices in Wicki et al. (2022), independent of the exact form they take.

In their case study of a redevelopment project in the city of Zurich, Gerber and Debrunner (2022) argue that NIMBY-ism against densification is caused by a lack of considerations for social issues on the side of private developers. They argue that, since Switzerland is a country where most people live in rented housing, evictions, high rents and a disregard for social cohesion have caused the citizenry to meet urban renewal projects with resistance (Debrunner et al., 2020).

2.1.2 Citizen Participation

In another study revolving densification, Bauer and Duschinger (2024) interviewed experts and surveyed residents in Munich, German. While experts tended to explain citizen action with NIMBY-ism, their findings from the surveys offer a more nuanced picture. Similarly to the findings of Gerber and Debrunner (2022) and Wicki and Kaufmann (2022), the acceptance of densification was strongly influenced by other factors. In this case, the three strongest were green spaces, density and traffic and parking.

Projects that maintained or improved green spaces were generally welcomed across the board, while increases in traffic and parking demand were seen negatively. The effects of densification, instead, were strongly dependent on how crowded the residents of an area felt, which was not directly correlated with actual density numbers. Bauer and Duschinger (2024) conclude that there is a divergence between experts and residents on what the local needs are, suggesting that increased public participation could help close this gap.

Geekiyanage et al. (2021) conducted a literature review of participatory methods in urban development between the years 2000 and 2020. Their results indicate that in most cases, public participation was limited to informing and consulting and mainly happened during the initial phases of the project. While community engagement was strong at first, it tended to wane in later on. The authors stress the gap found between intended and actual inclusivity, highlighting the lack of methods that are able to sustain engagement. Hügel and Davies (2020) come a similar conclusion in a review of participatory process in climate change adaption, indicating a deficient consensus on the definition and processes of public participation.

2.2 Extended Reality

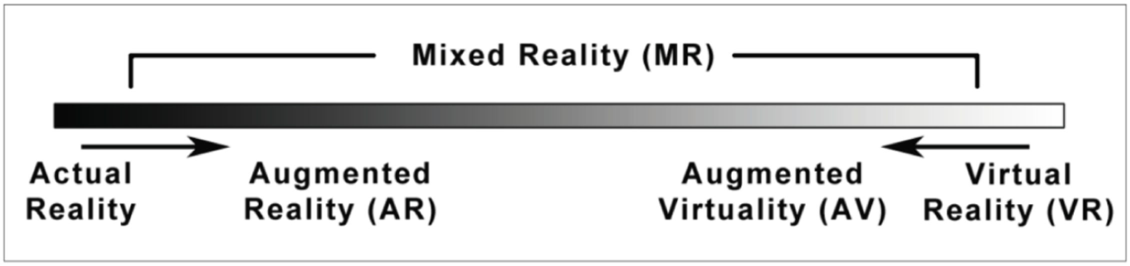
2.2.1 Definitions

The Reality-Virtuality Continuum

XR is an umbrella term that encompasses all display technologies found in the reality-virtuality continuum formalized in the seminal work of Milgram and Kishino (1994), which includes AR, mixed reality (MR) and VR (see Figure 2.1). The term XR, however, is not found in their paper and has instead been popularized more recently. Looking at Google Trends search statistics from 2004 to 2024 (Google LLC, 2024c), XR first appears in 2006, whereas the terms from Milgram and Kishino (1994), were already seeing use to different degrees since 2004.

Starting from the "reality" extreme of the reality-virtuality continuum, AR is the term used to describe the

Figure 2.1: Illustration of the Virtuality Continuum as proposed by Milgram and Kishino (1994) (graph taken from J.-H. Kim et al. (2023)).

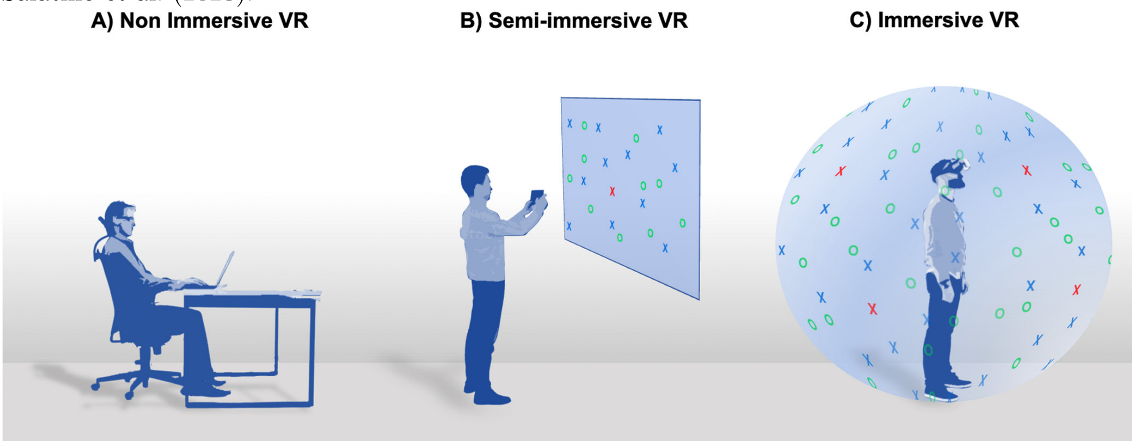


first steps towards blending virtual elements into the real world. Thus, by definition, AR depends on and enhances the real world. Typical examples of AR applications are Pokemon Go (Paavilainen et al., 2017) or face filters that add cat ears to a person, smooth their skin or reshape their face (Javornik et al., 2022). The level of spatial awareness found in AR technology can vary, from simply detecting specific types of objects (e.g., faces) to having local spatial awareness by detecting basic geometries (e.g., planes), making it able to anchor objects in the real world (e.g., to place furniture in a room), to supporting geolocation and having, accordingly, geographic spatial awareness.

At the other end of the spectrum, VR is a technology that presents us with a completely virtual environment and can therefore be completely disconnected from the real world. This makes it extremely flexible and allows for worlds that do not obey the rules of reality, which is probably why it has historically mainly seen development in the gaming industry. There are, however, other use cases, like education and simulation (Huang et al., 2019; Jantjies et al., 2018; Le et al., 2015). VR is mainly thought of as a technology that relies on HMDs blocking the real world from the user's perspective and immersing them into the virtual environment. Nevertheless, non-immersive VR, like a video game using a fixed monitor or using a HHD, is also part of it, in what Milgram and Kishino (1994) describe as a "window-on-the-world". Although this form of VR is less frequently called so, the term is often used when comparing immersive to non-immersive forms of the medium (Lee et al., 2020; Paes et al., 2017; Salatino et al., 2023).

MR, as described in Milgram and Kishino (1994), encompasses the entirety of the reality-virtuality continuum where both the real and virtual environment are combined. Until relatively recently, the term was sparsely used (Google LLC, 2024c), but this is changing fast. Passthrough, the ability to show the real environment through a VR headset using cameras on the outer side of the device, is changing the concept of MR to mean technology that is capable of transitioning between AR and VR modalities. The newly released Apple Vision Pro Apple Inc. (2023) has championed the idea of focusing on the AR experience of what would otherwise be considered a VR headset. Meta has also shifted their HMD technologies and their vocabulary from VR in the Meta Quest 2 (Meta Platforms, Inc., 2020) to both VR and MR for Meta Quest Pro (Meta Platforms, Inc., 2022) to mainly MR with the Meta Quest 3 (Meta Platforms, Inc., 2023). As these examples illustrate, MR is evolving and can mean different things to different people, which is why I

Figure 2.2: Levels of immersion in XR as proposed by Bamodu and Ye (2013). Illustration from Salatino et al. (2023).



will avoid the term and instead focus on AR, VR and XR.

Immersivity

As already touched upon, another important category when speaking of XR is the immersivity of a device or how immersive it is to the user. Milgram and Kishino (1994) refer to it as the "extent of presence metaphor" dimension, but further complex taxonomies have been created in more recent times (Hertel et al., 2021; Muhanna, 2015). For the purposes of this thesis, a simpler definition proposed by Bamodu and Ye (2013) will be used. The original definitions were meant for VR, but can also be applied to other forms of XR without problems.

This taxonomy distinguishes between immersive, semi-immersive and non-immersive experiences (Bamodu & Ye, 2013). Figure 2.2 illustrates the difference between these categories, which are often found in literature when XR technologies are applied to other fields, like education or medicine (Lee et al., 2020; Paes et al., 2017; Salatino et al., 2023). In non-immersive and semi-immersive systems, the user sees the virtual environment through a display while retaining awareness of the real world. Non-immersive systems rely on a joystick or a mouse and keyboard for interaction, like typical video games on a computer or console. Semi-immersive systems, on the other hand, distinguish themselves by either using a more immersive display system, like a cave automatic virtual environment (CAVE) (Cruz-Neira et al., 1992) or a more immersive input system, such as motion tracking. This can be achieved with a motion controller, like those used in immersive VR, or by building the functionality directly in a HHD, like in a smartphone. Immersive systems use a HMD to lock the user's vision into the devices display and react to the user's movements. This is what VR is colloquially understood to be.

2.2.2 Applications and Effects of Hand-Held XR

As already mentioned, research comparing AR vs. VR is relatively scarce and mostly focus on immersive VR vs. semi-immersive AR experiences (Huang et al., 2019; J.-H. Kim et al., 2023) and most of their findings are unfortunately not translatable to this study. However, studies on the effects of HHDs provide insights into the potential of the medium. For example, better information retrieval and task performance has been commonly reported when compared to traditional visualization methods (Chalhoub & Ayer, 2018; Chu et al., 2018; El Asmar et al., 2021; Machała et al., 2022; Rohil & Ashok, 2022; Yigitbas et al., 2023).

When comparing HHDs to 2D maps, reports are contradictory. Dong et al. (2021) found no significant difference in wayfinding performance, while Qiu et al. (2023) found better performance and spatial knowledge acquisition. In education, reports show that the medium significantly improves retention through a richer experience and increased immersion and interaction (Al-Ansi et al., 2023; Javornik et al., 2019). In tourism, the use of XR in HHDs has been reported to create high user engagement (Katkuri et al., 2019; Omran et al., 2023; Pervolarakis et al., 2023; Phipps et al., 2016) and in marketing, hand-held AR has been found to increase user-brand engagement (Scholz & Smith, 2016; Smink et al., 2020; Wedel et al., 2020).

Song et al. (2021) tested the effects of ads in VR using different formats (non-immersive computer monitors, semi-immersive HHDs and immersive HMDs) and virtual represenations of the self (present self vs. absent self). Interesting for this study is that no differences were found between the VR formats. In another marketing study, J.-H. Kim et al. (2023) compared hand-held AR to head-mounted VR. From it they concluded that the engagement in AR was mainly mediated through vividness (providing a rich rensorially medium), while VR was also positively affected by interactivity.

From these studies, it is safe to assume that semi-immersive XR using a HHD is effective in engaging the user and that this has positive effects in performance and memory retention. However, as reported by Berger and Gerke (2023) and Davila Delgado et al. (2020) the technology has yet to be widely adopted for citizen science projects (Berger & Gerke, 2023) and in the field of architecture, engineering and construction (Davila Delgado et al., 2020), mainly because of a lack of know-how and resources.

2.2.3 XR in Urban Planning

During the redesign of a park in a public participation process, J. van Leeuwen et al. (2018) studied whether different visualization technologies had an effect on public involvement. From all media used (VR headsets, smartphones, tablets, computers and 2D paper plans), VR headsets and smartphones had the highest level of engagement and significantly outperformed other media. In a later laboratory study comparing immersive head-mounted VR vs. non-immersive computer visualizations of the same park, the authors found significantly better levels of self-reported immersion, translocation and concentration in immersive VR (J. P. van Leeuwen et al., 2018).

Fegert et al. (2020) also conducted a study comparing AR and VR in public participation using a mixed-methods approach where non-*in situ* visualizations of a new zoo section were presented to the public. Here, VR showed a higher degree of translocation and engagement than AR, although the methods also varied in their presentation, with AR providing a scaled-down visualization using a HHD and VR showing a to-scale visualization in a HMD.

2.2.4 XR in Swiss Urban Planning

Various studies have investigated the viability and effects of XR technologies as a tool of public participation in the Swiss urban planning context (Boos et al., 2023; Chassin & Ingensand, 2022; Weber et al., 2022). Similarly to what this study was set to achieve, Boos et al. (2023) studied the suitability of HHD AR building visualization compared to construction frameworks. The experiment followed a between-subjects design, with three levels of detail (level of detail (LOD) 1, 2 and 3) as treatment. The results show that the LOD did not significantly affect the estimation of the building's dimensions. The participants did, however, tend to overestimate the building's height and width, while underestimating the length. Gathered from the participants' opinions, the experiment also clearly established AR as a better tool than construction frameworks for visualizing planned buildings. Here again, no significant differences were found between the different LODs. It is important to notice that most of the participants were under the age of 30 and from an academic background, meaning that the results may not be generalizable to the whole population.

Chassin and Ingensand (2022) developed a HHD VR web app for participatory urban planning, focusing on ease of access and use. Like the aforementioned AR product, this prototype was developed for *in situ* participation. As such, the virtual and real environment were linked together via global navigation satellite system (GNSS). The app also had a comment function, which allowed users to record positive or negative feedback with the option to add a written or vocal message. Using the VR app to explore the project, the users were asked to add comments. In a post-experiment survey, most participants gave a positive impression and found the prototype easy to use and interpret, immersive and suitable for public participation. Compared to a 2D map presented a the beginning, most people did not think the map was better. Negative aspects were that some participants were unsure what was part of the construction project, were not attentive to their surroundings and most of them wished for a more realistic visualization.

In another study, Weber et al. (2022) investigated how the voting behavior in a fictive hyperloop construction project was affected by the presentation format. The researchers compared conventional Swiss voting booklets with a HMD VR. The experiment followed a 2×2 design with the two treatments being the format (text vs. VR) and framing (pro vs. con). Before being presented with the treatment, participants had to first vote on the issue based on a summarized text. This vote was used as the baseline. The results showed that the VR treatments caused a significant shift towards accepting the project, irrespective of the framing. In contrast, the text treatment caused a shift towards rejecting the project. The framing did affect the voting for both VR and text, although the effect was stronger for the text treatment group, where a difference between the pro and con treatment was observed. This could, however, be explained by the VR groups noticing the framing less than the text groups. In general, the persuasive power shown by the VR presentation could be explained by it being more engaging and immersive, the design of the virtual environment and the novelty of the technology.

Summarizing the findings from these studies, it can be concluded that XR solutions are more engaging than their conventional counterparts and that, in general, XR is well accepted as a method of participation. Admittedly, the positive evaluation of these solutions could be caused by their novelty and thus amazement at the technology.

There remains research to be done regarding interpretability of the XR visualization and any influence this could have on decision-making. Differences between the various XR technologies could also be further studied in the urban planning context. For example, for HHD, AR allows for an easier transition between the hologram and the real world than VR.

But, it requires more processing power and infrastructure to accurately place the hologram ((Chetoui et al., 2022)), which can hinder a seamless experience. Since VR does not depend in real world like AR, it also comes with more flexibility. For example, it would be easier to simulate the shade generated by a building at different times of the day. Head-mounted VR is more immersive than hand-held VR but cannot be easily used *in situ*.

Chapter 3

Methodology

This chapter dives into all relevant information related to how the experiment was prepared and conducted. It starts by explaining the experiment in detail. From how it was designed, where it took place to how it was conducted. The structure of the experimental procedure and the wording of the questions reached its final form after a pilot experiment. It continues with the materials of the experiment, mainly what software was used for the prototypes and how they were put together into a smartphone app. The chapter ends with the recruitment process and an overview of the demographics of the people that took part in the study.

3.1 Experimental Design

The experiment followed a between-subjects design with the two prototypes, AR and VR, acting as the condition or independent variable. By consequence, the study consisted of two groups with each participant taking part in the experiment separately and only getting to see their respective prototype, which was randomly selected. This design was chosen to avoid muddying the results with confounding variables, like learning effects. The dependent variables used to test the hypotheses and answer the research questions were the participants responses to a series of tasks and questions, which will be described in more detail in section 3.1.1.

Since a construction project was to be assessed in a similar fashion to how it is done today with construction poles, the experiment had to take place outside with the building visualized on a 1:1 scale. Furthermore, the scenario and, subsequently, the site of construction had to feel realistic. To immerse the participant into the experiment, a scenario was developed in which the participant was a resident in the vicinity of the construction project (more on this in section 3.1.3). This was reinforced by visiting a real building that was supposed to be the participant's residence and looking at the virtual building from there. The selection of the experiment site will be explained later in section 3.1.2.

Given that this was a field experiment, many factors potentially affecting the results could not be directly controlled, i.e., were random variables. These included but were not limited to the weather and the business of the area. A measure implemented to constraint these was to provide time slots in a checkered manner, meaning that each group had alternating time slots available to them and their order also alternated between days so that disruptive factors, like rush hours, were not systematically given to the same group. The time slots were also limited to the hours between sunrise and sunset to avoid stark changes in light conditions. During the time of the year in which the experiment took place, this meant conducting the experiments between 8 a.m. and 6 p.m. Other variables were directly controlled for. For example, the gender ratio was balanced out between samples. Special care was also given to keeping the procedure, as well as the materials (i.e., the hardware and the software) constant between the groups and throughout the sessions.

3.1.1 Questionnaires

Three separate questionnaires were used in this study, which I will call the pre-experiment, the intra-experiment and the post-experiment questionnaires. The pre-experiment questionnaire was used for the recruitment process and will be described in section 3.3.1. The intra-experiment questionnaire had to be completed while the participant had access to the prototype and thus to the digital visualization of the construction project. It included building dimension estimation tasks and floor estimations tasks, as well as diverse statements regarding the participant's perception of the building and the visualization, what impact the project would have on its surroundings and whether the participant would take actions towards filing a building appeal.

For the dimension and floor estimations, the participant had to answer with a whole number. The number of floors was not directly relevant for the experiment results, but were rather put in place to further engage the participant into thinking about the shape of the building. The statements were answered by selecting an option in their accompanying 5-point Likert scale responses ("strongly disagree", "disagree" "neither", "agree", "strongly agree") (Likert, 1932).

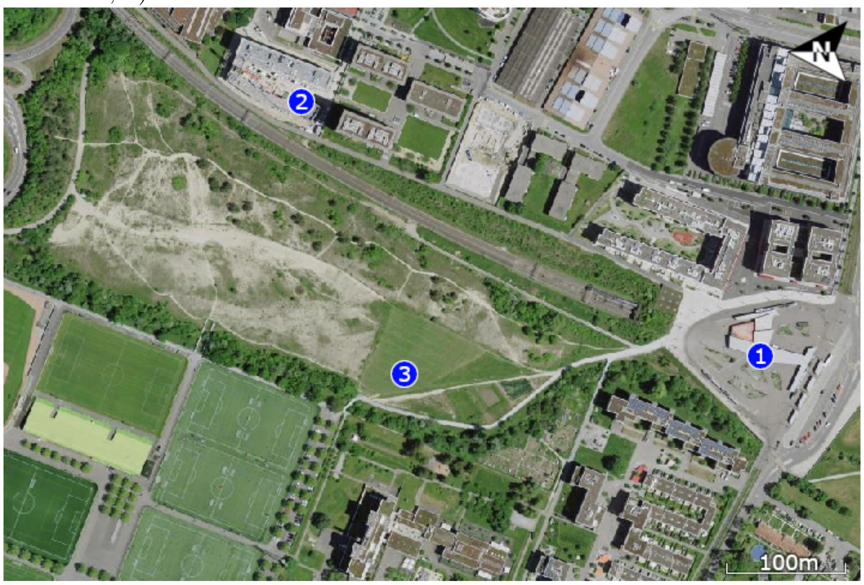
Lastly, the intra-experiment questionnaire had two questions that were to be answered in written form. One asked the participant what their impression of the site in which the building was to be constructed was. The other asked the participant to state the reason why they would or would not consider filing an appeal against the project.

The post-experiment questionnaire was to be answered retrospectively, after having used the prototype and not having access to it anymore. It only contained statements with a 5-point Likert scale and they encompassed statements related to the visualization and the app.

3.1.2 Experiment Site

The experiment took place in the surroundings of the Zurich Stettbach train station with the fictitious development project to be constructed in a close-by open field. Figure 3.1 shows a top-down photo of the areas of interest. The site of the building lies between two municipalities with contrasting character. On the Dübendorf side, in the Hochbord area, high-rises are allowed to be built with several towers reaching $100\,m$ in height or more. On the other side, in Zurich's Schwammendingen district, most buildings are less than $20\,m$ high. Both sides are experiencing active development, with construction sites for renovations or new buildings seen during the experiment sessions.

Figure 3.1: Top-down view of the experiment site. 1) Zurich Stettbach train station, 2) residential building with terrace, 3) fictitious construction site.



This site was chosen by a number of factors. An open area was needed so that the visualization would not be blocked by structures, like buildings or vegetation. Vegetation, especially large trees, can be extremely problematic because it is very difficult to adequately represent them in a virtual environment. Using a 3D iconic representation of a tree can work for certain projects, like Chassin and Ingensand (2022) did, but it is too reductionist when they directly affect the object being assessed. It is possible to use photogrammetry or LiDAR to generate a point cloud and later a mesh Miller et al. (2015) and Morgenroth and Gomez (2014), but this is out of study's scope. An open area also gave the participants the space needed to safely wander around and see the building from different perspectives. Chassin and Ingensand (2022) reported in a similar experiment that participants tended to lose awareness of their surroundings, so busy areas were to be avoided.

The development project also could not compete with something like a popular park that could strongly skew the participants' responses towards a building appeal. For the same reason it couldn't blatantly go against existing regulation by, e.g., proposing the building on a protected area. The idea also needed to seem plausible, so that the participants could buy into it. Contrary to what Boos et al. (2023) did in a similar research project, the building project was not placed on an actual construction site. Comparing the XR prototypes to construction poles would have been interesting, but it was not needed to answer the research questions. For this reason and to remain flexible and avoid unnecessary risks, a fictive construction site was chosen.

Adequate reachability by public transport was also important, since that was predictably how most participants would arrive to the experiment. Lastly, part of the motivation for this research was the alarming number of construction appeals issued in Zurich and so, a location within the urban fabric was preferred. Another building from which the virtual building could be observed was also needed for the tasks to be performed. The administration of the building Westhof at the address Zukunftstrasse 17 in Dübendorf (site 2 in Figure 3.1) was kind enough to allow us the use of their facility for the experiment, specifically its roof deck. This place served as the imagined balcony of the participants' fictive apartment.

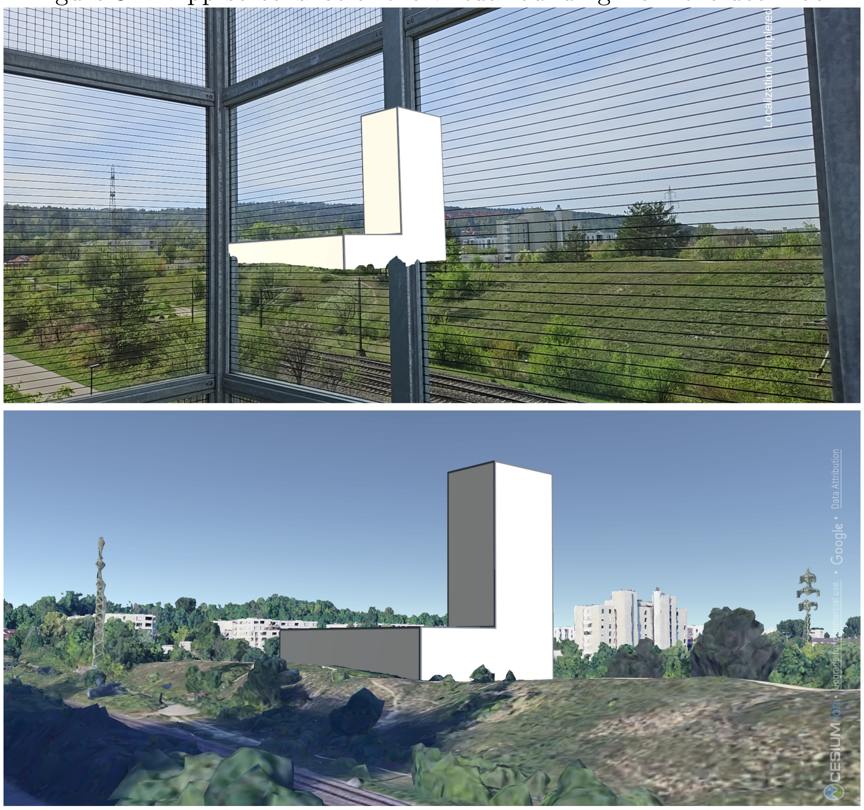
3.1.3 Experimental Procedure

A protocol was written for the experiment to formalize its procedure. The document can be found in appendix D. The participants were met at the train station. After greeting them and having them sign the consent form found in appendix E, they were introduced to the experiment. The introduction consisted of a brief overview of the experiment and its research purpose, an introduction to the experimental scenario and procedure, and an outline of how development project approvals and construction appeals work. They were also shown where the experiment would take place and told which prototype they were going to use without indicating how this differed from the other condition. The fictional scenario envisaged the participants living close to the proposed project, in a building from which the construction project would be seen (an example is found in Figure 3.2). The roof deck of site 2 in Figure 3.1 was used for this purpose. In this scenario, by being directly affected by the development of this high-rise, the participant would be interested in looking at what is being proposed, relying on the selected prototype to visualize it.

After the introduction, the roof deck of the participant's fictive place of residence was first visited. From there, the participants got to see the visualization for the first time. Two reasons made this choice sensible: The first one was for the participant to better understand the context of the scenario and how the high-rise would affect them, hopefully getting the participant invested in assessing the project attentively. The other reason was that, given the distance of around $230\,m$ from the construction site, the visualization was not as reliable as from proximity and it happened sometimes that the device was not able to correctly locate the device's pose. If this happened, the app had to be restarted and this could lead to a negative anchoring effect (Jacowitz & Kahneman, 1995) that could lead to skewed results in later questions.

The experiment continued in the immediate proximity to the construction site on the open field. Figure 3.3 illustrates how the building looked like from the field. This was the longest part of the session, with many dimension estimation tasks, followed by the assessment of various statements. The participants were placed in front of the building and from there were given free movement to inspect it and estimate the size. Once they were done with the estimations, they had to make some assessments about the building, its effect on the area and whether they would consider filing a building appeal or not. After finishing this part, the participants had to hand the device back to me and answer the post-experiment questionnaire.

Figure 3.2: App screenshot of the virtual building from the deck roof.

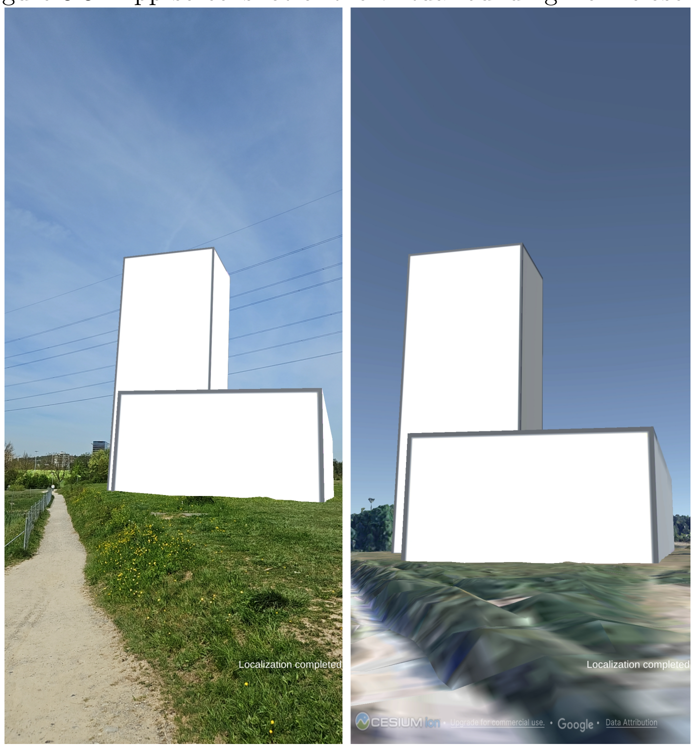


3.2 Materials

The experiment was set-up to be done using a HHD, namely a smartphone. A smartphone was chosen, instead of a HMD because smartphones have permeated virtually our whole society and can thus provide the best coverage and flexibility for the citizenry. Although HMDs devices have seen rapid development in the last decade, they are still far removed from the average person's daily life and face many challenges. While their use could increase in the future, it would be very speculative to say that it will find the kind of adoption that smartphones have seen.

Special attention was given to keeping the hardware and software experience the same across all experiments. Accordingly, all participants were given the same phone, a Samsung Galaxy S23 (Samsung Group, 2023) running on the Android 14 operating system (Google LLC, 2023a). A high-end phone was intentionally chosen to reduce constraints caused by hardware limitations.

Figure 3.3: App screenshot of the virtual building from close-by.



3.2.1 Software Components

The XR prototypes, the AR and VR version of the app are considered the independent variable and were developed using the Unity game engine version 2022.3.17f1 (Unity Technologies, 2024) using the universal render pipeline. Both prototypes were developed inside the same Unity project and built into the same app. The prototype selection was then done inside the app. This design was chosen to ensure that there were no differences between prototypes in the build.

Unity's AR Foundation package provides an interface for the game engine to work with the XR functionalities of the target platform. In the case of Android, these are provided by Google's ARCore service (Google LLC, 2023d). This Unity project used AR Foundation version 5.1.2 (Unity Technologies, 2023) with Google's ARCore Extensions 1.41.0 Google LLC (2023b). Both packages contain high-level functionalities that draw from lower level XR packages, but going into the details of these dependencies goes beyond the scope of this thesis. These two packages, AR Foundation and ARCore Extensions, are responsible for the tracking of the device's local pose (position and orientation), understanding image depth, anchoring virtual objects in the real world and so on.

To acquire a global pose, i.e., get the device's coordinates in a spatial reference system, Google's Geospatial API is also needed. To go beyond the typical GNSS accuracy of around $5\,m$ (National Coordination Office for Space-Based Positioning, Navigation, and Timing, 2024), Google's visual positioning system (VPS) technology is also used here (Google LLC, 2024a). This technology consumes the camera's feed to narrow down the position by comparing it to Street View imagery (Google LLC, 2024b). Since this feature uses a Google Cloud service as the backend to process the device's sensor data, this feature requires an internet connection and credentials to Google Cloud.

The last essential component for the geospatial capability of the prototypes is Cesium for Unity (Cesium GS, Inc., 2024a). This package enables the import and stream of geospatial data, like 3D tilesets. It is also responsible for the correct representation of geospatial data in game space. Unity uses a 3D Cartesian coordinate system and has no native way of dealing with the curved space of Earth's surface. Because of this, the delta between Unity's coordinates and Earth's coordinates increase the further away one is from Unity's origin (0, 0, 0). To alleviate this problem, Cesium for Unity shifts Unity's origin with respect to Earth's coordinates as the player/camera moves. In other words, its not the player that moves in Unity but rather the geospatial data that shifts around them. Since this would also mean that other objects inside of Unity would not move in relation to the player, anchors can be set to let them follow the displacement in Earth's coordinates.

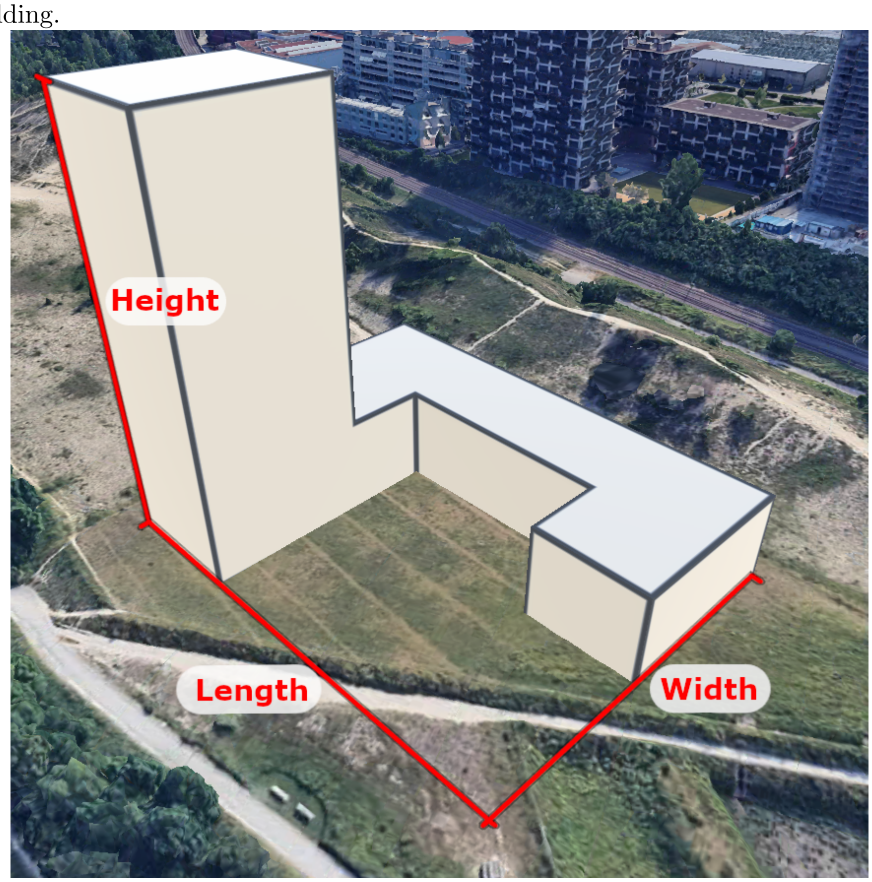
3.2.2 App Prototype

As already mentioned, only one app was developed with the capacity to display both the AR and the VR prototype. This was a deliberate choice to avoid erroneous differences between the two conditions. The camera settings were set to a vertical field of view of 60°, with the clipping planes of the frustum (the range in which objects are rendered) to 0.1–1000 m. Starting from the sample code in the ARCore Extensions package, the script "Geospatial Controller" was customized to fit the project needs. At the start of the app, a screen appears to select which version to be used. Once a version is selected, the XR session is started and VPS availability is checked and used if found. All experiments took place with VPS activated, as a warning would appear on screen if it could not get activated. In the few cases where this happened, a restart of the app solved the problem. One tangential but major error found during development was that starting the session over Wi-Fi would result in a black screen. The internet connection would not reach the Google Cloud service fast enough and cascade into the session crashing. Using the device's 5G connection would solve this problem.

Once the XR session is started, the app locates the user and displays the virtual objects visible from that pose. The structure shown in Figure 3.4 is the building that the study participants had to assess as the construction project of the experiment. It is based on the building "Basilisk" in Zurich's Altstetten district (CSL Immobilien AG, 2024). An existing building was chosen for realism and this one was specifically selected because it consists of a high-rise and a low-rise. This combination mirrors the surroundings of the construction site in that the area consists of high-rises on one side and low-rise buildings on the other side. This is looked at in further detail in Section 3.1.

The model was taken from the city's 3D city model (Stadt Zürich, 2024a), which contains LOD 2 buildings, and further modified using Blender (2024). There, the shape was simplified to only two heights, 64 m for

Figure 3.4: Image from Unity's editor from bird's perspective illustrating the dimensions of the virtual building.



the tower and $16\,m$ for the low-rise for easier visualization. Using $3.2\,m$ per floor as a reference (Kanton Aargau, 2014), this would mean that the tower has 20 floors and the low-rise has 5. All vertices were placed at whole numbers to ease the estimation tasks described later in section 3.1.1, leaving the total width at $54\,m$ and the length at $72\,m$.

A simple shape and texture was used because, while more complex visualization forms would be possible when compared to construction poles, Boos et al. (2023) did not find significant differences between different LODs and it made more sense to keep the design simple. The virtual building was given a custom texture with a beige fill similar to some of the surrounding buildings and gray edges to make the shape easier to understand. This texture was then added to the object in Blender.

The virtual environment displayed in the VR version of the app used Unity's default skybox showing a clear daytime sky. For the terrain, building and vegetation different options were at disposal. Google's Photorealistic 3D Tiles (Google LLC, 2024d) were chosen for their relatively high fidelity, but a combination of other products would have also been possible. Swisstopo, Zurich, Cesium and Open Street Maps all have various 3D datasets that could have been used (Cesium GS, Inc., 2024b; OpenStreetMap Wiki, 2024; Stadt Zürich, 2024a; Swisstopo, 2024). The advantage of Google's product, which is also what is seen on Google Earth, is that it has a relatively high temporal and spatial resolution. While on closer look its meshes are very chaotic, they provide more detail than other terrain models, especially with their realistic textures. By comparison, the 3D building and all the tree objects of the aforementioned alternatives use the same simple one-color textures for their different object categories.

One challenge of Google's 3D tiles is that they require large amounts of working memory and bandwidth to load. The tiles come in different resolution level and lower resolutions tend to be loaded when many tiles need to be downloaded simultaneously. They also get unloaded pretty fast when the user is not looking in the direction of the tile. This has the drawback that when the user moves the camera around, certain tiles can be temporarily missing or looking considerably worse. Another problem was that the 3D tiles were erroneously partially blocking the view from the roof deck where the far-off tasks were done (point 2 in Figure 3.1, more on this in section 3.1.2). To solve both problems, the tiles of the core area of the experiment were downloaded, modified in Blender where necessary and imported into the Unity scene as an asset. A "Cesium Box Excluder" component was then added to avoid loading the original tiles from the online dataset.

The AR version was first intended to rely on ARCore's occlusion functionality to cut out parts of the building that should not be visible from the device's pose. One obvious example where this should happen is the parts of the building that are below ground level. Unfortunately, this strategy proved unfeasible outdoors as the depth analysis is unreliable under such conditions (Alfakhori et al., 2023) and was causing major visual glitches, like the building disappearing behind the sky. For this reason, occlusion was deactivated and, instead, the modified meshes were also added to the AR prototype but, this time using a an occlusion shader that makes the object invisible to the camera, while still occluding virtual objects that are behind. The results can be seen in the upper image of Figure 3.2 where the virtual object gets cut by the invisible terrain on its lower side but is not occluded by the physical structure in front of the camera.

3.3 Participants

3.3.1 Recruitment Process

Participants were recruited into the study through email outreach inside the university's department of geography and through personal acquaintances. Candidates had to first fill out an online form to register to the study and, later on, register to a specific time slot. This twostep procedure was chosen in order to have better control over the distribution of participants. Something that will be further explained in section 3.1. This first registration form, found in appendix B, was used to gather some basic demographic data (i.e., age, gender, education, etc.) and pose other questions not directly relevant to the tasks in the experiment. These encompassed questions about previous experience and knowledge in topics relevant to the study, like architecture, geographic information systems (GIS) and, obviously, XR.

Five requirements were imposed in order to be able to participate in this study: Being of legal adult age (over 18 years old), being in a healthy condition, having normal or corrected-to-normal vision and not having any type of color blindness. Lastly, the participants had to have sufficient expertise in German or English, the two languages available for the experiment. Since the right to appeal against a project can be exerted by any resident and is thus not reserved to only a portion of the affected population, like votings are, no restrictions were set regarding nationality or the like.

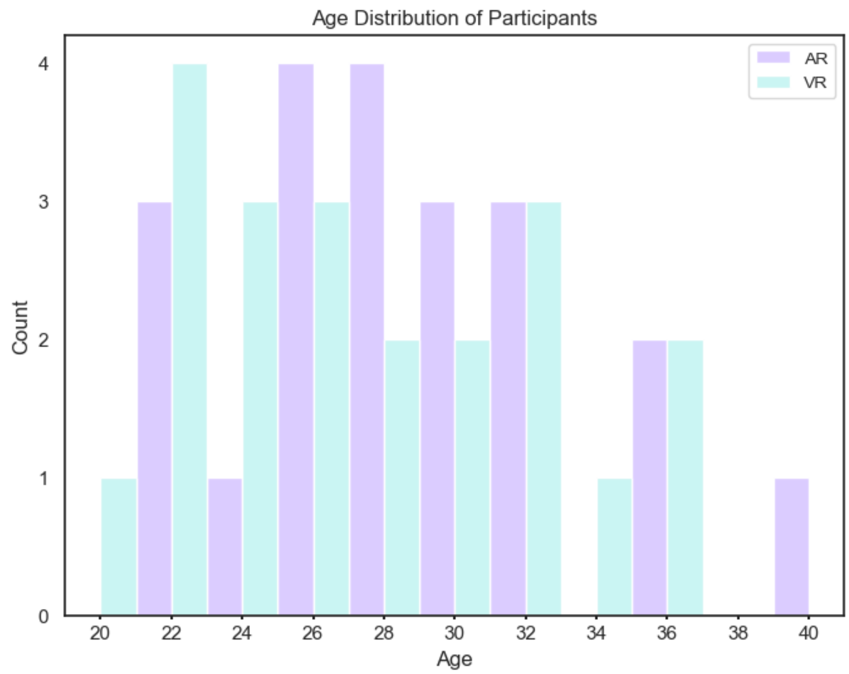
The age and health requirements had to do with the target group for the experiment, namely healthy adults with the capacity to take part in the experiment and take the legal action associated with building appeals (minors not being able to represent themselves in court per Art. 13 ZGB (2024)). Although no upper age limit was set, the recruitment strategy described in the last section was aimed at recruiting young adults, which are generally considered more tech-savvy. While this is not necessarily always true (Becker et al., 2012), it can help lessen possible struggles with the technology during the experiment. More importantly, it can reduce a novelty-induced wow-effect (Kamstrupp, 2016) that could skew the results compared to known technologies. The two requirements related to vision (vision correction and color blindness) were necessary to avoid such conditions affecting the study's results.

Given a relatively short time frame available for the recruitment process, a rolling recruitment strategy was used, meaning that candidates were sorted into the treatment groups before the registration window was closed. Once a certain amount of people registered, they were selected into the groups using a random sampling method. Within this random sampling, gender was used as a factor to ensure a balanced gender ratio. This was done to avoid any possible gender biases in the study's outcomes. In the end, 46 candidates registered to the experiment, out of which 42 also participated in the experiment. The candidates that did not take part in the experiment were not actively excluded but simply canceled their appointment because of illness or unknown reasons.

3.3.2 Demographics

Both treatment groups ended up having 21 participants in total, with AR having 9 females and 12 males and the VR group consisting of 10 females and 11 males. The participants' age ranged from 20 to 39 years old, with the exact distribution displayed in Figure 3.5. Overall, the participants had a mean $(M) = = 27.5$ years old and a standard deviation $(SD) = = 4.87$ years. For AR the values were $M = = 28.0$, $SD = = 4.92$ and in the case of VR, it was $M = = 27.0$ and $SD = = 4.89$. This was a young cohort when compared to the Swiss average of 42.8 years (Bundesamt für Statistik, 2023), which is naturally to be expected from the chosen recruitment strategy.

Figure 3.5: Barplot of the age distribution of the participants, separated by condition.



Regarding education, we observe an above average level of education (Bundesamt für Statistik, 2024). Of the 42 participants, only one person (2%) has only finished mandatory education (lower secondary education), compared to the Swiss average for the working population of 14%. Moreover, 13 people (31%) have a high school or apprenticeship diploma (upper secondary education), compared to the national average of 41%. Of those 13, however, eight (19%) are currently studying at an institute of higher education. The remaining 28 participants (67%) have a higher education degree, while for Switzerland the average sits at 44%. Looking at the treatment groups, their only difference is that AR as one individual at the lower secondary education level where VR has one more participant at the upper secondary level.

Looking at the area of residence, 17 (40%) identify as having grown up in a rural area, with 8 (19%) saying it was in a suburban area and the remaining 17 (40%) indicating it was in an urban area. Here, the treatment groups differ somewhat. In AR, 10 participants identified as having grown up in a rural, 5 in a suburban and 6 in a urban area, where VR had 7, 3 and 11 participants for the same categories. Thus, AR had more of rural upbringing, while the VR participants tended to rather grow up in the city.

For the current area of residence, however, the groups have equalized. Rural residence has gone down to 4 participants (10%), 10 (23%) live now in suburban areas and 28 (67%) are currently residing in an urban area. For these statistics, AR has 2 more suburban and VR 2 more urban residents. Since these values come from self-reporting, they are not one to one comparable with institutional statistics that rely on objective measurements. Nonetheless, using the quite granular cantonal statistics coming from the cantonal directional plan, where 23% of the population live in rural, 30% in suburban and 47% urban areas (Amt für Raumentwicklung, Kanton Zürich, 2023)), it becomes clear that the participants over-represent urban dwellers.

Lastly, when looking at the language selected by the participants, 39 chose to do the experiment in German and only 3 chose English. One was part of the AR group and two were in the VR group. From all these demographic data, we can say that the study population represents young, well-educated, urban-living people. These findings will be further discussed in section 5.1.

3.3.3 Experience and Knowledge in Related Fields

During the registration process, candidates also had to answer questions about knowledge and experience in areas related to the experiment, together with their familiarity of Stettbach (the neighborhood of the experiment site) and usage of smartphones and video games. To easily compare answers, a 5-point Likert-scale was used (Likert, 1932). The exact distribution of answers to questions related to experience and knowledge in related fields are found in Table 3.1. For the experience questions, computer-aided design (CAD) had the lowest value ($M = 2.10$, $SD = 1.39$), followed by AR ($M = 2.31$, $SD = 1.05$) and VR ($M = 2.48$, $SD = 1.17$). GIS had, with over one point difference, the highest value ($M = 3.55$, $SD = 1.15$). This was to be expected, since most participants had a background in geography. Aggregating these values together, participants had a $M = 2.56$ with a $SD = 0.73$, meaning that participants rated their overall experience in related technologies between little and moderate. The two questions related to knowledge showed similar results, with architecture showing a lower score ($M = 2.21$, $SD = 1.05$) than urban planning ($M = 2.38$, $SD = 1.13$). Aggregated, these resulted in a lower overall value than for the experience questions ($M = 2.30$, $SD = 1.01$).

Table 3.1: Participants' level of experience with diverse technologies and level of knowledge in topic related to the study.

	Level of experience or knowledge				
Topic	None	Minimal	Little	Moderate	Extensive
AR	10 (23%)	16 (48%)	10 (23%)	5 (12%)	1 (2%)
VR	11 (26%)	10 (23%)	13 (31%)	6 (14%)	2 (5%)
GIS	3 (7%)	4 (10%)	11 (26%)	15 (36%)	9 (21%)
CAD	22 (52%)	6 (14%)	6 (14%)	4 (10%)	4 (10%)
Architecture	11 (52%)	18 (14%)	7 (14%)	5 (10%)	1 (10%)
Urban Planning	12 (52%)	10 (14%)	13 (14%)	6 (10%)	1 (10%)

Regarding familiarity with the surroundings of the Stettbach train station (where the experiment took place), people tended to neither agree nor disagree with the statement of being familiar with the place ($M = 2.86$, $SD = 1.18$). When looking at smartphone usage, every participant stated using one on a daily basis. For video games, their usage was low, with 12 participants stating they never play video games, 15 saying they do so yearly, 4 playing monthly, 9 weekly and 2 daily ($M = 2.38$, $SD = 1.25$).

3.4 Data Analysis

All statistics and plots found in this thesis have been calculated in Python (Python Software Foundation, 2024) using the package SciPy (Virtanen et al., 2020) for statistical testing, the NumPy (Harris et al., 2020) and Pandas libraries (The pandas development team, 2024) for data manipulation and Matplotlib (Hunter, 2007) with Seaborn (Waskom, 2021) to create the plots.

Since the experiment follows an between-subject design with only two treatment groups, an independent t-test is the best choice for parametric tests, which assumes the samples to follow the same distribution (i.e., have the same mean) under and if the significance is reached, alternative hypothesis (HA) of unequal means is accepted. For this thesis, the standard level of significance ($\alpha = 0.05$) will be used. Furthermore, the t-test assumes that the data in the samples are at in either a ratio or an interval scale, that they follow a normal distribution and that they are homoscedastic (T. K. Kim & Park, 2019). Normality and homoscedasticity will be tested using a Shapiro-Wilks test and Levene's test, respectively. The null hypothesis (H0) of the Shapiro-Wilks test is that the data is normally distributed. Correspondingly, HA assumes non-Gaussian data. Levene's test, on the other hand, has a H0 of equal variances and an HA of unequal variances.

The dimension estimations conducted during the experiments all follow a ratio scala, while the Likert scale statements are ordinal. Nevertheless, the t-test is considered robust enough to handle even extreme violations of its assumptions (Norman, 2010; Winter & Dodou, 2010; Zimmerman, 1985), so also the Likert scale statements will be subjected to a t-test. An important advantage of the t-test is the amount of information than can be extracted, e.g., the confidence interval (CI) . However, a non-parametric Mann-Whitney U will also be conducted where violations occur to corroborate the findings.

For the Likert scale statements, a correlation analysis using Pearson's correlation will also be conducted where appropriate, like to test if similar statements correlate with each other. While this form of correlation also assumes the use of data in at least an interval scale and normally distributed, the test is still robust and can deal with these violations (Norman, 2010). Lastly, two questions were of a qualitative nature in that their answers were written down. One of them was set-up for the participants to take their time and absorb the atmosphere of the experiment site. For the other one, the repetition of themes will be counted.

Chapter 4

Results

This chapter presents the results from the experiment. An overall analysis of the Likert scale statements is first conducted, with a detailed review of these and other measurements in the later sections. These are divided into the Research Questions from Section 1.3.

4.1 Overall Statements Analysis

Figures 4.1 and 4.2 offer an aggregated overview of all statement assessments in the intra-experiment questionnaire and the post-experiment questionnaire, respectively. The statements of the intra-experiment questionnaire show a relatively balanced distribution across the agreement/disagreement range. The only clear exception is the last statement regarding the importance of building appeals as a legal protection instrument. As expected, this question received almost unanimous approval, showing that there was virtually no controversy regarding the legitimacy of the instrument.

The statements in the post-experiment questionnaire show a clear inclination towards positive answers (agreeing with the statement). This could be caused by a social-desirability bias, since they are all statements that indicate, in one form or the other, a positive attitude towards the experience and the app. Some participants actually made commentaries while completing the questionnaire that could be interpreted in this way.

All statements were tested for normality using a Shapiro-Wilk test. Both AR and VR clearly falsified the H0 of normality in all cases. For this reason, the results are not not being shown here. Instead, they can be found in Appendix A. In the case of Levene's W test for homoscedasticity, the H0 did hold in all cases, meaning that variance homogeneity can be assumed. These results are also found in Appendix A. Since the statements do not follow a normal distribution, both an independent t-test and a Mann-Whitney U test were conducted on the data. All results can be found in Table A.2, with individual results categorized per Research Question in the following sections. The statistical analysis shows that there are no significant differences between the t-test and the Mann-Whitney U test. For this reason and to enhance comprehension, only the results of the t-test will be discussed in the text.

4.2 Perception (RQ1)

Research Question 1. *Does the selection of HHD AR vs. VR for the on-site visualization of construction projects affect the user's perception of the project?*

4.2.1 Perception (H1)

Hypothesis 1. *AR will give a better understanding of the construction project than VR.*

Building Dimensions

A first measure indicating whether the users are able to understand the visualization or rather the building that was being proposed is to show a good grasp of its size. Five dimension estimation tasks were performed to measure this, one on the roof deck at the far-off spot (point 2 in Figure 3.1) and the other four at the construction site close to the building (point 3 in Figure 3.1). The distribution of the answers per treatment are displayed in Figure 4.3 for the vertical dimensions and in Figure 4.4 for the horizontal dimensions. The results are shown as the difference between the user estimate and the actual value.

Testing each treatment group for normality by using a Shapiro-Wilk test, the results shown in Table 4.1 reveal that some of the estimates come from non-Gaussian data. For most of the tasks, the assumption of normality under the H0 gets rejected in at least one of the conditions. Only for the low-rise height estimation does the H0 hold in both groups.

The non-normal distributions can be explained by the presence of outliers. Removing the outliers displayed in the box plots of Figures 4.3 and 4.4 changes the results of the test so that the assumption of normality holds for all samples. Nevertheless, since there is no clear mechanism that explains why these extreme values should be invalidated, they have been taken into consideration for the following tests.

The results of Levene's test shown in Table 4.2 indicate that the H0 holds in all five tasks, meaning that it is safe to assume that the samples have equal variances. Here again, because of the violation of the normality assumption, both a t-test and a Mann-Whiteney U test are conducted to test for differences in central tendency between both groups. The results are shown in Table 4.2 and, again, no contradiction in significance is found between the two tests.

The tower height estimate from the roof deck (far-off) shows a significant divergence between the treatments ($t(39) = 2.346$, p-value $(p) = .024$ CI [2.429, 32.818]). The AR group overestimated ($M = 9.10$, $SD = 26.75$), whereas VR underestimated ($M = \text{-}8.52$, $SD = 21.15$) the height of the 64 m high tower. Interestingly, when estimating the tower height from the close-by spot, both groups converge towards the real value without

Figure 4.1: Barplot showing all the responses of the statements posed in the intra-experiment questionnaire.

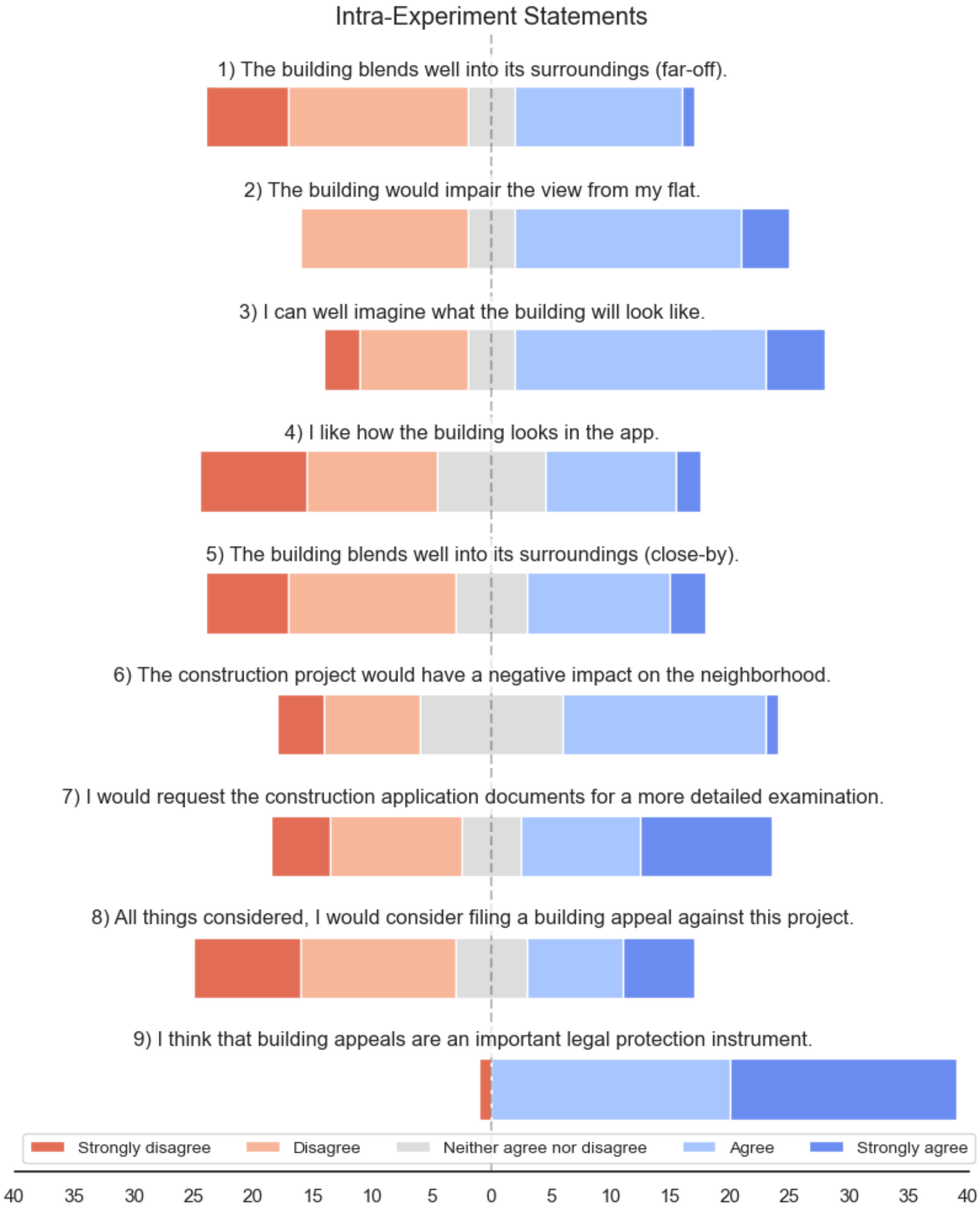
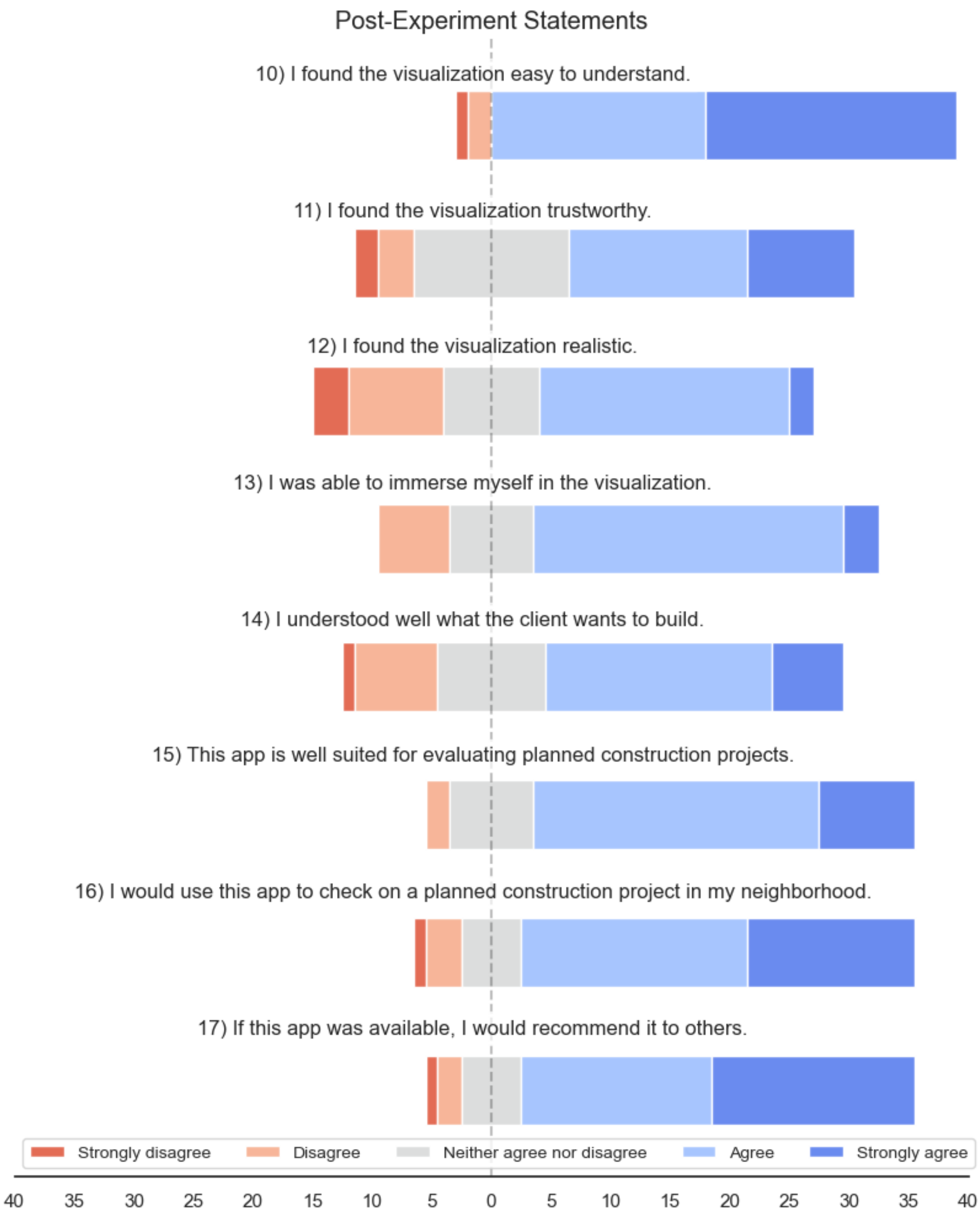


Figure 4.2: Barplot showing all the responses of the statements posed in the post-experiment questionnaire.



changing signs (AR: $M = 0.238$, $SD = 23.79$; VR: $M = -1.14$, $SD = 21.80$). Consequently, this time the difference between the conditions is not significant ($t(40) = 0.196$, $p = .846$, CI [-12.852, 15.614]).

AR ($M = 2.05$, $SD = 8.08$) also shows a slight overestimation of the 16 m high low-rise, while VR is, on average, almost spot on ($M = 0.10$, $SD = 6.85$). Here again, no significant difference is found between the conditions ($t(40) = 0.931$, $p = .150$, CI [-2.722, 6.627]), although an inclination towards higher values is found for AR.

Focusing on the estimation of the horizontal dimensions (width = 54 m, length = 72 m), AR ($M = -0.286$, $SD = 48.767$) gets very close to the actual width, while VR ($M = 13.714$, $SD = 49.084$) clearly overestimates it. Nonetheless, this difference does not reach significance level ($t(40) = -0.927$, $p = .359$, CI [-44.516, 16.516]).

The length shows a similar pattern, with AR ($M = -6.29$, $SD = 23.89$) underestimating the length and VR ($M = 30.62$, $SD = 88.75$) clearly overestimating it. Nevertheless, also here the t-tests does not surpass the threshold ($t(40) = -1.84$, $p = .073$, CI [-77.44, 3.63]), even though it gets close to it.

Comparing the vertical estimations with the horizontal estimations, there is a tendency for people using the AR prototype to overestimate the vertical dimensions and underestimate the horizontal dimensions, whereas the VR treatment tends towards the opposite–underestimating in the vertical and overestimating in the horizontal direction. The height overestimation in the AR group corroborates the findings of Boos et al. (2023), but the results are not as clear for horizontal estimates. The horizontal estimates also show a bigger spread, compared to the vertical estimates. This could be caused by a difficulty to interpret depth in a 2D screen, but it could also be caused by the shape of the building, which is more complex in those directions.

Despite the aforementioned trends, only one in five estimation tasks shows a clear divergence between the two conditions. Interestingly, it is also the only estimation made from the far-off spot, more than 200 m away from the virtual building. By contrast, all close-by estimations remain below the significance level.

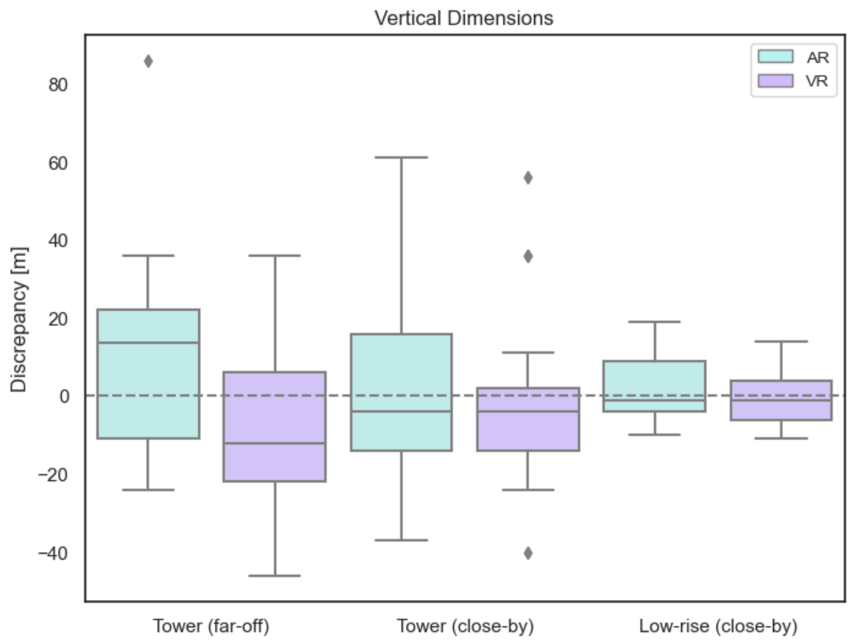
There are different possible explanations for this, like that a general tendency for AR to overestimate and for VR to underestimate only becomes significant when there is enough distance between the user and the virtual object. It could also be the case that the window at the roof deck (seen in Figure 3.2) affected the groups in opposite ways or with different magnitudes. At a minimum, it suggests that divergence may start to occur at a distance from the object that is being studied.

Visualization Comprehension

The understanding of the project was also measured through self-assessment with Statements 3, 10 and 14. Statement 3 ("I can well imagine what the building will look like") was answered while using the app at the construction site and shows a slightly positive value for both AR ($M = 3.381$, $SD = 1.117$) and VR ($M = 3.381$, $SD = 1.244$). Since both have conditions have the same mean, the t-test shows no difference ($t(40) = 0.0$, $p = 1.0$, CI [-0.737, 0.737]).

Statement 10 and 14 were part of the post-experiment questionnaire. Both groups tend to agree with

Figure 4.3: Boxplot showing the difference between estimated and actual values across all vertical dimension estimates per condition. Positive values indicate overestimations.



Statement 10 ("I found the visualization easy to understand"), with AR ($M = 4.095$, $SD = 1.136$) showing a lower value than VR ($M = 4.571$, $SD = 0.507$). Nevertheless, this difference of almost half a point is not enough to pass the significance level ($t(40) = -1.754$, $p = .087$, CI [-1.025, 0.072]).

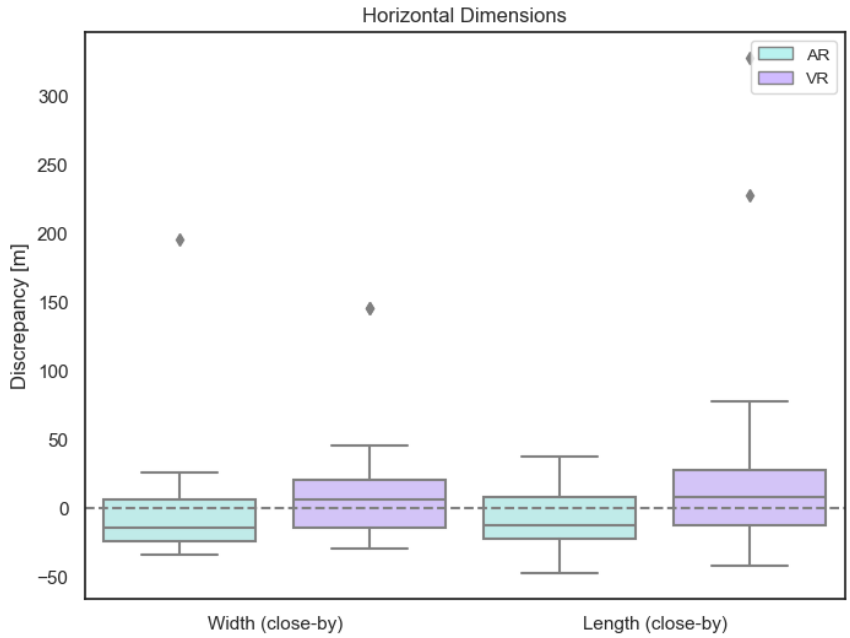
In the case of Statement 14 ("I understood well what the client wants to build"), participants show less agreement, with AR ($M = 3.381$, $SD = 1.071$) again showing a lower value than VR ($M = 3.667$, $SD = 0.966$), but with a smaller difference. Accordingly, no significant difference is found between the groups ($t(40) = -0.908$, $p = .37$, CI [-0.922, 0.351]).

These statements indicate that, although the visualization was not difficult to comprehend, participants did not find it particularly well suited to understand what the final product would be. Some participants did comment on wishing that the building would show more features, like seeing windows or a realistic facade. The lower value of the AR condition in Statement 10, although not significant, could be pointing towards differences in how the visualizations are rendered. This will be further discussed in the limitations.

Perception of the Surroundings

Four statements captured how the participants feel about the project, with Statements 1 and 2 being answered on the far-off roof deck and Statement 5 and 6 at the construction site. Statements 1 and 5 have the same text ("the building blends well into its surroundings") and in both cases the participants tend to

Figure 4.4: Boxplot showing the difference between estimated and actual values across all horizontal dimension estimates per condition. Positive values indicate overestimations.



disagree with it.

On the roof deck (Statement 1) AR ($M = 2.6$, $SD = 1.188$) is slightly more critical than VR ($M = 2.762$, $SD = 1.221$), but not significantly so ($t(39) = -0.43$, $p = .669$, CI [-0.923, 0.599]). This perception inverts at the construction site (Statement 5), where AR ($M = 2.857$, $SD = 1.153$) becomes less and VR ($M = 2.667$, $SD = 1.354$) more critical, but the differences are minimal. As such, no significance is found ($t(40) = 0.491$, $p = .626$, CI [-0.594, 0.975]), so this variation between responses can be attributed to randomness.

The results show participants only slightly agreeing with Statement 2 ("the building would impair the view from my flat"). AR ($M = 3.2$, $SD = 1.152$) does less so than VR ($M = 3.429$, $SD = 0.978$)) with no signs of a significant difference ($t(39) = -0.686$, $p = .497$, CI [-0.902, 0.445]).

On Statement 6 ("the construction project would have a negative impact on the neighborhood"), AR ($M = 3.0$, $SD = 0.949$) tends to neither agree nor disagree, with VR ($M = 3.143$, $SD = 1.153$) showing only a minimal increase. Here again, no evidence of divergence between the groups has been found ($t(40) = -0.439$, $p = .663$, CI [-0.801, 0.516]).

The results show clearly that there is no difference between the conditions for these statements, so it can be ruled out that the environment (virtual or real) in which the building is placed has any meaningful effect on how people perceive it in its surroundings. The building was designed to stick out and be somewhat irritating, so that participants would react to that. These results indicate that this was achieved.

From all the findings in this section, no strong evidence has been found to supports Hypothesis 1. In other words, no tangible difference has been found between the AR and the VR condition regarding users' perception of the visualization. More specifically, the type of environment displayed in HHD XR does not affect how well people understand the visualization nor does it influence their perception regarding the size of the building or its presence in its surroundings.

4.2.2 Confidence (H2)

Hypothesis 2. *AR will generate more confidence in the visualization than VR.*

The trustworthiness of the XR visualization was measured with Statement 11 ("I found the visualization trustworthy"). The results show that the AR group ($M = 3.333$, $SD = 1.155$) tends to trust the visualization less than the VR treatment ($M = 3.905$, $SD = 0.889$). While a trend is visible, the difference is not found to be significant ($t(40.0) = -1.797$, $p = 0.08$, CI [-1.214, 0.071]). Hypothesis 2 stated the opposite, that AR would generate more confidence. It was expected that, being grounded in the real world, participants in the AR group would be less suspicious of the visualization, but this has clearly not been the case. The findings go against this hypothesis but the evidence is not strong enough to say that VR is significantly more trustable.

Looking at the correlation, Statement 11 is found to significantly correlate negatively with wanting to request the construction documents (Statement 7, correlation $(r) = -.486$, $p = .002$) and positively with immersion (Statement 13, $r = .530$, $p = .001$) This seems to suggest that one factor influencing the request of construction documents is a lack of trust, but this is not enough evidence to sustain the idea. The connection to immersion is also unclear. It could be argued that immersion generates trust, but it could also mean that trust generates immersion.

Table 4.1: Results of the Shapiro-Wilk test for normality and Levene's test for homogeneity of variance on both treatment groups. Significant results ($p < 0.05$) marked in **bold**.

Estimate	Shapiro-Wilk (AR)		Shapiro-Wilk (VR)		Levene's Test	
	W	p-value	W	p-value	W	p-value
Tower height (far-off)	0.902	**.044**	0.970	.744	0.830	.368
Tower height (close-by)	0.962	.557	0.893	**.025**	0.668	.418
Low-rise height	0.931	.150	0.950	.340	0.680	.414
Building width	0.584	**<.001**	0.733	**<.001**	0.218	.642
Building length	0.964	.603	0.658	**<.001**	2.713	.107

Table 4.2: Results of the independent t-test and Mann-Whitney U test for all dimension estimates. Significant results ($p < 0.05$) marked in **bold**. *Tower Height (far-off): $t(39)$.

Estimate	Independent t-Test		Mann-Whiteney U test	
	$t(40)$*	p-value	U	p-value
Tower height (far-off)	2.346	**.024**	293.5	**.03**
Tower height (close-by)	0.196	.846	235.0	.723
Low-rise height	0.844	.404	243.5	.569
Building width	-0.927	.359	163.0	.15
Building length	-1.840	.073	161.5	.14

Table 4.3: Results of the independent t-test and Mann-Whitney U test for Statements related to Research Question 1. *1, 2): $t(39)$

Statement (during Experiment)	Independent t-test		Mann-Whitney	
	$t(40)$*	p-value	U	p-value
1) The building blends well into its surroundings (far-off).	-0.43	0.669	194.5	0.681
2) The building would impair the view from my flat.	-0.686	0.497	186.0	0.508
3) I can well imagine what the building will look like.	0.0	1.0	217.0	0.935
5) The building blends well into its surroundings (close-by).	0.491	0.626	242.0	0.584
6) The construction project would have a negative impact on the neighborhood.	-0.439	0.663	197.5	0.551
10) I found the visualization easy to understand.	-1.754	0.087	175.5	0.210
11) I found the visualization trustworthy.	-1.797	0.080	160.0	0.115
14) I understood well what the client wants to build.	-0.908	0.370	191.0	0.439

4.3 Appeals (RQ2)

Research Question 2. *Does the use of AR vs. VR affect the decision to file a building appeal against a development project?*

Hypothesis 3. *AR will diminish the number of appeals compared to VR.*

Three statements (7, 8 and 9) were answered during the experiment to study the effect of the treatments on the intention to file an appeal against the development project. Of these three, Statement 9 ("I think that building appeals are an important legal protection instrument") was a control question to check if someone's perception on the legitimacy of building appeals could be related to avoiding the use of the instrument. This statement had a high approval rate for both AR ($M = 4.286$, $SD = 0.902$) and VR ($M = 4.526$, $SD = 0.513$), with no significant difference ($t(40) = 0.554$, $p = .583$, CI [-0.63, 1.106]). This shows that most participants are overwhelmingly supportive of the instrument.

Statement 7 ("I would request the construction application documents for a more detailed examination") refers to the first step and prerequisite to any building appeal, which is to request the documents of the project. Here, AR ($M = 3.619$, $SD = 1.284$) showed a relatively strong inclination towards requesting the documents, while VR ($M = 2.905$, $SD = 1.48$) showed a slightly negative response. The difference does not reach significance level ($t(40) = 1.671$, $p = .103$, CI [-0.15, 1.578]).

Statement 8 ("all things considered, I would consider filing a building appeal against this project") is the essential statement to test Hypothesis 2. Participants in both groups tended to disagree with the idea, with AR ($M = 2.857$, $SD = 1.195$) being only slightly more in favor of an appeal than VR ($M = 2.619$, $SD = 1.564$). Such a small difference is, as expected, not significant ($t(40) = 0.554$, $p = .583$, CI [-0.63, 1.106]). This shows that the type of XR experience presented to the user is ultimately not of relevance when deciding whether to file an appeal or not.

Statements 7 and 8 both correlate with each other (Statement 8, $r = 1.0$, $p = 0.0$), which is to be expected

Table 4.4: Results of the independent t-test and Mann-Whitney U test for Statements related to Research Question 2. *9): $t(38)$

Statement (during Experiment)	Independent t-test		Mann-Whitney	
	$t(40)$*	p-value	U	p-value
7) I would request the construction application documents for a more detailed examination.	1.671	0.103	283.0	0.109
8) All things considered, I would consider filing a building appeal against this project.	0.554	0.583	252.0	0.423
9) I think that building appeals are an important legal protection instrument.	-1.022	0.313	175.5	0.468

Table 4.5: Results of the independent t-test and Mann-Whitney U test for Statements related to Research Question 3. *15, 17): $t(39)$

Statement (during Experiment)	Independent t-test		Mann-Whitney	
	$t(40)$*	p-value	U	p-value
4) I like how the building looks in the app.	1.539	0.132	280.5	0.124
12) I found the visualization realistic.	1.019	0.314	254.0	0.371
13) I was able to immerse myself in the visualization.	0.0	1.0	219.5	0.988
15) This app is well suited for evaluating planned construction projects.	0.219	0.827	218.5	0.814
16) I would use this app to check on a planned construction project in my neighborhood.	0.309	0.759	232.0	0.767
17) If this app was available, I would recommend it to others.	-0.813	0.421	180.5	0.417

considering that one is a prerequisite for the other. The correlation analysis also shows a linkage with negative views on the building's effect on the neighborhood (Statement 5, $r = -0.477$, $p = 0.001$ and Statement 6, $r = 0.622$, $p = 0.0$) and, in the case of Statement 7, also not trusting the visualization (Statement 11, $r = -0.486$, $p = 0.001$).

The participants also had to write their reasoning behind Statement 8, which could contain multiple arguments. Of the 14 participants in favor of an appeal (rating ¿ 3), 13 argued with the loss of the green area or nature, eight with aesthetics, two with higher traffic and one also mentioned that the visualization was too simple.

22 participants are against filing an appeal (rating ¡ 3). Of those, 12 mention that the project does not affected them negatively. Five mention the loss of part of the field, but they either think that enough would be left or that it just is not very valuable in its current. Four argue that the city is in need of more housing and also four say that the building blends well into the surroundings or that the surroundings are not pretty anyways. One mentions a lack of resources and one not having enough confidence for such a decision. Lastly, two people actually think the project would be positive for them.

4.4 Feasibility (RQ3)

Research Question 3. *How feasible is the use of HHD AR and VR as a tool for the on-site visualization of building projects under current consumer-grade state-of-the-art technology?*

This research question was posed with two insights in mind. The first one was accompanied by Hypothesis 4 below and was that for the app to work, it needs to attract users. As already discussed in Chapter 2, XR is generally engaging. However, this needs to be substantiated with some utility that goes beyond a shiny app. The second insight is that this tool must have the capacity to find wide adoption, so that it becomes a viable alternative to the current *status quo*. This necessitates that current mass-market technologies are able to run the app and provide accurate geolocation services. This second part did have an accompanied hypothesis, but the entire study served to answer it.

4.4.1 Engagement (H4)

Hypothesis 4. *AR and VR will generate the same level of engagement.*

When looking at the time spent on each section of the experiment (the roof deck, the dimension estimations and the evaluation of the intra-experiment questionnaire) as a measure of engagement, the results look very similar for both groups, which is why I will present the aggregated values. The roof deck was the shortest part of the experiment, amounting to $M = 190$ and $SD = 97$ seconds. The close-by estimations took the most time, with $M = 302$ and $SD = 187$ seconds, while the statement evaluations during the experiment had a $M = 264$ and $SD = 168$ seconds. In other words, the average participant spent 12 minutes and 36 seconds completing the experiment tasks (excluding the post-experiment questionnaire, which was not measured). In general, the total duration of the experiment from the greetings to the farewells, took between 30 and 45 minutes.

The level of engagement was measured through analogues, such as those found in Statements 4, 12, 13. Statements 4 ("I like how the building looks in the app") recorded the visual appeal. The results show a minimal disagreement in the AR treatment ($M = 2.952$, $SD = 1.161$) and more clear disagreement in the VR condition ($M = 2.381$, $SD = 1.244$). The difference between the groups is not significant ($t(40) = 1.539$, $p = .132$, CI [-0.179, 1.322]), but VR seems to be more critical of the building. This is surprising because the building should stick out less in VR, since there everything is digital. However, a general negative attitude was expected, since the building was plain.

AR ($M = 3.429$, $SD = 1.028$) also showed a more positive response to Statement 12 ("I found the visualization realistic") than VR ($M = 3.095$, $SD = 1.091$), which was rather neutral. Intuitively, it makes sense that AR finds the visualization more realistic, since it uses the camera's feed as background, while VR uses a somewhat abstract and chaotic 3D reconstruction of reality. In this case, the t-test shows clearly that there is no significant divergence between the means ($t(40) = 1.019$, $p = 0.314$, CI [-0.328, 0.995]).

Regarding how immersive the visualization is, both AR ($M = 3.619$, $SD = 0.865$) and VR ($M = 3.619$, $SD = 0.805$) display an equally favorable agreement with Statement 13 ("I was able to immerse myself in the visualization"). Accordingly, no difference is found between the treatments ($t(40) = 0.0$, $p = 1.0$, CI [-0.521, 0.521]).

Using immersion (Statement 13) as a measure of engagement, hypothesis 4 has been corroborated, with AR and VR showing the exact same score ($M = 3.619$). The results show that immersion correlates significantly with ease to understand the visualization ($r = 0.399$, $p = .012$), trustworthiness ($r = .530$, $p = .001$) and realism ($r = .407$, $p = .010$). Users that found the the visualization immersive also tended to claim that they understood well what the developer wanted to build ($r = .491$, $p = .001$), found the app suited for the evaluation of such projects ($r = .378$, $p = .018$) and, accordingly, would recommend the app to others ($r = .022$, $p = .366$).

The last three statements (15–17) of the post-experiment questionnaire were posed to see what the overall impression of the prototype was. Statement 15 ("this app is well suited for evaluating planned construction projects") got a good score in both AR ($M = 3.952$, $SD = 0.805$) and VR ($M = 3.9$, $SD = 0.718$) and no significant difference between the two ($t(39) = 0.219$, $p = .827$, CI [-0.43, 0.535]). Also Statement 16 ("I would use this app to check on a planned construction project in my neighborhood") got a good approval rating from AR ($M = 4.048$, $SD = 0.973$) and VR ($M = 3.952$, $SD = 1.024$). Also here, the difference is found to be minimal ($t(40) = 0.309$, $p = .759$, CI [-0.528, 0.718])). The same applies for Statement 17 ("if this app was available, I would recommend it to others"), where both AR ($M = 4.0$, $SD = 1.049$) VR ($M = 4.25$, $SD = 0.91$) reach four points on average. And, again, no difference is found between the means ($t(39) = -0.813$, $p = .421$, CI [-0.872, 0.372]).

4.4.2 Technical Feasibility

The app showed that current mobile and geospatial technology is capable of displaying a semi-immersive experience in both AR and VR. Some problems did arise during the development of the prototypes, but none was a deal-breakers for the use case in this study. However, some of these problems could become highly problematic if an app like this was to be marketed for mass consumption. For this experiment, first class technology was used for the device (Samsung Galaxy S23) and the internet connection (5G), which cannot be expected as the norm. Geolocation was a major challenge that persisted throughout the experiment session, despite the use of the VPS service provided by Google (2023d). This will probably remain a problem in the near future and seems to be the major challenge of geospatial-enabled XR. On the other hand, Google LLC (2024d) 3D tiles have been shown to be an incredible asset and have the potential to push the technology to new limits. However, for a HHD the quality of the image has room for improvement.

Chapter 5

Discussion

This chapter discusses the results from the previous chapter and puts them into the research context. The same order will be used as in Chapter 4, going in the order of the Research Questions. Section 5.1 is dedicated to the limitations of this research and its results. Lastly, possible further research will be highlighted in Section 5.2.

Perception

The study conducted in this thesis was not able to show any significant differences between HHD AR andVR in how users perceive the development project. The only significant difference in the dimension estimations occurred when estimating the tower height from the roof deck 230 m away, with AR overestimating and VR underestimating it. Since the technologies show contradictory biases. An overestimation could exaggerate a negative impression on the user, while an underestimation could cause an undeserved positive impression that would unfairly benefit the developer. Since all other estimations were made from close-by, this finding suggests that the more distant one is to an object, the harder it becomes to estimate its size. The overestimation of the AR group also coincides with the results from Boos (2020) which suggests that this effect is inherent to this type of visualization.

It remains unclear what caused the higher variability in the horizontal estimations. One possibility is that the shape chosen for the building just made it harder to estimate correctly. E.g., from the starting position at the construction site, the width of the building was not completely visible. Participants were given the possibility to move around and look at the building from other angles, but many did not use this opportunity. Another option is that the phenomenon is caused by a difficulty to perceive depth on a 2D screen.

In general, participants found the visualization easy to understand, but the visualization itself not particularly informative. This is probably due to the simple LOD 1 geometry and bland texture. From Boos et al. (2023) we know, however, that users find construction poles even less appealing. Since in this experiment there was no comparison to be made for the individual participant, this probably reflects a higher expectation from the participants rather than the XR experience not being useful.

While it is self-evident that people would generally prefer more rich visualizations, more realistic images may actually make the visualization less comprehensible (Boos et al., 2023). A detailed model could also give the wrong impression that the design of the building if final (Zanola et al., 2009), which is not the case. For these reasons, caution is recommended when choosing how complex the model is going to be for such a project.

The participants were relatively critical regarding how well the building would fit the surroundings, but did not think that the project would necessarily be adverse for the neighborhood. This shows that while people were not happy with the aesthetics of the building, there was no clear sentiment against densification.

The two major concerns with the building were the destruction of a green area and the disruptive view. However, these opinions were not affected by the treatment received, but are rather specific to this project. This coincides with the findings of Bauer and Duschinger (2024), which show that the removal of green spaces is a major factor for the rejection of densification efforts.

An interesting result of this experiment was that participants using AR tended to trust the visualization less. The results were not significant, but at a difference of 0.572 points, it should also not be ignored. One possible explanation for trust to score higher in the VR condition is that errors in the device's pose (position and direction) cause less disruption.

When VR gets a faulty pose, the virtual environment shows the scene from the wrong point of view. In the case of AR, it places the virtual building at the wrong spot instead. So, while VR may not be show the scene at the right angle, the scene itself will remain consistent because it is purely virtual. AR, on the other hand, is dependent on both the real and the virtual environment to show the correct scene. So, when if the AR device gets the pose wrong, the virtual elements will move around the scene, while the scene itself remains constant. In other words, VR will remain internally valid independent of positioning errors, whereas AR is prone to inconsistencies caused by contradictory information between the real and the virtual world. And, given that our current mobile geolocation technology are not that reliable, this happens frequently.

Ultimately, the two tested conditions (AR vs. VR) did not affect the decision to file a building appeal or not, which is good. This means that there would be more freedom in the implementation strategy. In the development of such a hand-held XR product more emphasis could be given to decisions regarding the technical implementation, instead of effects on the user.

5.1 Limitations

This study had the format of a field experiment. As such, there are certain variables that cannot be controlled. Some participants had to endure rain and strong winds, while others had a sunny sky. This was not recorded or controlled for, only constrained through the time slots available for each group. Moreover, also this measure was not necessarily very helpful, since changes in the environment could easily happen in less than an hour (the time between experiments). Examples include the sudden increase in pedestrian traffic caused by the arrival of a packed train, the unexpected appearance of dog-owners or pick-nickers (with music) or the sporadic shower taking place.

The population recruited for this experiment was also younger, more urban and better educated than the average Swiss person. This should not pose a problem for the comparison between the two XR technologies but it does mean that the absolute values, e.g. the average statement scores, are not representative of the Swiss population.

Also, the aforementioned problem with the device's pose happened admittedly too often and could have negatively affected the results. This was mainly a problem at the roof deck, where the greater distance was naturally prone to greater errors. The sight interference caused by the windows (see Figure 3.2) on the roof deck could also have an effect, since it made AR not have a same clear view that VR enjoyed.

Despite using the same settings for both AR and VR, there were also some undesirable differences between the AR and the VR images. This can be seen in Figure 3.2, where VR seems to be zoomed in compared to AR. This probably has to do with how Unity projects 3D space into a flat screen and, despite all the efforts made to keep both prototypes mostly equal, this effect slipped through the cracks.

5.2 Further Research

The potential of XR technologies is still relatively untapped. There are many opportunities for research in this area, especially with software and cloud computing becoming more accessible and hardware getting cheaper are more robust. Many studies are based on use cases that do not implement comparative research (Rohil & Ashok, 2022). There is still room for XR technology to be tested in urban planning settings.

The next logical step for this research would be to develop real-world cases studies of XR being used to assess proposed projects. The prototype used for this study was also very basic in its functionalities. Adding new functionalities to it could open up the technology up to new forms of e-participation that have not been thoroughly studied.

The mobile device has also given us the opportunity to study people's behavior without interfering with them. It would be interesting, e.g., to study modes of e-participation that do not require supervision. This study, e.g., studied the introduction of XR on the current building approval process through a guided experiment. There is, however, potential for broader studies that expand this concept to encompass, e.g., asynchronous forms of participation.

There is also a lack of studies investigating the uses of semi-immmersive hand-held VR, even though there is a lot of potential in the technology because the barrier to entry is comparatively low and is more flexible than AR, because it only relies on the virtual environment. The use of such tools on-site is especially perplexing, given advantages that HHDs have over the much bulkier HMDs.

Densification (and gentrification) will remain a challenge for the foreseeable future. There is still potential for studies addressing this issue. Most experiments use simulations (Chassin & Ingensand, 2022), are based on self-reporting (J. P. van Leeuwen et al., 2018) or take place in highly supervised settings (Fegert et al., 2020). This can make the results non-representative.

Chapter 6

Conclusion

This study investigated the differences between hand-held AR and VR when used to assess virtual buildings. By introducing participants into a fictive scenario, the users had to complete dimension estimation tasks and assess statements related to the project. The results did not find any major difference between the two conditions, except for the far-off height estimation which in itself does not support one technology over the other.

Two non-significant but interesting differences were that the VR visualization received higher scores in ease to understand and trustworthiness. I propose an explanation for the difference in trust being that VR's virtual environment retains internal validity independent of inconsistencies with the real world, something that is not true for AR.

The prototypes was generally well received, earning positive scores from the users. Although many wished for more realism, this does not seem to sway opinions regarding the project. There are also challenges that need to be solved for the technology to hit mass adoption, geolocation capabilities showing high priority. Nevertheless, this study has proven that the technology currently available to us is mature enough to support hand-held XR as a tool for public participation. At the current rate of progress seen in the field, it could soon be stable enough to also allow mass adoption.

Ultimately, this study concludes that the choice of AR or VR will not significantly affect the user experience and therefore other factors, like technical requirements, availability of resources and accessibility should take priority in the choice of technology.

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Appendix A

Supplementary Statistics

Table A.1: Results of the Shapiro-Wilk test per treatment group for all statements posed during and after the experiment.

Statement	Shapiro-Wilk (AR)		Shapiro-Wilk (VR)		Levene's Test	
	W	p-value	W	p-value	W	p-value
1) The building blends well into its surroundings (far-off).	0.824	.002	0.869	.009	0.027	.869
2) The building would impair the view from my flat.	0.826	.002	0.716	.0	1.958	.17
3) I can well imagine what the building will look like.	0.836	.002	0.855	.005	0.093	.762
4) I like how the building looks in the app.	0.903	.039	0.876	.012	0.038	.846
5) The building blends well into its surroundings (close-by).	0.88	.014	0.89	.023	0.349	.558
6) The construction project would have a negative impact on the neighborhood.	0.841	.003	0.854	.005	0.549	.463
7) I would request the construction application documents for a more detailed examination.	0.788	.0	0.887	.02	0.615	.437
8) All things considered, I would consider filing a building appeal against this project.	0.841	.003	0.831	.002	1.841	.182
9) I think that building appeals are an important legal protection instrument.	0.63	.0	0.641	.0	0.228	.636
10) I found the visualization easy to understand.	0.735	.0	0.633	.0	2.462	.124
11) I found the visualization trustworthy.	0.904	.042	0.867	.008	1.289	.263
12) I found the visualization realistic.	0.878	.014	0.773	.0	0.216	.644
13) I was able to immerse myself in the visualization.	0.819	.001	0.728	.0	0.17	.682
14) I understood well what the client wants to build.	0.875	.012	0.877	.013	0.138	.712
15) This app is well suited for evaluating planned construction projects.	0.849	.004	0.79	.001	0.436	.513
16) I would use this app to check on a planned construction project in my neighborhood.	0.828	.002	0.79	.0	0.179	.674
17) If this app was available, I would recommend it to others.	0.793	.001	0.788	.001	0.151	.7

Table A.2: Results of the independent t-test and Mann-Whitney U test for all statements posed in the intra-experiment (1–9) and post-experiment (10–17) questionnaires. *1, 2, 15, 17): $t(39)$; 9): $t(38)$

Statement (during Experiment)	Independent t-test		Mann-Whitney	
	$t(40)$*	p-value	U	p-value
1) The building blends well into its surroundings (far-off).	-0.43	0.669	194.5	0.681
2) The building would impair the view from my flat.	-0.686	0.497	186.0	0.508
3) I can well imagine what the building will look like.	0.0	1.0	217.0	0.935
4) I like how the building looks in the app.	1.539	0.132	280.5	0.124
5) The building blends well into its surroundings (close-by).	0.491	0.626	242.0	0.584
6) The construction project would have a negative impact on the neighborhood.	-0.439	0.663	197.5	0.551
7) I would request the construction application documents for a more detailed examination.	1.671	0.103	283.0	0.109
8) All things considered, I would consider filing a building appeal against this project.	0.554	0.583	252.0	0.423
9) I think that building appeals are an important legal protection instrument.	-1.022	0.313	175.5	0.468
10) I found the visualization easy to understand.	-1.754	0.087	175.5	0.210
11) I found the visualization trustworthy.	-1.797	0.080	160.0	0.115
12) I found the visualization realistic.	1.019	0.314	254.0	0.371
13) I was able to immerse myself in the visualization.	0.0	1.0	219.5	0.988
14) I understood well what the client wants to build.	-0.908	0.370	191.0	0.439
15) This app is well suited for evaluating planned construction projects.	0.219	0.827	218.5	0.814
16) I would use this app to check on a planned construction project in my neighborhood.	0.309	0.759	232.0	0.767
17) If this app was available, I would recommend it to others.	-0.813	0.421	180.5	0.417

Appendix B

Registration Form

Registration form in English on page 67.

Registration form in German on page 73.

Both documents have been printed from the Microsoft Form website with some modifications for better pagination.

Experiment registration "XR in urban planning"

Thank you for registering for the "XR in urban planning" experiment. In order to take part in the experiment, I need some data about you. More detailed information about available time slots will be sent by email at a later date.

* Required

Demographics

1. Full name *

2. Age *

The value must be a number

3. Gender *

- ◯ Woman
- ◯ Man
- ◯ Non-binary

4. Preferred language during the experiment *

- ◯ German
- ◯ English

5. Email *

6. Phone number *

7. What is your highest achieved level of education? *

- ◯ Compulsory school
- ◯ Apprenticeship / high school
- ◯ Higher education

8. Are you currently studying at a higher education institution? *

- ◯ Yes
- ◯ No

Further relevant data

9. What best describes the area where you grew up? *

- ◯ Urban
- ◯ Suburban
- ◯ Rural

10. What best describes your current area of residence? *

- ◯ Urban
- ◯ Suburban
- ◯ Rural

11. I am familiar with the area surrounding the Stettbach train station *

- ◯ Strongly agree
- ◯ Agree
- ◯ Neither agree nor disagree
- ◯ Disagree
- ◯ Strongly disagree

12. How often do you use smartphones? *

- ◯ Daily
- ◯ Weekly
- ◯ Monthly
- ◯ Yearly
- ◯ Never

13. How often do you play video games? *

- ◯ Daily
- ◯ Weekly
- ◯ Monthly
- ◯ Yearly
- ◯ Never

14. How much experience do you have with Augmented Reality (AR)? *

Examples: Microsoft Hololens, Pokémon GO, IKEA Place

- ◯ Extensive experience
- ◯ Moderate experience
- ◯ Little experience
- ◯ Minimal experience
- ◯ No experience

15. How much experience do you have with Virtual Reality (VR)? *

Examples: Oculus Rift, Meta Quest, Playstation VR, Google Cardboard

- ◯ Extensive experience
- ◯ Moderate experience
- ◯ Little experience
- ◯ Minimal experience
- ◯ No experience

16. How much experience do you have with GIS and/or geospatial software? *

Examples: ArcGIS, QGIS, Google Earth, Cesium Ion

- ◯ Extensive experience
- ◯ Moderate experience
- ◯ Little experience
- ◯ Minimal experience
- ◯ No experience

17. How much experience do you have with CAD and/or 3D modelling software? *

Examples: Autodesk, SketchUp, FreeCAD, Blender

- ◯ Extensive experience
- ◯ Moderate experience
- ◯ Little experience
- ◯ Minimal experience
- ◯ No experience

18. How much knowledge do you have about Architecture and/or Building Design? *

- ◯ Extensive knowledge
- ◯ Moderate knowledge
- ◯ Little knowledge
- ◯ Minimal knowledge
- ◯ No knowledge

19. How much knowledge do you have about Urban Planning? *

- ◯ Extensive knowledge
- ◯ Moderate knowledge
- ◯ Little knowledge
- ◯ Minimal knowledge
- ◯ No knowledge

20. Comments or questions?

Language: Deutsch

Anmeldung Experiment "XR in der Stadtplanung"

Vielen Dank, dass du dich für das Experiment "XR in der Stadtplanung" anmeldest. Um am Experiment teilnehmen zu können, benötige ich einige Angaben über dich. Genauere Informationen über die verfügbaren Termine werden zu einem späteren Zeitpunkt per Email verschickt.

* Required

Demographische Daten

1. Vor- und Nachname *

2. Alter *

The value must be a number

3. Gender *

- ◯ weiblich
- ◯ männlich
- ◯ nichtbinär

4. Bevorzugte Sprache während des Experiments *

◯ Deutsch

◯ Englisch

5. Email *

6. Telefonnummer *

7. Was ist dein höchster Bildungsabschluss? *

◯ obligatorische Schule

◯ Lehre / Gymnasium

◯ Hochschule

8. Studierst du derzeit an einer Hochschuleinrichtung? *

◯ ja

◯ nein

Weitere relevante Daten

9. Was beschreibt den Ort, an dem du aufgewachsen bist, am besten? *

- ◯ städtisch
- ◯ suburban
- ◯ ländlich

10. Was beschreibt deinen derzeitigen Wohnort am besten? *

- ◯ städtisch
- ◯ suburban
- ◯ ländlich

11. Ich kenne mich in der Umgebung des Bahnhofs Stettbach aus *

- ◯ trifft sehr zu
- ◯ trifft zu
- ◯ weder noch
- ◯ trifft nicht zu
- ◯ trifft gar nicht zu

12. Wie häufig verwendest du Smartphones? *

- ◯ täglich
- ◯ wöchentlich
- ◯ monatlich
- ◯ jährlich
- ◯ nie

13. Wie häufig spielst du Videospiele? *

- ◯ täglich
- ◯ wöchentlich
- ◯ monatlich
- ◯ jährlich
- ◯ nie

14. Wie viel Erfahrung hast du mit Augmented Reality (AR)? *

Beispiele: Microsoft Hololens, Pokémon GO, IKEA Place

- ◯ umfassende Erfahrung
- ◯ moderate Erfahrung
- ◯ wenig Erfahrung
- ◯ minimale Erfahrung
- ◯ keine Erfahrung

15. Wie viel Erfahrung hast du mit Virtual Reality (VR)? *

Beispiele: Oculus Rift, Meta Quest, Playstation VR, Google Cardboard

- umfassende Erfahrung
- moderate Erfahrung
- wenig Erfahrung
- minimale Erfahrung
- keine Erfahrung

16. Wie viel Erfahrung hast du mit GIS und/oder Geospatial Software? *

Examples: ArcGIS, QGIS, Google Earth, Cesium Ion

- umfassende Erfahrung
- moderate Erfahrung
- wenig Erfahrung
- minimale Erfahrung
- keine Erfahrung

17. Wie viel Erfahrung hast du mit CAD und/oder 3D-Modellierungssoftware? *

Beispiele: Autodesk, SketchUp, FreeCAD, Blender

- umfassende Erfahrung
- moderate Erfahrung
- wenig Erfahrung
- minimale Erfahrung
- keine Erfahrung

18. Wie viel Wissen hast du über Architektur und/oder Bauplanung? *

- ○ umfassendes Wissen
- ○ moderates Wissen
- ○ wenig Wissen
- ○ minimales Wissen
- ○ kein Wissen

19. Wie viel Wissen hast du über Stadtplanung? *

- ○ umfassendes Wissen
- ○ moderates Wissen
- ○ wenig Wissen
- ○ minimales Wissen
- ○ kein Wissen

20. Kommentare oder Fragen?

Appendix C

Experiment Questionnaire

Experiment questionnaire in English on page 80.

Experiment questionnaire in German on page 84.

Universität Zürich[UZH]

XR in Urban Planning
Part 1

What is the height of the high-rise building?

______________________ meters

How many floors does the high-rise building have?

____

Evaluate the following statements. There is no correct or incorrect answer.

The building blends well into its surroundings.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

The building would impair the view from my flat.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

Participant ___________________________

Universität Zürich[UZH]

XR in Urban Planning
Part 2

In a few words, what do you think of this location?

____

What is the length (north-south axis) of the entire building?

______________________ meters

What is the width (east-west axis) of the entire building?

______________________ meters

What is the height of the low-rise building?

______________________ meters

How many floors does the low-rise building have?

____

What is the height of the high-rise building?

______________________ meters

How many floors does the high-rise building have?

____

Participant ____________________________

Universität Zürich[UZH]

XR in Urban Planning
Part 2

Evaluate the following statements. There is no correct or incorrect answer.

I can well imagine what the building will look like.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

I like how the building looks in the app.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

The building blends well into its surroundings.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

The construction project would have a negative impact on the neighborhood.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

I would request the construction application documents for a more detailed examination.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

All things considered, I would consider filing a building appeal against this project.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

Reason

____

____

I think that building appeals are an important legal protection instrument.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

Participant ____________________________

Universität Zürich[UZH]

XR in Urban Planning
Part 3

Evaluate the following statements. There is no correct or incorrect answer.

I found the visualization easy to understand.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

I found the visualization trustworthy.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

I found the visualization realistic.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

I was able to immerse myself in the visualization.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

I understood well what the client wants to build.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

This app is well suited for evaluating planned construction projects.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

I would use this app to check on a planned construction project in my neighborhood.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

If this app was available, I would recommend it to others.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

Participant ______________________________

Universität Zürich[UZH]

XR in der Stadtplanung
Teil 1

Welche Höhe hat das Hochhaus?

______________________ Meter

Wie viele Geschosse hat das Hochhaus?

____

Werte folgende Aussagen aus. Es gibt keine korrekte oder falsche Antwort.

Das Gebäude fügt sich in seine Umgebung gut ein.

○	○	○	○	○
Lehne stark ab	Lehne ab	Weder noch	Stimme zu	Stimme stark zu

Das Gebäude würde die Aussicht von meiner Wohnung aus beeinträchtigen.

○	○	○	○	○
Lehne stark ab	Lehne ab	Weder noch	Stimme zu	Stimme stark zu

Teilnehmer:in ____________________________

Universität Zürich[UZH]

XR in der Stadtplanung
Teil 2

In wenigen Worten, was hältst Du von dieser Örtlichkeit?

____

Welche Länge (Nord-Süd-Achse) hat das gesamte Gebäude?

________________________ Meter

Welche Breite (Ost-West-Achse) hat das gesamte Gebäude?

________________________ Meter

Welche Höhe hat der Flachbau?

________________________ Meter

Wie viele Geschosse hat der Flachbau?

____

Welche Höhe hat das Hochhaus?

________________________ Meter

Wie viele Geschosse hat das Hochhaus?

____

Teilnehmer:in ______________________________

Universität Zürich[UZH]

XR in der Stadtplanung
Teil 2

Werte folgende Aussagen aus. Es gibt keine korrekte oder falsche Antwort.

Ich kann mir gut vorstellen, wie das Gebäude aussehen wird.

○	○	○	○	○
Lehne stark ab	Lehne ab	Weder noch	Stimme zu	Stimme stark zu

Mir gefällt, wie das Gebäude in der App aussieht.

○	○	○	○	○
Lehne stark ab	Lehne ab	Weder noch	Stimme zu	Stimme stark zu

Das Gebäude fügt sich in seine Umgebung gut ein.

○	○	○	○	○
Lehne stark ab	Lehne ab	Weder noch	Stimme zu	Stimme stark zu

Das Bauprojekt würde sich negativ auf die Nachbarschaft auswirken.

○	○	○	○	○
Lehne stark ab	Lehne ab	Weder noch	Stimme zu	Stimme stark zu

Ich würde die Dokumente des Baugesuchs für eine genauere Untersuchung einfordern.

○	○	○	○	○
Lehne stark ab	Lehne ab	Weder noch	Stimme zu	Stimme stark zu

Alles in allem würde ich in Erwägung ziehen, ein Baurekurs gegen dieses Projekt einzureichen.

○	○	○	○	○
Lehne stark ab	Lehne ab	Weder noch	Stimme zu	Stimme stark zu

Begründung

____

____

Ich denke, dass Baurekurse ein wichtiges Rechtsschutzinstrument sind.

○	○	○	○	○
Lehne stark ab	Lehne ab	Weder noch	Stimme zu	Stimme stark zu

Teilnehmer:in __________________________

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XR in der Stadtplanung
Teil 3

Werte folgende Aussagen aus. Es gibt keine korrekte oder falsche Antwort.

Ich fand die Visualisierung einfach zu verstehen.

○ Lehne stark ab ○ Lehne ab ○ Weder noch ○ Stimme zu ○ Stimme stark zu

Ich fand die Visualisierung vertrauenswürdig.

○ Lehne stark ab ○ Lehne ab ○ Weder noch ○ Stimme zu ○ Stimme stark zu

Ich fand die Visualisierung realistisch.

○ Lehne stark ab ○ Lehne ab ○ Weder noch ○ Stimme zu ○ Stimme stark zu

Ich konnte mich in die Visualisierung hineinversetzen.

○ Lehne stark ab ○ Lehne ab ○ Weder noch ○ Stimme zu ○ Stimme stark zu

Ich habe gut verstanden, was die Bauherrschaft bauen will.

○ Lehne stark ab ○ Lehne ab ○ Weder noch ○ Stimme zu ○ Stimme stark zu

Diese App eignet sich gut zur Bewertung von geplanten Bauprojekten.

○ Lehne stark ab ○ Lehne ab ○ Weder noch ○ Stimme zu ○ Stimme stark zu

Ich würde diese App nutzen, um ein geplantes Bauprojekt in meiner Nachbarschaft zu überprüfen.

○ Lehne stark ab ○ Lehne ab ○ Weder noch ○ Stimme zu ○ Stimme stark zu

Wenn diese App verfügbar wäre, würde ich sie anderen weiterempfehlen.

○ Lehne stark ab ○ Lehne ab ○ Weder noch ○ Stimme zu ○ Stimme stark zu

Teilnehmer:in ____________________________

Appendix D

Experiment Protocol

Experiment protocol in English on page 89.

Experiment protocol in German on page 90.

Universität Zürich[UZH]

XR in Urban Planning
Protocol

Protocol for the Experiment

Greetings

Welcome to the experiment "XR in Urban Planning".

1. The consent form needs to be signed
2. The data is treated confidentially
3. You can opt-out at any time and without a reason
4. The experiment should last around 30 minutes

Reference building:

50m high

Distance to construction project:

230m

Aim

1. In this experiment we want to test how different XR visualization methods affect the understanding and perception of construction projects. We also want to test whether this could have an impact on the submission of building appeals.

Building appeals

2. Buildings in Switzerland must be approved by the authorities and, if you do not agree with the approval, you can file an appeal against the project.
3. Under Swiss law, any affected person has the right to file an appeal against a construction project.
4. The construction documents must be requested on-time for review in order to later, in a second step, be able to file an appeal.

Scenario

5. We have developed the following scenario for this experiment: You live in the Westhof, a new building is planned on this field and you want to take a look at the project.
6. I will give you a smartphone to visualize the construction project. Using the visualization, you will have to answer some questions related to the project and the visualization.

App

7. For the visualization you will use an AR/VR app. That means:
   a. AR: You see a live stream from the camera with an overlay of the building.
   b. VR: You see the building in a virtual environment that depicts reality. The environment consists of data from Google Earth.
8. The app works using GPS data and the location may not work correctly. If the image does not correct itself, we will have to restart the app.

3 Parts

1. The experiment consists of three parts with their own set of questions:
   a. In the first part, you will look at a building from the balcony of your apartment.
   b. In the second part, you will look at the building from the field.
   c. In the third part, you will retrospectively answer questions about the experiment.

Protokoll für das Experiment

Begrüssung

Willkommen am Experiment «XR in der Stadtplanung»

1. Einverständniserklärung wurde unterschrieben
2. Daten werden vertraulich gehandelt
3. Kann zu jeder Zeit aussteigen
4. Das Experiment soll ungefähr 30 Minuten dauern

Referenzgebäude:

50m high

Entfernung zum Bauprojekt:

230m

Einführung

1. In diesem Experiment wollen wir testen, wie sich unterschiedliche XR-Visualisierungsmethoden auf dem Verständnis und der Wahrnehmung von Bauprojekten auswirken. Wir wollen auch testen, ob dies Auswirkungen auf die Einreichung von Baurekursen haben könnte.

Baurekurse

1. Unter Schweizer Recht hat jede betroffene Person das Recht, ein Rekurs gegen ein Bauprojekt zu erheben.
2. Bauten in der Schweiz müssen von den Behörden bewilligt werden und, wenn man mit der Bewilligung nicht einverstanden ist, kann man ein Rekurs gegen das Projekt einreichen.
3. Dafür müssen die Baudokumente fristgerecht zur Überprüfung eingefordert werden, um später, in einem zweiten Schritt, ein Baurekurs einreichen zu können.

Szenario

4. Für dieses Experiment haben wir folgendes Szenario entwickelt: Du wohnst im Westhof, an diesem Feld ist ein neues Gebäude geplant und du willst dir das Projekt anschauen.
5. Ich gebe dir ein Handy, mit dem du das Bauprojekt visualisieren kannst. Anhand der Visualisierung musst du einige Fragen zum Projekt und die Visualisierung beantworten.

App

6. Für die Visualisierung brauchst du eine AR-/VR-App. Das heisst:
   a. AR: Du siehst ein Live-Stream der Kamera mit einer Überlagerung vom Gebäude. Es gibt ein transparented digitales Oberflächenmodell, das das Gebäude verdeckt, aber Objekte in der realen Welt verdecken es nicht.
   b. VR: Du siehst das Gebäude in einer virtuellen Umgebung, die die Realität abbildet. Die Umgebung besteht aus Daten von Google Earth.
7. Die App funktioniert anhand GPS-Daten und es kann sein, dass die Verortung nicht richtig funktioniert. Wenn sich das Bild nicht korrigiert, müssen wir die App neustarten.

3 Teilen

8. Das Experiment besteht aus drei Teilen mit ihrem eigenen Fragenkatalog:
   a. Im ersten Teil schaust du dir das Gebäude aus dem Balkon deiner Wohnung an.
   b. Im zweiten Teil schaust du dir das Gebäude aus dem Feld an.
   c. Im dritten Teil beantwortest du rückblickend Fragen zum Experiment.

Appendix E

Participant Consent Form

The consent form in English can be found on page 92.

The consent form in German can be found on page 94.

Study Information and Declaration of Consent

This document is a declaration of consent for the study "XR in urban planning" at the GIVA unit in the Department of Geography of the University of Zurich,. Should any questions arise at a later date, Marcel Garate (marcel.garate@uzh.ch) or Dr. Tumasch Reichenbacher (tumasch.reichenbacher@geo.uzh.ch) will be happy to answer them.

Please read the information in this document carefully.

Purpose of the Study

The purpose of the study is to determine the suitability of extended reality applications in visualizing construction projects for the public. The study also examines how different forms of visualization affect the perception of the construction project.

The study is being carried out as part of Marcel Garate's master's thesis. The master's thesis is supervised by Tumasch Reichenbacher and Armand Kupaj.

Exclusion Criteria for the Study

To participate in the study, you must:

- be of legal age
- be in a healthy condition
- have normal or corrected-to-normal vision
- not have color blindness

Procedure of the Study

During the study, you will view a visualization of a proposed building in an Extended Reality smartphone application at two different locations. With the help of this application, you will be asked to answer several questions about the building project. You will then be asked to answer a few questions about the visualization. The study takes about 30 minutes.

You can stop the experiment at any time and without giving a reason.

Confidentiality of the Data

The data collected during the study will be treated confidentially and will not be passed on to third parties.

With your signature, you give your consent for us to publish the anonymized and aggregated results of the study. The data published in this way will not allow any conclusions to be drawn about you personally.

Harms

This is a low-risk study and we are not insured against any harm you may suffer during the experiment. However, if you wish to attribute any form of physical or mental impairment to the study, please contact us immediately. We will help you as much as possible and offer you clinical counseling if needed.

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Notification of the Results

If you are interested in the results of the study, you can leave us your e-mail address.

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Email

Declaration of Consent

With your signature you confirm that you have read the above information carefully. You thereby confirm your agreement to the study conditions.

____________________________	____________________________
Full Name	**Signature**

____

Date, Time

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Studieninformation und Einverständniserklärung

Dieses Dokument gilt als Einverständniserklärung für die Studie «XR in der Stadtplanung» an der Abteilung GIVA vom Geographischen Institut der Universität Zürich. Sollten zu einem späteren Zeitpunkt Fragen aufkommen, wird Marcel Garate (marcel.garate@uzh.ch) oder Dr. Tumasch Reichenbacher (tumasch.reichenbacher@geo.uzh.ch) diese gerne beantworten.

Bitte lesen Sie die Informationen in diesem Dokument sorgfältig durch.

Zweck der Studie

Zweck der Studie ist, herauszufinden, inwiefern Extended Reality-Applikationen geeignet sind, ein Bauvorhaben für die Bevölkerung zu visualisieren. Weiter wird untersucht, wie sich unterschiedliche Visualisierungsformen auf die Wahrnehmung des Bauvorhabens auswirken.

Die Studie wird im Rahmen der Masterarbeit von Marcel Garate durchgeführt. Die Masterarbeit wird von Dr. Tumasch Reichenbacher und Dr. Armand Kupaj betreut.

Ausschlusskriterien der Studie

Um an der Studie teilnehmen zu können, müssen Sie:

- volljährig sein
- sich in einem gesunden Zustand befinden
- eine normale oder zu normal korrigierte Sehstärke haben
- keine Farbblindheit haben

Ablauf der Studie

Während der Studie werden Sie eine Visualisierung eines geplanten Gebäudes in einer Extended Reality Smartphone-Applikation an zwei unterschiedlichen Standorten betrachten. Mit Hilfe dieser Applikation sollen Sie mehrere Fragen zum Bauvorhaben beantworten. Anschliessend werden Sie gebeten, einige Fragen zur Visualisierung zu beantworten. Die Studie dauert ca. 30 Minuten.

Sie können das Experiment zu jeder Zeit und ohne Begründung abbrechen.

Vertraulichkeit der Daten

Die während der Studie erfassten Daten werden vertraulich behandelt und nicht an Dritte weitergegeben.

Mit Ihrer Unterschrift geben Sie Ihr Einverständnis, dass wir die anonymisierten und aggregierten Ergebnisse der Studie publizieren dürfen. Die so publizierten Daten lassen keine Rückschlüsse auf Ihre Person zu.

Schäden

Dies ist eine Studie mit geringem Risiko und wir sind nicht gegen Schäden versichert, die Ihnen während des Experimentes entstehen könnten. Wenn Sie jedoch der Studie jegliche Form von körperlicher oder geistiger Beeinträchtigung zuschreiben möchten, kontaktieren Sie uns bitte

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umgehend. Wir werden Ihnen so gut wie möglich helfen und Ihnen bei Bedarf eine klinische Beratung anbieten.

Bekanntgabe der Ergebnisse

Wenn Sie an den Ergebnissen der Studie interessiert sind, können Sie uns Ihre Emailadresse hinterlassen.

____

Emailadresse

Einverständniserklärung

Mit Ihrer Unterschrift bestätigen Sie, dass Sie die obenstehenden Informationen sorgfältig durchgelesen haben. Sie bestätigen damit Ihr Einverständnis zu den Studienbedingungen.

____

Vorname, Nachname

____

Unterschrift

____

Datum, Uhrzeit

Personal declaration:

I hereby declare that the submitted Thesis is the result of my own, independent work.

All external sources are explicitly acknowledged in the Thesis.

Marcel Garate 30.04.2024