Universität Zürich[UZH]

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

OPEN COMMUNICATION BY AUGMENTED REALITY EXPERIENCES IN URBAN PLANNING

GEO 620 Master's Thesis

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Zurich, 30th September 2020

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ABSTRACT

Due to the ongoing population growth, construction activity is likely to stay on a high level to enlarge the living and working space. Traditional methods to visualise construction projects like construction spans, 2D, or 3D visualisations, fail to give a complete picture of the projects. Therefore, Augmented Reality (AR) may be a possible solution for visualising building projects for citizens.

The main aim of this research was to assess the suitability of an AR application based on four research questions. First, this study set out to evaluate how suitable an AR application is for visualising a construction project compared to construction spans. Second, it was assessed how difficult it is for users to interpret the visualisation in an AR application correctly. Third, it was tested whether different levels of detail (LOD) had an influence on task performance of the participants, thereby making one LOD more suitable than another. Fourth, it was examined whether the LODs had an influence on the participants' decision-making.

A prototype AR application was developed in the course of this research and tested in the field with thirty participants in a between-subjects user study. Three gradually more detailed LODs, namely LOD 1, LOD 2, and LOD 3, were randomly assigned to the participants. They had to solve some estimation tasks first using construction spans and then the AR application. In addition to the tasks, the participants were given a questionnaire to assess their opinion on both visualisation methods quantitatively and qualitatively.

The participants were in general confident about the potential of an AR application to visualise a construction project. The study could show that there are no significant differences between the different LOD groups in both task performance and subjective assessment of the AR application. However, participants who were assigned LOD 3 performed best in terms of estimating the visualisation's dimensions. Participants who were assigned LOD 1 or LOD 2 commented that the visualisation is lacking façade elements, such as windows. Visualising a building's external structure can facilitate estimation tasks as these elements can give an indication of the building's size. Furthermore, this study suggests AR could be used in public participation processes and, thus, support citizens in their decision-making processes.

Keywords: Augmented Reality, AR, ARKit, ArcGIS Runtime SDK, 3D Visualisation, Level of Detail, City Visualisation, Urban Planning, Smart City, Decision-Making, User Expectations

ACKNOWLEDGEMENTS

I wish to express my gratitude to the following:

Dr Tumasch Reichenbacher, *Dr Peter Kiefer* and *Christian Sailer* for the guidance through this Master's thesis, taking their time for many discussions and for giving me valuable feedback throughout this project.

Matthias Schenker and *Aldis Grauze* from Esri Schweiz for their technical support and providing access to the Apple Developer license.

Christian Hürzeler from Amt für Städtebau of the city of Zurich, for providing the data from the construction project *Schulhaus Allmend*.

All the *participants* of the pilot and main studies, without whose time and effort of this project would not have been possible.

Jasmin Allenspach and *Amy Kunz* for proof-reading and providing valuable feedback.

Finally, to my family for their interest in my thesis and their support throughout my time at university.

Zurich, 30th September 2020

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ABBREVIATIONS

ANOVA	Analysis of Variance
API	Application Programming Interface
AR	Augmented Reality
AV	Augmented Virtuality
BIM	Building Information Modelling
BMS	Vocational Secondary School (German: Berufsmaturitätsschule)
CAD	Computer-Aided-Design
DEM	Digital Elevation Model
ETHZ	Swiss Federal Institute of Technology in Zurich (German: Eidgenössische Technische Hochschule Zürich)
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPU	Graphics Processing Unit
IDE	Integrated Development Environment
IoT	Internet of Things
LiDAR	Light Detection And Ranging
LOD	Level of Detail
MAR	Mobile Augmented Reality

MR	Mixed Reality
MSPK	Mobile Scene Package
QR code	Quick-Response code
RV Continuum	Reality-Virtuality Continuum
SDK	Software Development Kit
UZH	University of Zurich
VR	Virtual Reality
2D	Two Dimensional
3D	Three Dimensional

1 INTRODUCTION

The population of the city of Zurich, Switzerland has grown by more than 50,000 people over the past twenty years. By 2035 the population is predicted to increase by another 45,000–100,000 (Figure 1) [1]. To facilitate a living and working space for the growing number of people in Zurich construction activity is likely to stay on a high level in the future. It is therefore important to inform the citizens about new building projects. Informing the public includes creating visualisations of a planned building.

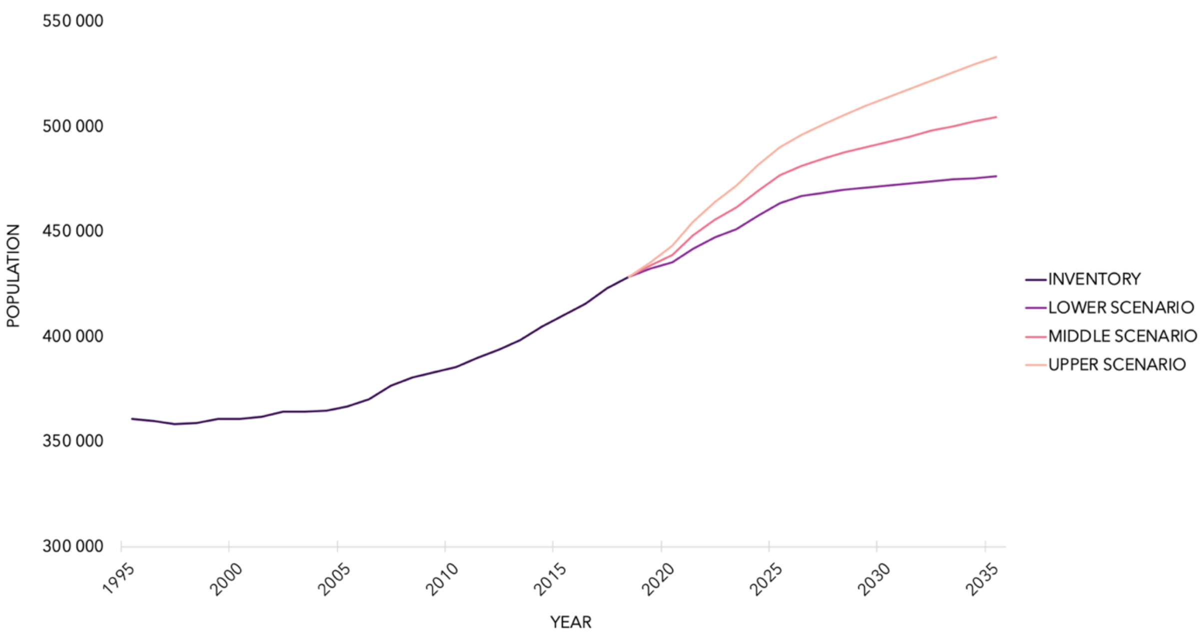

Figure 1: Growth of population of the city of Zurich since 1995 including three different scenarios for future growth [1].

This is particularly important because major construction projects are subject to popular vote in Switzerland [2]. Citizens are sent voting documents, which inform them about a construction project in detail. These documents consist mainly of a textual description; sometimes two-dimensional (2D) maps or realistic three-dimensional (3D) visualisations are included. Especially the realistic 3D visualisations have led to major debates in the past [3]. These visualisations often show the building on a sunny summer day. Parameters, such as the perspective, the exposure to light, the number of people in the scene, and others, are often manipulated by the designer of the static 3D scene. Usually, the projects are visualised in the best possible way [4]. This can lead to a discrepancy between 3D visualisation and reality. The visualisations often show only certain perspectives and do not feature all elements of the project. To compensate for the lacking elements, a textual description explains the project in detail in the voting brochures. However, imagining a building based on a text and a single photomontage or a construction plan is not trivial. Furthermore, language can be a barrier. Therefore, new methods for visualising construction projects are needed.

A possible solution to visualise construction projects is Augmented Reality (AR). AR is a new means of communicating with citizens [5], [6]. Both AR and Virtual Reality (VR) are receiving widespread attention from the media and are thriving in the tech industry. These technologies redefine how we communicate, interrelate, and work together. Both offer new experiences and interactions either cut off from or blended with the real world and, hence, can supplement the real world according to the demands of the citizens [7].

A mobile AR solution, which the citizens could download to their mobile devices, could facilitate a more objective communication about construction projects. The application would allow viewing a project from multiple angles by walking around the construction site. The light settings would be given by the current weather conditions. Thus the AR application could assist citizens in forming an opinion about the project before casting their vote.

Additionally, the AR application could facilitate the conversion from classical city to Smart City. The city of Zurich was ranked the fifteen-smartest city in the world in 2019 [8]. Zurich's definition of "smart" includes linking humans, infrastructures and organizations to generate a social, economic and ecological added value. The interconnectedness between data, sensors and applications increases participation possibilities for Zurich's citizens [9]. Therefore, an AR application could be used to strengthen public participation in the city of Zurich.

Previous research compared traditional visualisation methods such as construction spans, plaster models, 2D, and 3D visualisations with both AR and VR as visualisation methods [10]. Ilin's (2019) [10] research was based on collecting opinions about the different visualisation methods. This necessitates investigating whether user acceptance is consistent with the suitability of AR as a visualisation method. Even if the user acceptance of a method is high, this method is not necessarily suitable for presenting information in a way that is as easy to interpret as possible.

Moreover, the question arises how to represent the virtual construction project. The 3D building can be visualised in different level of details (LOD) such as block models, models including roofs and more detailed architectural models [11]. Choosing different LODs could influence the ease of interpretation of the visualisation. Döllner (2007) [12] found that details could be distracting for an intelligible visualisation. Non-photorealistic visualisations allow removing unnecessary details and stress relevant features of the object [13]. Therefore, the question arises how different LOD could influence the perceived suitability of AR as a visualisation method. It is also not clear if different LOD could influence the acceptance of the presented project.

1.1 MOTIVATION AND AIM

This research seeks to find out how suitable AR is to visualise planned construction projects compared to construction spans, a visualisation method commonly used in Switzerland. For this purpose, two projects in different planning stages are used. Both projects are located in Zurich Manegg, which is in the south of the city of Zurich and lies between the river Sihl and the motorway A3. The approximately 200,000m^2 large area has been under construction recently: a new district called *Greencity* with commercial and residential usage is developed. Shopping facilities, leisure usage and a new school are built. The development of this district is of high density and urbanity and high demands are placed on the design, especially to meet sustainable standards of the area and use environmentally friendly energy supplies as this district should be the first to meet the 2000-Watt Society standards in Switzerland [14], [15]. This aims to reduce energy consumption in long-term to 2000 watts per capita to ensure sustainable use of resources [16].


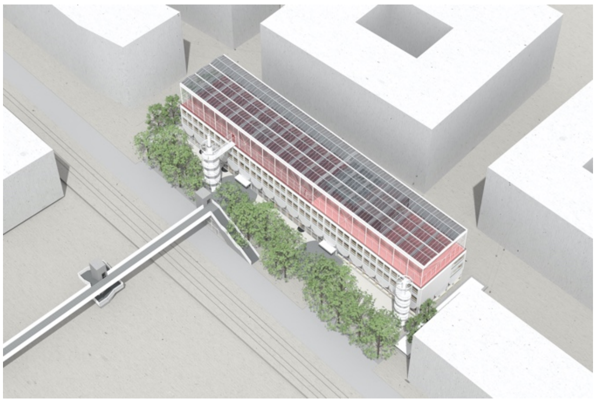

Figure 2: Visualisation of residential buildings on upper Allmend site (left) [17] and *Allmend school building* including foot passage Haspelsteg (right) in Zurich Manegg [20].

The first project used features the construction spans and is located on the upper Allmend site. Around 270 flats are to be built on the current industrial site by 2022. These 270 flats will be divided between four buildings, which are currently visualised with construction spans (status summer 2020) (Figure 2) [17], [18].

The project visualised in the prototype AR application used in this study is the *Allmend school building*, which is to be built in Manegg by the end of 2022 (Figure 2). The school building project includes a footbridge, which connects both sides of the Manegg area, which are divided by railway tracks. The footbridge is to the west of the school building and ensures a safe connection of the two parts of the district over the railway tracks [19], [20]. This project is already at an advanced stage as the voting population of the city of Zurich accepted the credit of CHF 57,318,875 for this new building on 17th November 2019 [21].

This research compares the two visualisation methods in a user study. More specifically, this research focuses on how different LOD of a 3D visualisation in an AR application influence the ease of interpretation of the visualisation and, therefore, which LOD is best used for this purpose. So, a user study is conducted, in which the two visualisation methods are compared. The user study's participants are divided into groups to further examine whether different LODs have an influence. The comparison of the methods and LODs is twofold. First, the efficiency of the visualisation methods is tested by giving the participants of the field study some estimation tasks. Second, the participants' ratings of the perceived suitability of visualisation methods, assessed in a questionnaire, can be compared to their task performance. Finally, it is investigated how the different LODs influence the participants' decision outcome. The findings of this thesis should assist authorities in choosing a suitable LOD for an AR visualisation for future construction projects. Choosing a suitable visualisation will support a transparent communication for future construction projects between the authorities, architecture offices and, most importantly, the citizens. Furthermore, it is hoped that a visualisation that is as realistic as possible will lead to fewer appeals and, thus, the city of Zurich may avoid unnecessary expenses, as the project will not have to be cancelled at an advanced stage.

1.2 RESEARCH QUESTIONS AND HYPOTHESES

Building on the previously mentioned goals, the following research questions and respective hypotheses are examined in the context of this thesis.

RESEARCH QUESTION 1 How suitable is an AR application for visualising new building projects in an understandable and realistic way to assist decision-making compared to construction spans?

> ***HYPOTHESIS 1*** *An AR application is more suitable than construction spans to visualise new building projects.*

RESEARCH QUESTION 2 How difficult is it for users to interpret the visualisation of a building project in an AR application correctly?

> ***HYPOTHESIS 2*** *The more detailed the rendering of the object, the easier it is to interpret the visualisation correctly.*

RESEARCH QUESTION 3 What is the most effective degree of abstraction for visualising a planned building project in an AR application?

> ***HYPOTHESIS 3*** *The lower the degree of abstraction of the object, the easier to make decisions.*

RESEARCH QUESTION 4 How is the decision outcome of the citizens influenced by the different degrees of abstraction?

> ***HYPOTHESIS 4*** *The more realistic the visualisation, the higher the acceptance of the project.*

1.3 OUTLINE

In the next chapter the theoretical background for this research is introduced. Research on urban planning, smart cities and augmented reality is reviewed. Chapter 3 explains the methodology used in the user study and gives an overview of the used data, hardware, software and implementation of the prototype AR application. The results of the user study are presented in chapter 4. Then the results are discussed in chapter 5 based on the previously proposed research questions and the earlier introduced literature. Moreover, limitations of the applied methodology and results are highlighted in this chapter. Finally, chapter 6 concludes this research and gives recommendations and future research prospects.

2 THEORETICAL BACKGROUND

2.1 URBAN PLANNING

Urban planning is shaped by architecture and town construction [22]. According to the City of Zurich (2020) [22] forward-looking urban planning always starts with the people who live and work in the city, who are directly affected by it. It is necessary to consider the people living and working in the city now and in the future when designing urban development concepts and making decisions. Therefore, urban planning can be described as follows:

> *"Planning tomorrow's future with the knowledge of yesterday is the aim of urban planning. With the people and for the people"* [22].

Hence, urban planning includes community planning and public participation as well as issues of site location [23]. With urban planning comes urban design, which is the brainstorming process and preparation for developing the urban structure and environment according to Zhang and Zhu (2004) [24].

VISUALISATIONS IN URBAN PLANNING

Visualisations play an important role in urban planning. They are used as common ground to facilitate a dialogue between architects, planners, decision-makers and the citizens. Visual communication can enhance understanding and, therefore, lead to better decisions [25], [26]. Zeile (2017) [27] emphasises that spatial planning should generally be intelligible and transparent and, if possible, presented in 3D. Computer Aided Design (CAD) software systems such as Geographic Information System (GIS) and Building Information Modelling (BIM) are widely used in urban planning. They assist in developing multidimensional models which allow presenting spatial data interactively [28]. Hence, visualising data helps transforming complex and abstract issues into a visual format, which assist comprehension of issues and decision-making [29]. According to Schröder and Dörk (2019) [29], the appropriate visualisation of urban data can be formulated as three essential demands:

1. Context,
2. Participation,
3. Critique [29].

First, it is important to visualise the data in its spatial context. Second, it is important to seek a dialogue with citizens. For example, displaying visualisations of a building project in a community centre can lead to dialogues between citizens and the planners. Last, the visualisations need to reflect the design decision and, more importantly, the effects of the planned construction project [29].

Over the last twenty years, there has been a shift from ink-based drawings to CAD to visualise projects. CAD is also used to create 3D building models, which can be enhanced with additional metadata [30]. Hence, all relevant data about the building project are registered digitally [31]. BIM resulted from this shift from CAD to full 3D models. BIM can either be a technology or a process [32].

In particular the use of computer simulations in urban planning has been researched [24]–[27], [33]–[36]. Rohrmann and Bishop (2002) [26] could show in their study that computer simulations are an acceptable representation of environmental objects for most participants. They also found that the perceived realism can be enhanced when providing sound. Especially foreground vegetation and the ground surface's appearance had noteworthy effects on the participants' ratings of the different scenes shown.

Radford et al. (1997) [37] identified the three distinct qualities abstraction, accuracy and realism of such computer simulations. Abstraction is the amount of detail included within the scene. For example, a building can be visualised as a block. On the other hand, accuracy is the level of dimensional accuracy, which is defined by the data's accuracy. How convincingly the objects are modelled can be described with the third property, realism. Realism relates to the appearance of the scene, the amount of detail included and the colouring of the objects. Hence, realism describes how "real" the impression of a scene is [37].

Appleton and Lovett (2003) [25] investigated if there is a sufficient level of realism below the highest conceivable level and if any objects within a visualisation have a higher relative importance than others. In their research, participants had to rate different visualisations of an environmental scene. The results show that some objects are more significant than others; however, they could not find a sufficient level of realism. Further, a minimal degree of realism is still crucial for the users to relate to a scene and form an opinion on it. Scenes which show high degrees of abstraction are inadequate [38]. Still, it is necessary to define a sufficient level of realism for decision-making. Moreover, it cannot be ruled out that the difference between the ratings is not due to landscape preference. Hence, there is still a need to investigate whether landscape preference plays a part when rating scenes of different realism [25].

Moreover, the understanding of the impact of landscape visualisations on the user's evaluative and perceptual reaction remains to be investigated [33].

However, realistic scenes might give the illusion of precision. The designer of the visualisation is free to model the scene exactly how she or he wants the viewer to see. In order to achieve a realistic visualisation of the data, the designer has to make a variety of choices about the visual properties. Normally the scenes are visualised on a sunny day and the objects are well-lit. Hence, the scene is viewed in ideal conditions. The resulting image is highly subjective even though an objective view should be represented [39].

DECISION-MAKING AND PUBLIC PARTICIPATION

A good visualisation is key for a good understanding of a presented project to facilitate decision-making processes [40]. In particular 3D virtual environments can assist understanding and learning processes in decision-making [41]. Improving the quality of the decisions helps building trust and resolves conflict [42]. To enable better decision-making, public participation is widely incorporated into planning processes [43]. However, conventional public participation methods are unsuitable for many people and, therefore, there is a need for new methods [44], [45].

Digital tools (i.e., web applications or mobile applications) enable citizens to engage within their environment and empowers them [46]. For example, web applications have potential to improve public participatory planning because the communication between decision-makers and users is more interactive in design [47]. Moreover, interactive tools allow users to choose viewing direction and what content to see [48]. In particular, mobile AR environments have the advantage that citizens can view the data any time without the need to attend a formal meeting [49]. Moreover, visualisation tools allow laypersons and policy makers to comprehend the consequences of planning choices [44]. However, it is important to look at the same data using multiple methods because they could affect knowledge production processes in different ways [43].

2.2 SMART CITY

With growing populations and a migration from rural to urban places, cities are becoming immense and complex congregations of people, which need to be managed accordingly. Growing cities are faced with new issues such as difficulty in waste management, traffic congestions, pollution and associated human health concerns. Therefore, new, smarter approaches of managing growing cities are required. Cities applying smarter ways to manage their challenges are called smart cities [50]. In this thesis, the definition of smart cities by Yin et al. (2015) [51] is adopted:

> *"a smart city is a system integration of technological infrastructure that relies on advanced data processing with the goals of making city governance more efficient, citizens happier, businesses more prosperous and the environment more sustainable"* [51].

According to Kaji et al. (2018) [52], smart cities are characterised by six key characteristics: government, environment, economy, mobility, living and people. Generally, smart cities try to enhance the new interaction between citizens and their city, mainly using the Internet of Things (IoT). Sensors, devices and citizens are connected and, therefore, analysing the information created by the IoT is fundamental (Figure 3) [52], [53]. These technological infrastructures are used to provide solutions to achieve a smart, digital, efficient and sustainable city which facilitates and improves the citizens' lives [7], [54]. According to Zhang et al. (2018) [54], city components such as transportation, governance, finance and environment are improved in smart cities. If cities do not enhance technology, they cannot be considered a smart city [7].

To improve the efficiency of the city's operations and enhance the citizens' quality of life, an integrated, sustainable approach is needed. Those benefitting from smart city initiatives are the citizens, who play a major role in the concept of smart cities [55]. The technologies used by smart cities provide users new ways of interacting with their city, in particular data about the city collected by IoT. The planning and management of a city is improved by visualising data. Nowadays, city data visualisation is implemented mostly on computers and other handheld devices. New ways of visualising data and distributing the visualised data are needed as data play a fundamental part in the implementation of a smart city [54].

The concept of smart cities is still emerging. Different stakeholders have different visions of what a smart city should be. As each city focuses on different facets, the objectives and implementation strategies vary for each smart city project. Moreover, different projects are driven by different stakeholders, some are driven by companies, projects taking a collaborative approach are run by a consortia of companies, city councils, and universities [55]. A good implementation of a smart city project should reduce the effort and simplify the decision-making and city management [56].

Once a smart city project is implemented, it cannot be adopted for other cities without modifications. Smart cities are a "glocal" phenomenon; it includes both global and local aspects. Because smart cities are spread all over the globe and show comparable features, they can be considered a global phenomenon. However, each city is unique and therefore needs specific, locally adapted solutions for its local problems. Therefore, smart cities can also be viewed as a local phenomenon [57].

Figure 3: Exemplary illustration of a smart city [53].

Furthermore, smart cities can be classified into smart city 1.0 and smart city 2.0 [58]. The focus of the vision of the smart city 1.0 was based on technology and economy. Top-down projects are executed by centralised privileged actors and experts and the ability of citizens to participate in the process of these projects is limited [59], [60]. In contrast, the smart city 2.0 puts the people into the centre. Technology is used to resolve residents' needs, social problems and improve governance. The citizens play an active role in the planning and innovation process. Moreover, best practices are not imported from elsewhere but endogenously generated for local issues [58]. For this type of smart city, it is critical to educate and train citizens to develop the digital and data knowledge [61].

2.3 AUGMENTED REALITY

In 1994, Milgram et al. [62] introduced the Reality-Virtuality (RV) continuum which includes real and virtual environments. On the left side of the continuum is reality which defines any physical environment consisting only of real objects. Reality includes both objects viewed in a real-world scene directly in person and those perceived through a video display. The other extreme, placed at the right side of the continuum, is Virtual Reality (VR). VR only includes virtual objects which are either monitor-based or immersive. Between the two extremes is Mixed Reality (MR), to which AR can be assigned to. The class of MR combines objects from both real and virtual environments in one single display (Figure 4) [62], [63].

Figure 4: Simplified Reality-Virtuality continuum [62].

Milgram et al. (1994) [62] distinguish between Augmented Reality and Augmented Virtuality (AV), of which AR is closer to the real environment. "The closer the system towards Virtual world, the more increase in computer generated content; hence reduction in real world elements" [64].

The concept of AR can be defined as the enhancement of a real-world environment augmented by virtual, computer-generated objects [62], [63], [65]. Milgram et al. (1994) [62] stated in AR and VR are related. The difference between the two for the user is the level of immersion: with VR, the user cannot see the real environment and, therefore, is entirely immersed into the virtual world. In contrast, the user primarily sees the real environment when using AR [62], [65]. Therefore, another definition of AR is adding virtual objects to real environments [52]. Nowadays, the real environment in AR applications is captured by the camera on mobile devices. The camera feed is combined with context-appropriate virtual information in such a way that they seem to be one environment [7].

The design of an AR application should exhibit three main characteristics according to Azuma (1997) [66]:

1. Real and virtual elements should be combined,
2. The AR application should be interactive in real time and,
3. A 3D model of the world should be provided [66].

Hence, the AR application should allow analysing the local environment in real time. Thus, a full sensory experience facilitated by data interaction and immersion can enhance mental projections and visuospatial thinking in space and time [67]. AR has redefined the way we communicate, interact and work together [7].

AR and VR are both booming in this digital era. The media has given these evolving technologies plenty of attention [7]. Apart from gaining attention in the media, the search interest for the term "AR" is increasing on internet search engines. Worldwide search interest peaked on Google when Apple and Google announced their AR frameworks *ARKit* and *ARCore* in 2017 (Figure 5) [64], [68]. These announcements have brought an advancement in mobile devices and therefore, more accessible Mobile Augmented Reality (MAR), a game changer for travel, hospitality and also retail [7]. Furthermore, technological advances such as big data, IoT and Graphic Processing Units (GPUs) have helped to develop improve implementations, higher performance and better human-computer interaction, which have improved solving solutions to more difficult and real-world issues [69].

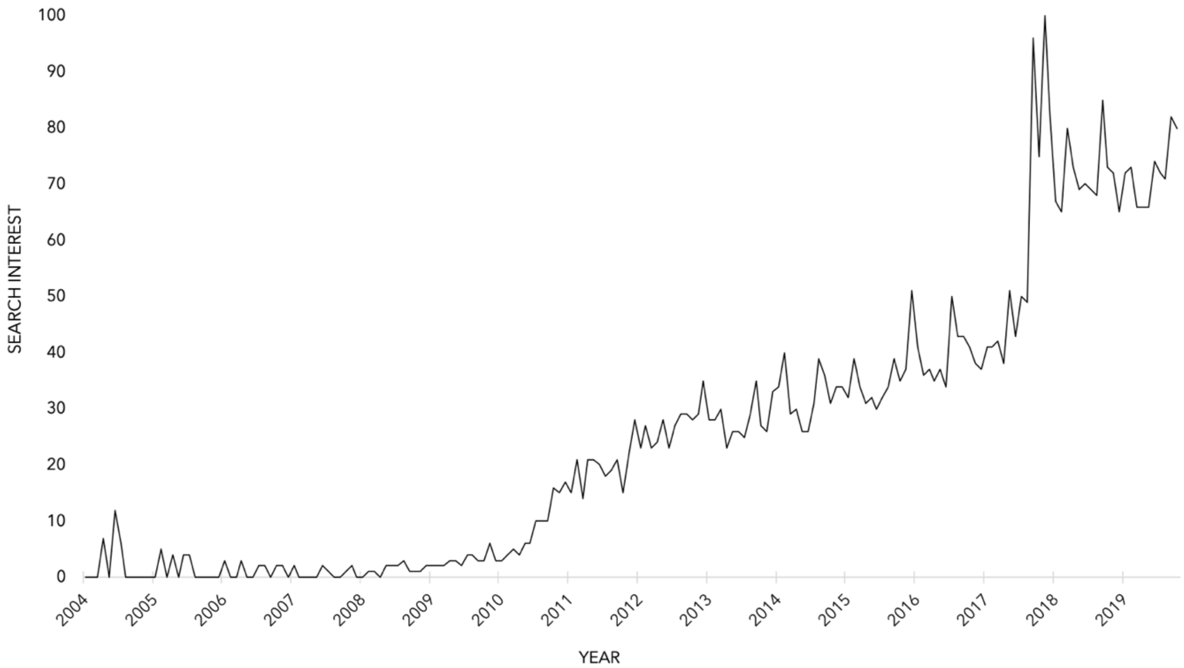

Figure 5: Worldwide search interest of the term "AR App" on Google between 2004 and 2019 [68].

TRACKING TECHNOLOGY

Accurate localisation of the AR scene's viewpoint is the most challenging task [52], [70]. At present, two technologies exist for tracking the location in AR applications: (1) marker-based and (2) marker-less approaches [71], [72]. Marker-based augmented reality uses markers, which are characterised by their colour and based on the virtual information (i.e., 3D virtualisations) [6]. The markers located in the scene are used as an initial location hint for the device. The focus of the mobile device's camera(s) lies on these markers, which are overlaid with the virtual information. Limitations of this approach include shadows, disturbing light sources or unexpected movements [72].

In contrast, marker-less or positioning-based AR systems use the mobile device's camera(s), the in-built GPS, accelerometer and compass to locate the position, direction and height of the device by using the current coordinates to display the virtual objects [6]. Hence, the software does not require markers to display the virtual content. Compared to the marker-based approach, this approach is more interactive [71]. However, one drawback of this method is that the device must be connected to the internet [6]. Moreover, the accuracy of compass and Global Navigation Satellite System (GNSS) are limited [73]. Under open skies the accuracy of GPS-enabled smartphones is usually within a 4.9 metre radius [74]. GPS accuracy decreases in urban environments because of satellite shadowing and reflections from buildings. Additionally, a device's magnetometer can be disturbed by nearby metallic objects, for example cars [75].

REALISM AND ABSTRACTION IN AUGMENTED REALITY AND VIRTUAL REALITY

An ideal AR application should give users the impression that virtual and real objects coexist in the same space [66]. Virtual objects in these augmented scenes can be implemented in two possible ways: the augmented world can either be visualised as realistic as possible or in an artistic, non-photorealistic way [76]. According to Ferwerda (2003) [77], realism can be divided into physical realism, photorealism and functional realism. Physical realism is when virtual objects deliver the same visual simulation as real scenes. If the response of the virtual scenes is the same as the response of real scenes, one speaks of photorealism. Lastly, functional realism provides the same visual information as real scenes [77].

Photorealistic virtual objects should not be distinguishable from a photograph and, therefore, provide little abstraction [77], [78]. Photorealistic effects play an important role to obtain a realistic scene and, therefore, a realistic behaviour of the scene. An important effect for realistic AR applications is illumination, which consists of shadowing and lighting effects [76]. In particular, shadows are essential for a 3D impression of a virtual scene as they give direct information about objects spatial relationships

[79]–[81]. To achieve impressing photorealistic results, graphical and geometric detail is required. For example, photorealistic building façades can be generated with photo-textures [12].

The counterpart to photorealism is non-photorealism. The border between these two realisms can be fuzzy [82]. Non-photorealistic rendering is strongly related to existing artistic techniques and is also known as cartoon-style rendering [12], [78], [83], [84]. The goal is to present virtual objects in a style, which may not be present in the real world. This style may be characterised by an object having a sharp coloured outline [76], [84]. More abstract visualisations allow accommodating further semantic information in the visualisation process. Furthermore, they have a functional character as the cognitive load of viewers may be reduced because non-relevant information is eliminated. Therefore, the information communication could be more efficient as the guidance of the viewers' gaze to more important information is facilitated [85], [86]. Therefore, one could speak of generalising the model when increasing the level of abstraction. The more abstract a visualisation, the less information density is processed. Moreover, with a decreasing level of abstraction storage capacity is also decreasing. A reduced file size is particularly useful for mobile applications [86].

CityGML concept can be used for visualising and abstracting city models. This concept defines five LODs, ranging from LOD 0 to LOD 4 (Figure 6) [87]. The LODs are discrete and defined with geometry and semantics. The concept allows a simultaneous representation of different LODs of the same object [88]. LOD 0 is the only 2D depiction of a building and represents the footprint of a building. Alternatively, the roof outline of a building can also be represented by LOD 0. LOD 1 represents a building by a 3D block model, missing any semantically structuring. LOD 2 is a an extension of LOD 1 with a geometrically simplified exterior husk, including a roof. The exact exterior shell of a building is represented in LOD 3. Furthermore, windows and doors can enrich this LOD. LOD 4 is the most detailed model, where interior structures are also represented [89].

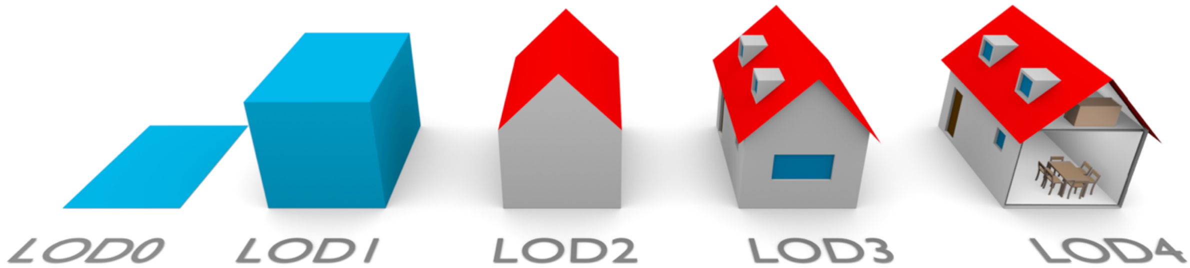

Figure 6: The *CityGML* concept's five levels of detail (LOD). Ranging from the most abstract LOD 0 to the most detailed LOD 4 [87].

Photorealism and non-photorealism have their values in an AR application, choosing an appropriate realism is based on the users of the AR application and their needs [76]. However, not only the rendering technique plays an important role for making virtual objects appearing real but also their physical behaviours and interactions [76], [90]. For example, a ball falling from above should fall until it hits the ground and then continue with a bouncing movement. Durand (2002) [82] suggested that the interpretation of virtual objects rather be convincing than realistic. Döllner (2007) [12] found photorealistic scenes do not provide best possible solutions for understandable visualisations because they are mostly not cognitively adequate. In contrast, non-photorealistic visualisations, are created to express some visual goal and, therefore, provide more purpose-oriented and task-oriented visualisations [12], [84].

APPLICATION FIELDS OF AUGMENTED REALITY SYSTEMS

In 2016, *Pokémon Go,* a mobile location-based social game application, was introduced. This is possibly the most popular ever example of an AR GIS application. This geosocial game relies on smartphones location services to provide its experience [69]. Location-based games such as *Pokémon Go* have been recognised to show health benefits as people are more physically active [91]–[93]. However, AR applications are not only popular in the gaming industry but also in other fields, which will be presented in this chapter.

AR is used in a variety of medical practices. For example, the technology can be used to practice surgery in a controlled environment. Medical AR provides a useful tool for medical guidance, training, education, procedure and workflow. AR helps to project anatomical information or image guided surgical landmarks onto the patient [64].

Beside medical training is AR used for educational purposes. AR technology can be extremely useful to increase students' motivation and content understanding but also to improve academic achievements [64], [94]. However, using AR for educational purposes also comes with its drawbacks. Students might be cognitively overloaded by the technology, the large amount of information it presents and also the complexity of the task [95].

AR experiences are increasingly used in tourism [6], [52], [65], [96]–[102]. Literature shows that using AR experiences could help tourists to enhance their experience on site [96], [97], [100]. In particular, young people enthusiastically accepted the AR experiences [52], [101]. However, the provided applications need to be easily accessible to the public and need to fulfil a specific goal [96], [100]. Vlahakis et al. (2001) [101] developed an AR system, which displays ancient ruins at archaeological sites in Olympia, Greece. Lee et al. (2012) [96] proposed an AR application to visualise demolished buildings in Christchurch, New Zealand. However, the users' acceptance of these AR systems is often not evaluated [103].

AR technology makes the visualisation of 3D city models possible [54], [96]. Zhang et al. (2018) [54] presented a method for visualising Toronto's 3D city model using *Microsoft HoloLens*, a mixed-reality headset. They implemented a tabletop AR experience and could show that visualising 3D city models in an AR experience holds several advantages over the traditional computer-monitor method. However, their approach still requires improvements in gesture interaction and computing power [54]. The question arises whether creating an AR experience for *Microsoft's HoloLens* is appropriate, as this device is still costly and, therefore, not widely accessible [104]. Another drawback of *Microsoft's HoloLens* is the device only recognises limited gestures, which can easily trigger user exhaustion [54].

AUGMENTED REALITY IN URBAN PLANNING

The use of AR in urban planning has been investigated by various scientists. This section gives a short overview what has been researched in this area so far.

Research showed the integration of AR and BIM has high potential to assist in maintaining a building, assessing operations and infrastructure installation. Additionally, on construction sites the reaction time for possible solutions for re-fitting activities can be reduced by the intuitive interaction made possible with the integrated BIM models [105].

Chu, Matthews and Love (2018) [106] researched the effectiveness of AR system integration in BIM to improve task productivity. They developed a cloud-based mobile BIM AR system, which provides users with additional information sources. Users' capabilities in information retrieval processes improved as the mental workloads were lowered thanks to the AR system. Therefore, users were able to complete tasks with minimal error. Hence, a minimal modification to existing 2D information can significantly improve the information extraction on site, productivity of users and reduce cognitive failures. Further, such AR systems can be personalised cost-effectively. However, Chu Matthews and Love (2018) [106] did not research if the AR system is useful long-term when familiarisation with the application is reached.

Kälin (2015) [107] researched what possible value AR can offer in terms of planning support. He tested whether the functionality and perception of a 3D visualisation changed when using an AR application by opposing visualisations visualised with AR by computer generated 3D visualisations. He found that using AR only serves a purpose if it is combined with other methods, such as construction plans. Nonetheless, AR has high potential to communicate spatial information [107]. This aligns with Wietzel (2007) [108], who suggested AR is unlike other visualisation methods capable of showing constructional effects of planned building projects in-situ. Further, he found AR can be used as an objective basis for discussion and decision-making [108].

Cirulis and Brigmanis (2013) [109] developed a pilot project, *City 3D-AR*, which merges virtual 3D building objects with physical city objects. To position the virtual objects they used a marker-less approach. Even though their solution is far from real use for professional applications, they found that using such an AR application can reduce financial resources before construction works are commenced or completed. Further, AR can improve citizens' satisfaction as the public interests are integrated in discussion processes and decision-making processes are made more transparent. Architects, planners, authorities and municipalities can also benefit from using AR, particularly in designing processes [109].

AR technology can also be used to visualise invisible, underground objects [110]–[113]. Kaddioui, Shahrour and El Oirrak (2019) [113] state AR offers powerful functions for visualising underground services and their related real-time data. Fenais et al. (2019) [111] investigated on the integration of GIS and AR as a solution for the construction industry. They developed a cloud-based mobile AR GIS application for mapping underground utilities [111]. Stylianidis et al. (2020) [112] developed *LARA project*, which includes both soft- and hardware to display underground objects. They found that processing power for mobile AR systems is still lacking. Further, the precision of 3D GIS data is another flaw of the application. Hence, the virtual pipelines will appear at in the geodatabase the stored locations, which might not correspond with the real positions [112]. Another project, *AR Pipeline Visualiser*, enables users to identify pipelines, display corresponding attributes and colour classify them accordingly. The software bases on a marker-less approach and was developed with *Unity3D engine* and *Mapbox SDK for Unity*. They could show that such an AR application assists field workers and increases their understanding of water pipelines compared to conventional methods. Research suggested future applications should also enable offline use [110]. Moreover, the visualisation of pipelines could be improved for future projects [67], [110].

Wang and Love (2012) [114] investigated how BIM and AR can be integrated. They state that AR should be ubiquitous and work with accurate positioning systems (e.g., laser pointing). They found that BIM can be extended by AR to visualise projects onsite. This leads to visualising BIM into physical context of a construction project and individual tasks of the project. Their work can be used as a starting guide, however, they did not implement any prototype application to show the usefulness of the integration of BIM and AR [114].

Fraunhofer Institute for Applied Information Technology FIT (2020) [32] developed an AR system, *Auto AR*, to visualise planned building projects on site. It is a mobile hard- and software solution which is installed onto a car. A digital model is connected with location data captured in real-time. The model can be viewed by a front-seat passenger through a head-mounted VR display [32]. Even though the front-seat passenger can conveniently and safely change position in the model by requesting the driver to drive to a certain position, the model comes with some drawbacks. First, the name of the system is misleading as the model has to be viewed through VR glasses and therefore, is not an AR application. Second, the system is not widely available and always requires a car [32]. Hence, the system would need some adaptations to be used by the public or more companies.

Depicting 3D data is fundamental for urban planning processes as it can support the design of urban spaces and assists understanding the processes [67], [109], [115]. Thanks to AR applications, urban planning experts can move around in a city and view real objects of the city merged with virtual 3D objects [109]. An intuitive, contextual and immersive solution is found with AR experiences to geovisualise data in an urban context [52]. Different project proposals and scenarios can be easily visualised and compared before construction work starts [115]. Experts and citizens can benefit from getting an immersive connection with objects surrounding them and, thus, receiving additional information about the objects [52], [64]. Further, visualising complex urban spaces supports visuospatial thinking, cognitive processes and decision-making [5], [116], [117].

> *"Using AR can compensate for the weaknesses of ineffective verbal communication, time-consuming data accessibility, and distraction caused by domain switching"* [118].

However, most AR systems are still too abstract for most users [119]. Moreover, many systems used in the reviewed literature are still heavy to carry and not accessible to the wide public [107], [120]. Some researchers tested their AR applications in real urban context [7], [52], [54], [96], [101], [107], [121]. Results of an evaluation of an AR system in a user study are often based on self-reported data [7], [96]. Therefore, experimentations with actual users and statistical results are needed [7], [67]. Additionally, it is necessary to evaluate the AR applications in a real urban environment and not only in a controlled environment [52].

3 METHODOLOGY

To answer the presented research questions in chapter 1.2 a user study had been conducted. The methodologies of the user study are described in this chapter. The participants of the study are described first, followed by the experimental design. Next, the used data, software and hardware are described. Last, the procedure for the pilot study and the main study are explained.

3.1 PARTICIPANTS

The user study was carried out with thirty-two participants, three additional participants were recruited for the pilot study. The participants had to meet the following criteria to participate in the study:

- The participants needed to be entitled to vote in Switzerland,
- They had to have little or no previous knowledge about the project *Allmend school building*,
- Prior knowledge with iOS devices (i.e., iPhone or iPad).

The participants were recruited via e-mail at Institute of Geography and Institute of Psychology at University of Zurich (UZH) and Institute of Cartography and Geoinformation at Swiss Federal Institute of Technology in Zurich (ETHZ). Furthermore, the study was announced on the webpage of the Geographic Information Visualisation and Analysis group and UZH Marktplatz webpage. Finally, participants were recruited through acquaintances.

Out of thirty-two participants did only thirty participants meet the criteria for the study. Two persons had too much previous knowledge of project *Allmend school building*. Therefore, their results were not used in the evaluation. Of the remaining thirty participants were two colour-blind and two had impaired vision. The participants were randomly split into three groups. These defined which LOD (LOD 1, LOD 2, or LOD 3) the participants would view during the study. The groups are referred to as *group LOD 1*, *group LOD 2* and *group LOD 3* in the following sections.

The groups were composed of eighteen women and twelve men (Figure 7), aged between 21 and 58 years. On average, participants in *group LOD 1* were 30.9 years (s_{LOD1} = 9.88), these in *group LOD 2* 33 years (s_{LOD2} = 11.78) and in *group LOD 3* 28.2 years old (s_{LOD3} = 6.66) (Figure 8). The age distribution was not taken into account in the group allocation because the ages over 40 were not representative.

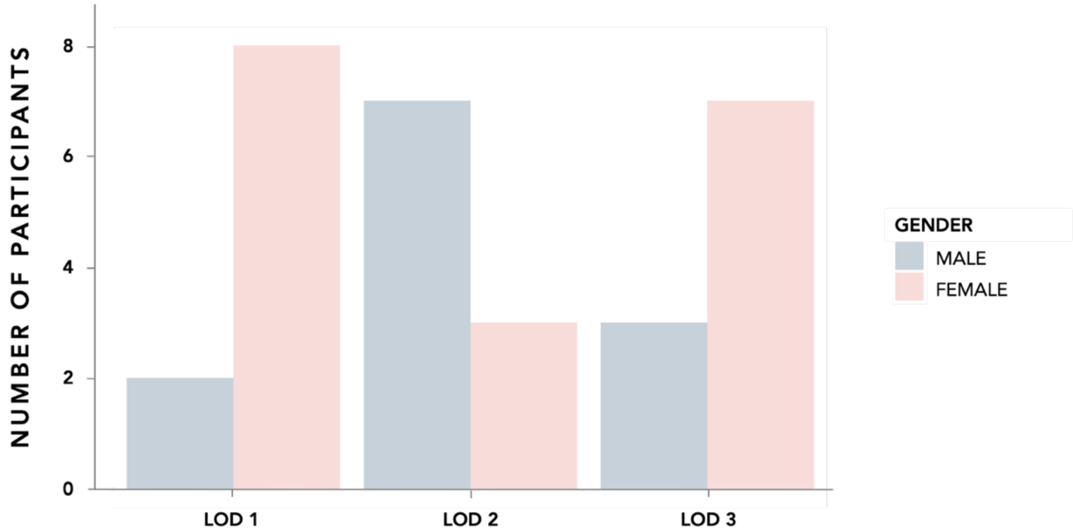

Figure 7: Gender distribution among the three *groups LOD 1*, *LOD 2*, and *LOD 3*.

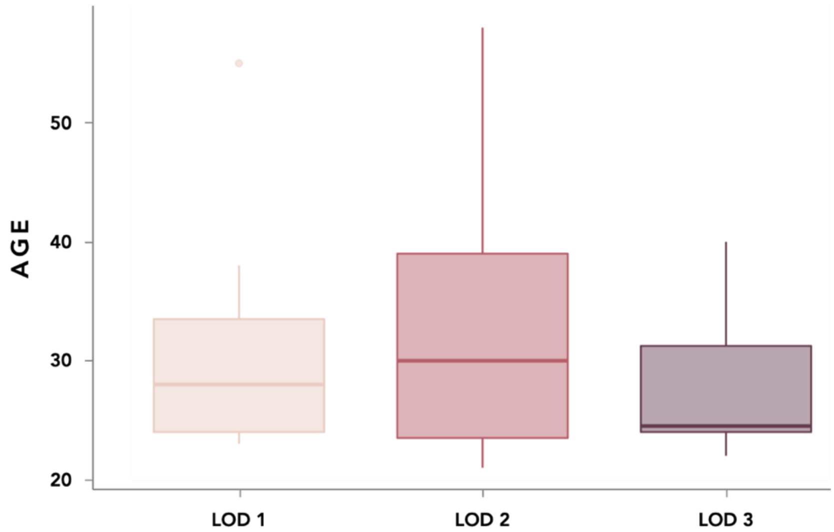

Figure 8: Age distribution of participants among *LOD groups*.

The participants can also be divided into their place of origin. Twelve participants each grew up in a city or in the countryside, respectively (Figure 9). The place origin was not taken into account for the allocation of a LOD because the definition of the place of origin is rather subjective. For example, someone from the city of Wädenswil, Switzerland could classify her/ his origin as agglomeration or city and both classifications would be correct [122], [123]. Moreover, some participants classified their place of origin as countryside even though statistically this place would be considered a city and/ or agglomeration.

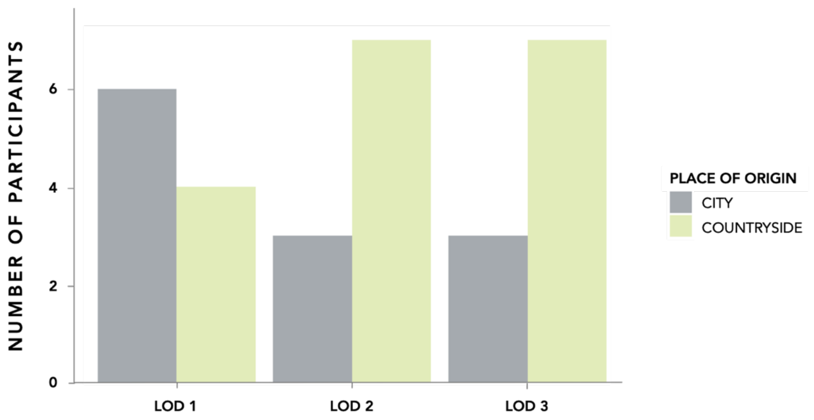

Figure 9: Environment, divided into city and countryside, where participants grew up according to *LOD groups*.

In addition to origin, the highest education level of the participants was recorded. The levels of education are divided into apprenticeship, Matura/ vocational secondary school (BMS)/ seminary, university of applied sciences (FH)/ secondary technical college (HF), Bachelor's and Master's degree (Figure 10). The most common highest education level is Matura, which a third of all participants have. A Master's degree is the second most common (eight participants), followed by a Bachelor's degree (five participants). Four participants' highest education level is an apprenticeship and only three participants have a degree from a university of applied sciences or higher technical college. As the distribution of the highest education level cannot be evenly divided into apprenticeship and higher education (Matura to Master's degree), the highest education level was not taken into account in the group allocation.

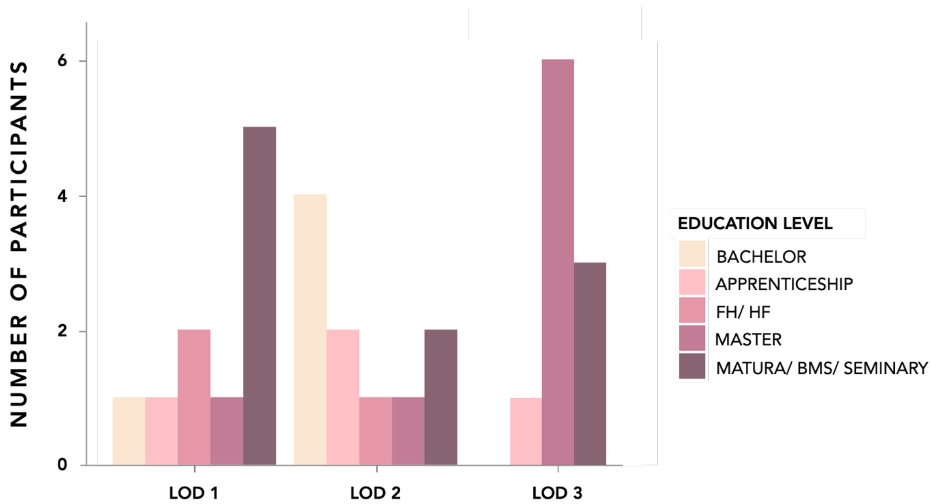

Figure 10: Highest education level of the participants by *LOD groups*. The education levels are divided into apprenticeship, Matura/ vocational secondary school (BMS)/ Seminary, university of applied sciences (FH)/ secondary technical college (HF), Bachelor's degree and Master's degree.

The highest education level may not give an indication whether the participants have any previous knowledge of any connected field to this study. The previous knowledge of these fields was rated on a scale of 1–6 and can be divided into:

- Computer games
- 3D-Visualisations
- GIS
- Architecture
- Urban Planning (Figure 11).

GIS was the field in which the average previous knowledge of the participants was highest ($\bar{x}$ = 3.0, s = 2.05). Participants had the least previous knowledge of architecture ($\bar{x}$ = 1.87, s = 1.07) followed by urban planning ($\bar{x}$ = 2.21, s = 1.32). Participants stated that they had little previous knowledge of computer games ($\bar{x}$ = 2.8, s = 1.86) and 3D-visualisations ($\bar{x}$ = 2.87, s = 1.46).

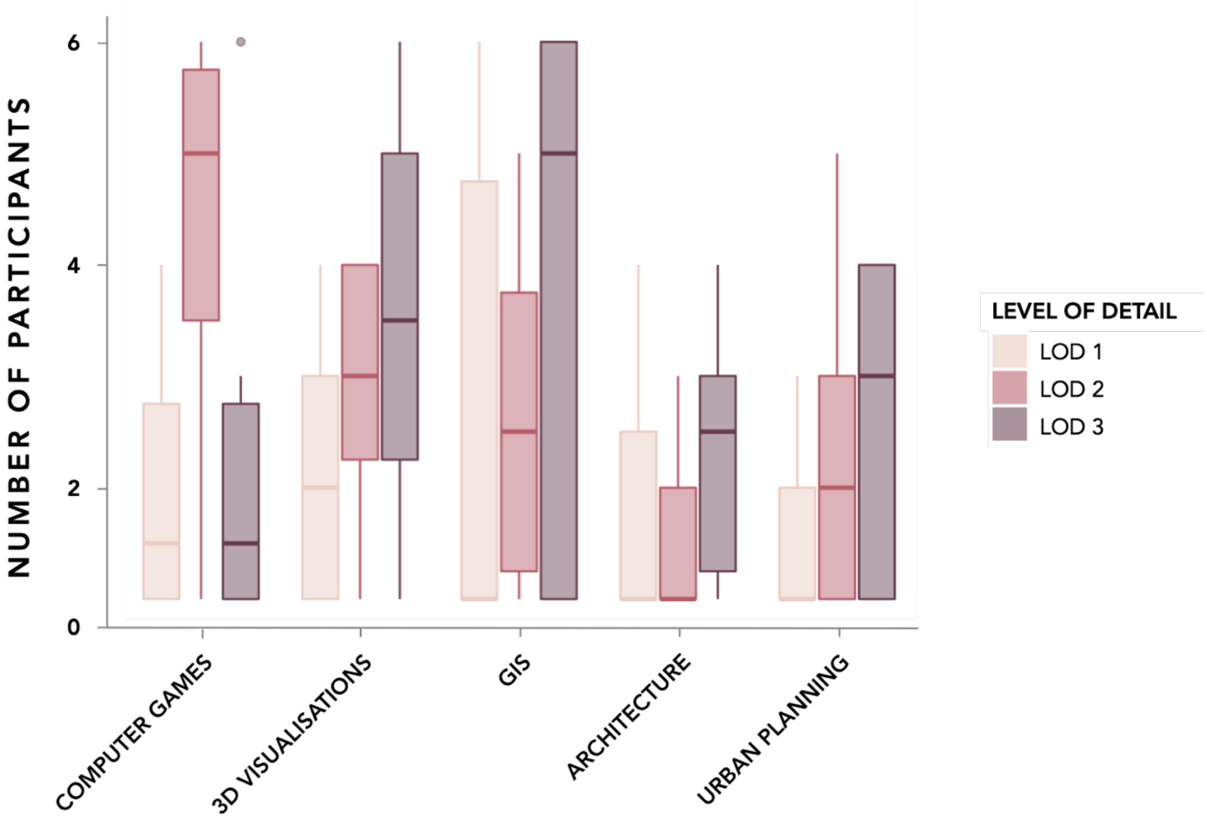

Figure 11: Previous knowledge in computer games, 3D-visualisations, GIS, architecture, and urban planning (from left to right) according to *LOD groups*.

Additionally, the previous experiences with AR and VR were assessed. Eleven participants had no experience with AR (Figure 13) and fourteen participants had no experience with VR (Figure 14). Both technologies are mostly used on an annual basis, two participants use AR on a weekly basis. In contrast, VR is not used more frequently than on a monthly basis.

In addition to AR, construction spans played an important role in this study. Three participants stated they had never seen construction spans before, one participant did not answer this question.

As stated above, the most crucial factor was participants did not have any previous knowledge of the project *Allmend school building*. Participants gave their previous knowledge of the project a rating of 1.43 (s = 0.68) on a scale of 1–5 (Figure 12).

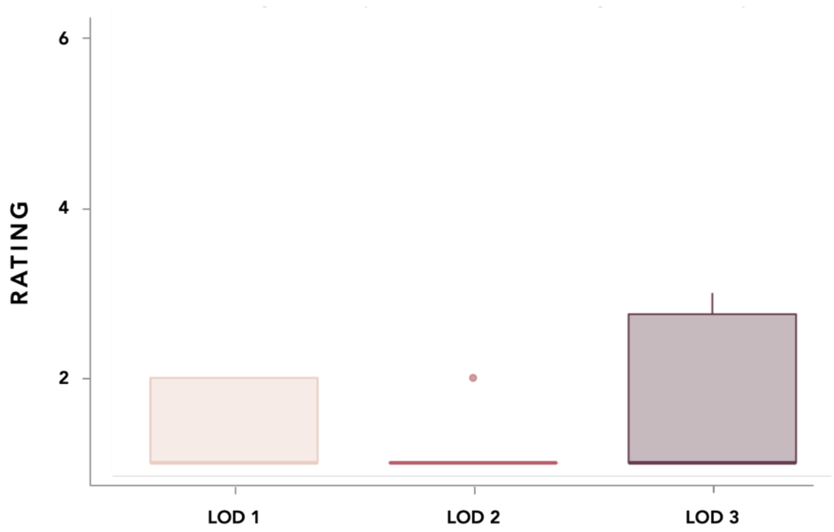

Figure 12: Assessment how much previous knowledge the participants had on project *Allmend school building.*

The annual voting frequency of the participants was also assessed. Twenty participants vote three or four times a year, nine participants vote once or twice a year and one participant did not specify.

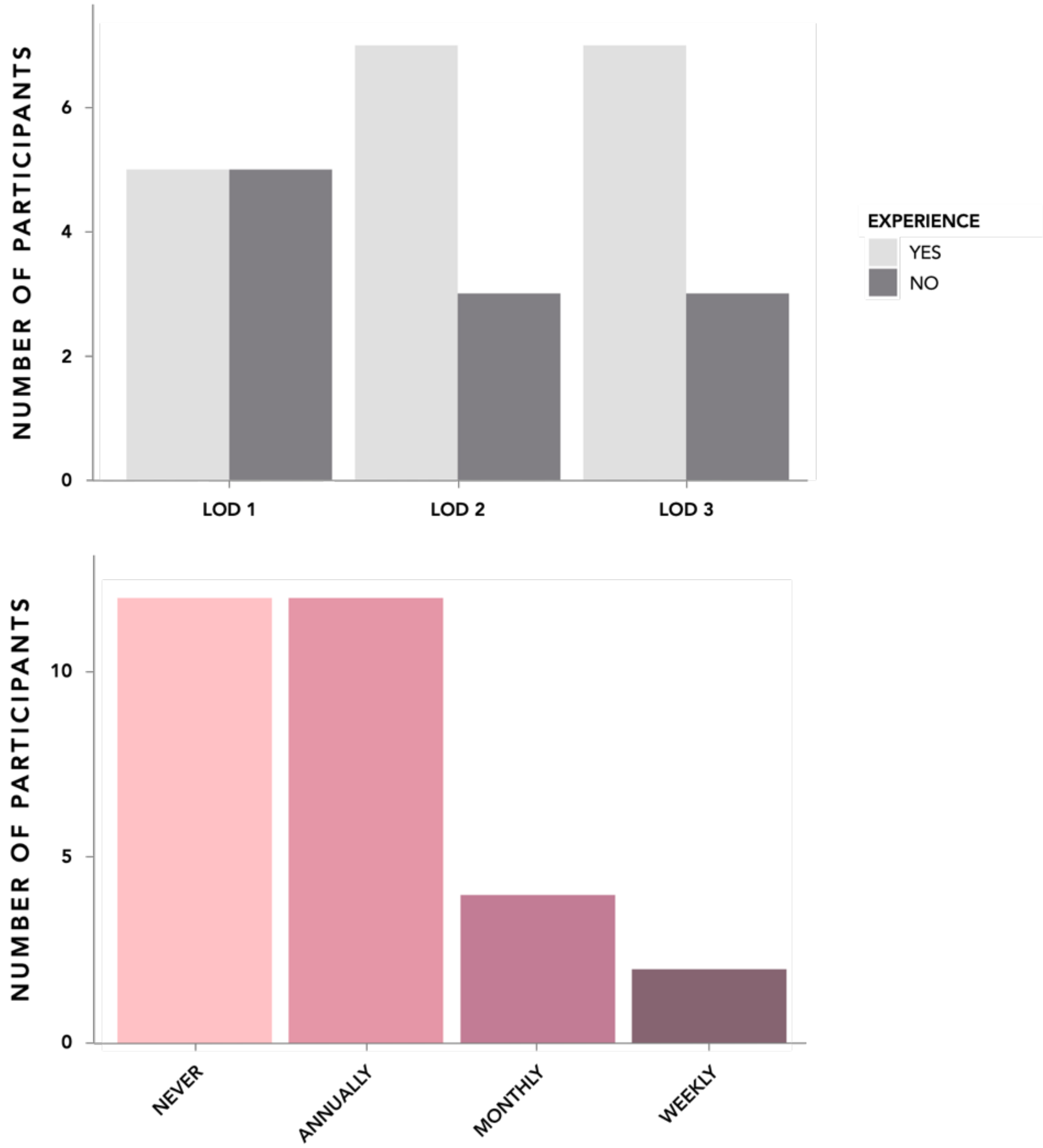

Figure 13: Previous experience with AR technology (top) and frequency of us of AR applications (bottom). If a participant stated she/ he never used AR before, *never* was automatically chosen as frequency of AR use.

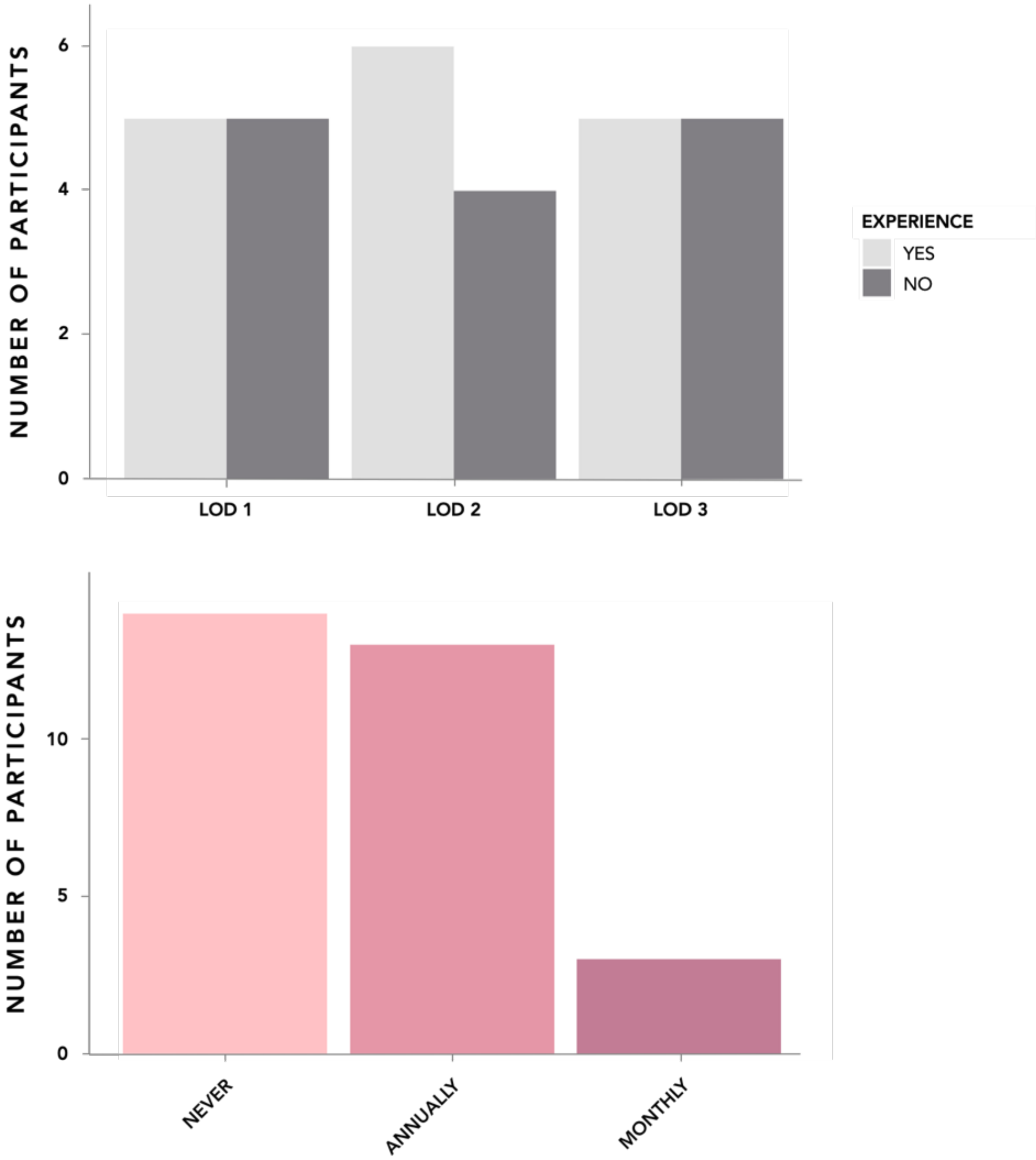

Figure 14: Previous experience with VR technology (top) and frequency of us of AR applications (bottom). If a participant stated she/ he never used VR before, *never* was automatically chosen as frequency of AR use.

3.2 EXPERIMENTAL DESIGN

The goal of this user study was to investigate the suitability of an AR application and exploring the different LOD of a virtual construction project. To answer these questions, various variables were examined in this study. The independent variable is the manipulated variable which is independent from the user's behaviour. This variable can be manipulated by choosing different levels [124]. In this study, the levels were defined by the LODs. The LODs were assigned to three groups, following a between-subjects design. This study design implicates that only one LOD is shown to each participant. Showing only one independent variable ensures that the participants' behaviour cannot be affected by other levels of the independent variable. Another advantage is that during a single study session more data could be collected for a specific level. This also made it possible to keep the individual sessions shorter which advantageous because participants lose interest or become tired less quickly [124].

The reaction to the independent variable is the measured behaviour. This is called dependent variable as it is dependent on the independent variable [124]. The influence of the independent variable was tested in two ways. First, task performance of the participants was measured. Better task performance suggests that the difference between the estimated value and the actual value is minimal. In addition, the time was measured while the participants solved the task. Hence, task performance and elapsed time can be regarded as dependent variable. Second, the participants' reactions to the shown LOD were measured with a questionnaire. Their answers can also be regarded as dependent variable.

The measured dependent variable can be changed by the independent variable but also other circumstances. Therefore, it is important to account for these other circumstances in the study and control them. Controlling them ensures that changes in the dependent variables are due to the independent variable [124]. The controlled circumstances in this study included the order of the tasks posed and, thus, the order of the visualisation methods (i.e., construction spans and AR visualisation) shown.

However, not every circumstance can be controlled. The remaining circumstances are called random variables. Varying some circumstances randomly ensures that they will not bias the study [124]. The random variables in this study include a random assignment of the participants to the three *LOD groups*, weather, time of the day at which the study took place and the mood of the participants.

3.3 MATERIAL

This chapter describes the used data, hardware, and software to answer the previously introduced research questions. To get insights how suitable an AR application is compared to construction spans, an AR application had been implemented. The AR application visualises the project *Allmend school building* in Manegg, Switzerland. First, the software and hardware used to implement the AR application, and questionnaires used in the user study are described in this chapter. Second, the project, corresponding data and implementation of the application are explained.

3.3.1 SOFTWARE AND HARDWARE

The AR application was implemented for iOS devices (i.e., iPhone) running at least iOS 11 [125]. Platform independency was not accounted for in the scope of this project. Hence, the application is not available for Windows and Android devices.

TOOLS FOR NATIVE iOS DEVELOPMENT

To develop the AR application Xcode version 11.6 was used. Apple's Xcode is an Integrated Development Environment (IDE) for macOS which is needed for developing software for Apple products (i.e., iOS, iPadOS, macOS, tvOS, and watchOS). The IDE supports source code in various programming languages, C, C++, Objective-C, and Swift amongst others [126].

Software for iOS devices can be developed in Objective-C and Swift. The AR application developed within the scope of this Master's thesis bases on the programming language Swift 5 because Swift is a modern programming language which is continuously evolving. Swift is the successor of C and Objective-C. The development of the programming language Swift resulted from latest research on programming languages. It features a clean and easy readable syntax, includes types, flow control, operators and also object-oriented features such as classes. This open source programming language is integrated in all of Xcode 11 and is built into all Apple platforms. This ensures smaller apps which download faster and will also work for future Swift releases [127].

However, Swift alone does not suffice to implement an AR application. In order to create an AR experience, the Application Programming Interface (API) ARKit is required. Apple's ARKit allows motion tracking using the device's camera(s), supports depth sensing including plane detection, light estimation and perception [128]. The AR experience can be used with front and rear camera of any iOS device with an Apple A9 processor or later [129]. For the implementation of the native AR application, ARKit 3 was used.

SCENE INTEGRATION WITH ARCGIS RUNTIME SDK

To integrate a scene view into the AR application, ArcGIS Runtime SDK for iOS Version 100.7.0 including ArcGIS Runtime Toolkit were used. From simple 2D map display to advanced analysis and visualisations, such as AR visualisations, can be added to the application using the ArcGIS Runtime SDK. The scene views support table-top, flyover, or a world-scale view [130]. This Software Development Kit (SDK) supports developing native applications for several platforms and devices and includes an open source toolkit which comprises a component for developing AR experiences on Android and iOS devices [130], [131].

ARCGIS SURVEY123 FOR QUESTIONNAIRE PREPARATION

The participants were presented four different online questionnaires in the study. These surveys were created using ArcGIS Survey123. This form-centric solution offers a tool for designing, sharing and evaluating online surveys which can easily be integrated into other solutions of Esri (e.g., ArcGIS Online Map). The surveys also offer default values and skip logic, for example, if a question is answered with "No", a following question will not be shown to the user [132]. The surveys used in this research included mainly the question type *Likert* and *Multiline Text*. The question type *Likert* was used to make statements about the visualisations which the participants could answer with selecting a choice on a 5-point Likert scale. The second question type, *Multiline Text*, was used to obtain qualitative feedback from the participants.

The surveys were then downloaded onto the Survey123 Connect App, which was used to collect data offline. This app allowed filling in the survey when disconnected from the internet and once the device was connected again, the survey answers were uploaded to the Survey123 platform. The results stored on the Survey123 platform could then be downloaded as Excel spreadsheet for an in-depth analysis [132].

HARDWARE

The AR application was installed in an iPhone 6s (OS Version 13.5). Additionally, an iPad 6. Generation (OS Version 13.7) was used during the study to present the surveys in the ArcGIS Survey123 Connect App.

3.3.2 DATA

The AR application displays a scene consisting of four central elements. The scene is based on a digital elevation model (DEM). This elevation model is based on swisstopo's *swissALTI3D* and is used as altitude information of the entire scene. The DEM was delivered in a file geodatabase raster and in coordinate system *LV95 LN02*. The aperture width of these data is 2m and has an accuracy of 0.3m for the new generation of LiDAR data [133].

The elevation model is overlaid with the default *World Imagery basemap* from ArcGIS Online. The basemap comes in coordinate system *WGS 84 Web Mercator* (epsg: 3857) [134] and was clipped to the extent of Manegg to minimise storage size.

On top of this basemap lies the visualisation of the planned school building [135]. These data were delivered by the city of Zurich in an .FBX format. The data contain three objects, stored in a local coordinate system. The visualisations of LOD 1 and LOD 2 are visualised in white. LOD 3 is displayed in colours in which the building will shine in the future (Figure 15). The foot bridge included in the planned project is not shown in the application for the sake of simplicity.

Figure 15: 3D visualisations of the *Allmend school building* in Zurich Manegg in three levels of detail (from left to right LOD1, LOD2, and LOD3) placed on Esri's *World Imagery basemap* to give some spatial context. Data source: [134], [135].

The fourth element in the virtual scene consisted of the school's surrounding buildings (Figure 17). The entire 3D model of the city of Zurich is freely accessible in their geoportal. A section of this 3D city model tailored to Manegg was downloaded as file geodatabase. The data in the file geodatabase came in *CH1903+ LV95* (epsg: 2056) and are visualised in LOD 1 [136].

Elevation source, basemap, school building and surrounding building objects were eventually projected into *WGS 84* coordinate system (epsg: 4326). Although a local coordinate system such as *CH1903+ LV95* would be more precise *WGS 84* coordinate system was used because an *AGSCamera* object of the ArcGIS Runtime SDK expects the data to be in this coordinate system. The entire scene was packaged into a mobile scene package (mspk), which was required for using the AR application in an offline mode.

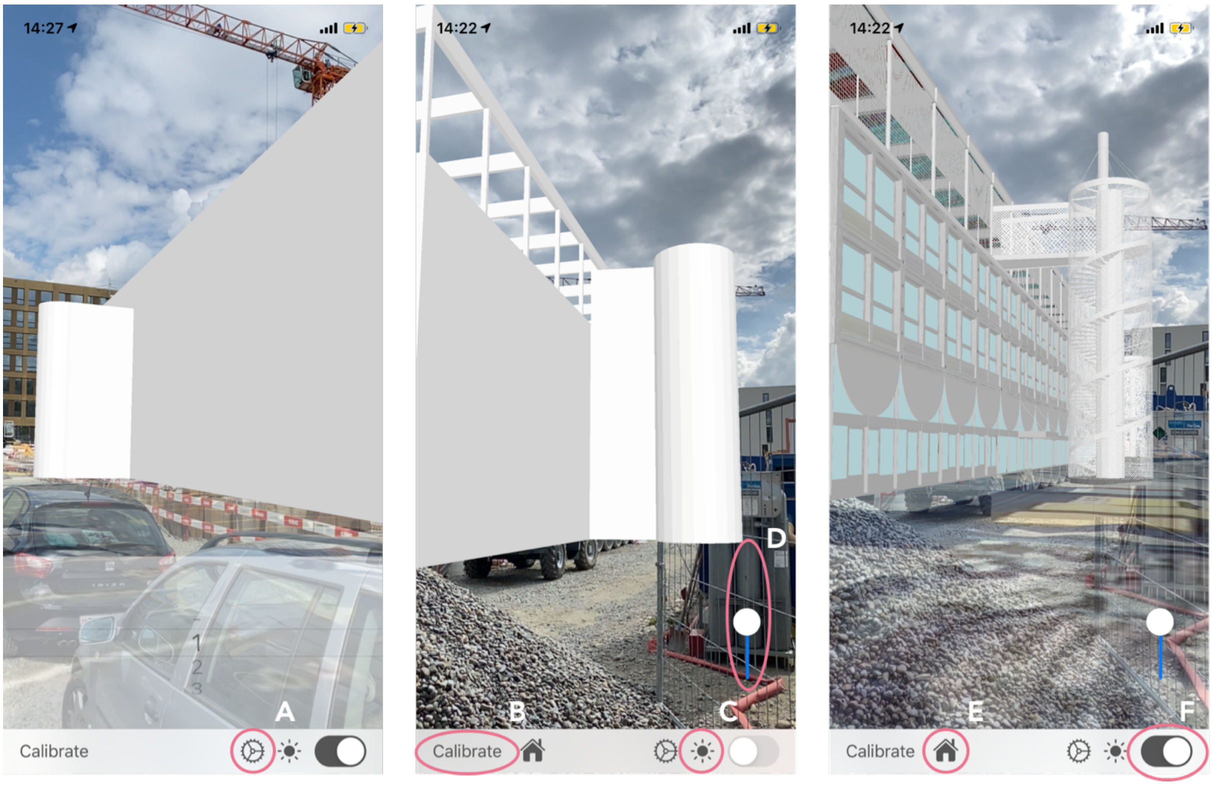

Figure 16: Prototype AR application displaying LOD 1 (left), LOD 2 (middle) and LOD 3 (right). Function A allows choosing a LOD, the switch button (F) displays or hides the basemap and the sun symbol (C) allows choosing different lighting based on a specified date and time. The calibrate button (B) triggers two additional interface components: a slider is displayed to change the height of the scene (D) and an additional house symbol appears on the pane for displaying surrounding buildings (E). Data source: [134], [135].

3.3.3 PROTOTYPE AUGMENTED REALITY APPLICATION

The data described in the previous subchapter was displayed in a world-scale scene in a prototype AR application using ArcGIS Runtime SDK for iOS. Only the basemap is displayed upon starting the application. This was chosen that the participants will only see the LOD assigned to them; the corresponding LOD of the visualisation can be selected and displayed using a picker view (Figure 16). As the basemap is only a reference for the current orientation of the virtual content, there is a switch button which enables hiding the basemap. Additionally, ambient lighting and, therefore, the shadows casted onto the virtual buildings can be controlled in the application.

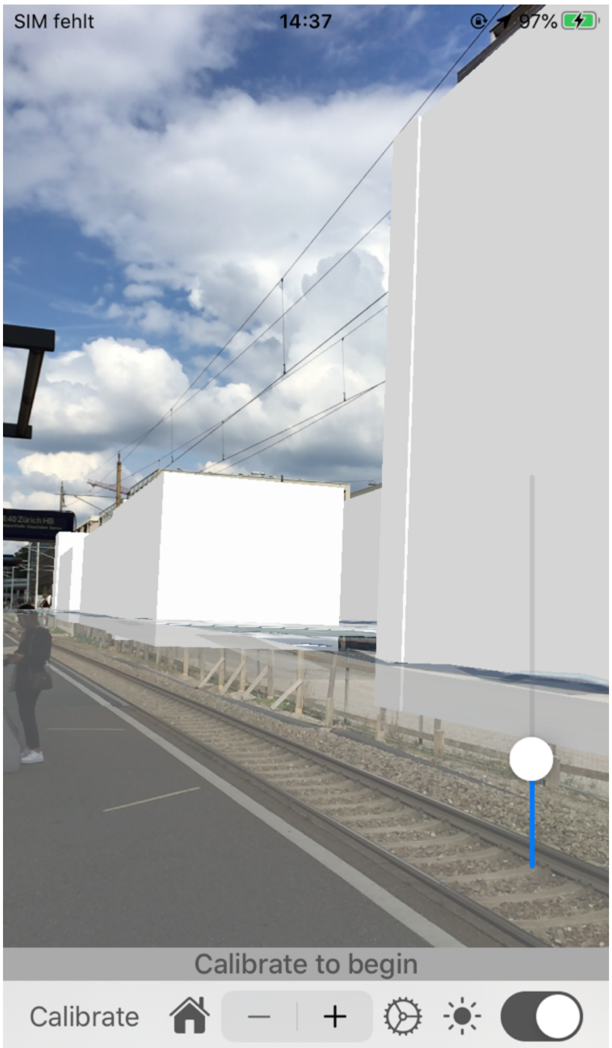

Figure 17: Digital twin buildings of the physical buildings in Manegg, seen from Manegg station in northern direction with enabled basemap. The buildings can be made transparent with the (–/+) button in the middle of the functions bar (bottom). Data source: [134], [136].

TRACKING AND CALIBRATION OF VIRTUAL OBJECTS

The biggest challenge in deploying a world-scale AR experience is maintaining the level of accuracy for the device's position [137]. As GNSS and compass accuracy are limited [73] an approach was chosen where tracking of the GPS position for displaying the content was disabled. To display the content at the correct location an initial viewpoint was set with an *AGSCamera* object. This camera object contains a 3D viewpoint and, thus, defines the perspective of the scene [138]. This viewpoint is initially set to 47.3402179 N, 8.5200106 E, the location where the tasks with the AR application need to be solved.

However, an initial calibration effort is required for AR workflows to improve the overlay accuracy because of limitations of AR frameworks and mobile devices [137]. If the initial starting position would not be calibrated, the experience could be degraded due to any error in the device's position [73]. The position and orientation of the virtual (scene camera) and physical (device camera) content should remain in sync while the user and, hence, the device, move around in the real world. The calibration of the scene is controlled by two functions. First, the height of the scene can be changed with a slider, which moves the entire scene up and down. Second, changing X and Y positions is handled via gestures.

The GPS position of the viewer is tracked in a background process while using the application. The tracked position is accurate to within ten metres. The tracked location is updated every second and is saved as *latitude, longitude* in a text file. Additionally, the selected LOD and timestamp at which the location was updated is saved into the same file to get an exact chronical sequence of the visited locations.

3.4 EXPERIMENTAL PROCEDURE

The main study took place in Zurich Manegg, Switzerland between 26th June and 31st July 2020. The three places Spinnereiplatz, Allmendstrasse and Maneggstrasse were visited in Manegg (Figure 18). Two thirds of the experiment days were sunny, with an average temperature of 27.5°C. The remaining days were cloudy with an average temperature of 20°C.

The study followed a similar study design and procedure as described in Lee et al. (2012) [96], however, this study was two-fold. First, a pilot study was conducted. Second, the main study followed. Both pilot study and main study took approximately 45 minutes per session.

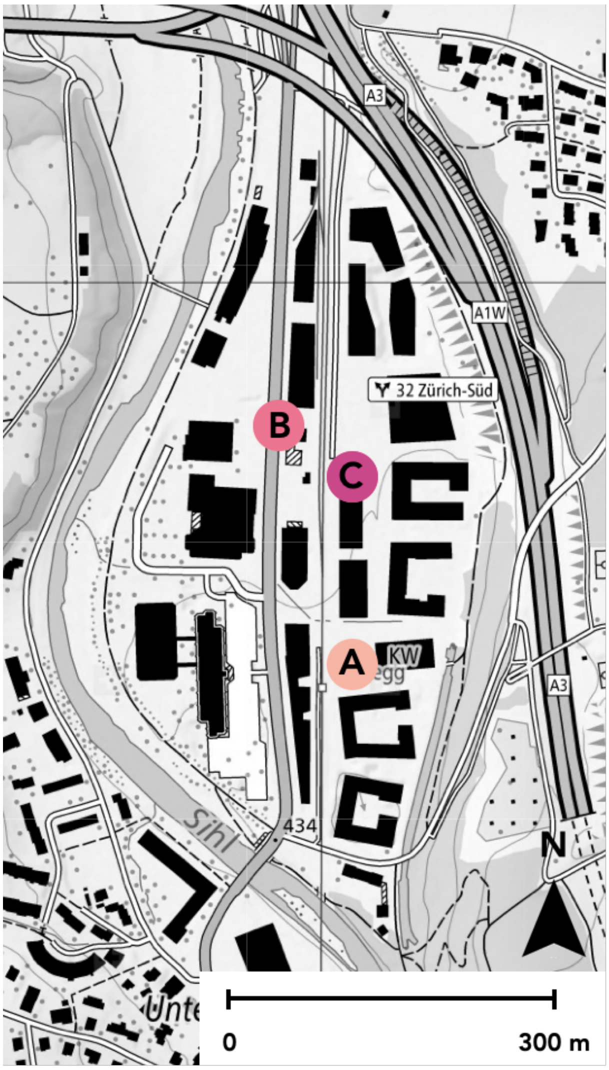

Figure 18: Map of Zurich Manegg, Switzerland, indicating the visited places during the study, namely Spinnereiplatz (A), Allmendstrasse 96 (B) and Maneggstrasse (C). Data source adapted from: [159].

PILOT STUDY

To evaluate the feasibility of the AR application and chosen study design a pilot study was conducted. The pilot study was performed with three participants on three afternoons in mid-June 2020. Prior to the pilot study, the participants were asked to fill in a consent form which was sent to them digitally. The pilot study started near the train station in Manegg with a brief introduction about the aim of the study and some background information about the project *Allmend school building*. The introduction finished with a digital questionnaire asking demographic data and previous knowledge in related fields, including urban planning, architecture, GIS, AR and VR technology. After this, the participant and I walked to the study location, where the school building is built. At this location, the participant was asked to estimate the length of a concrete block and the height of a residential building south east of the building site of the school. These two estimates were used as baseline for the participants' estimation skills. Having estimated this baseline, the participants were shown the AR application. In a first step, the virtual content in the AR application had to be calibrated. In a second step, the participants had to estimate the height of the virtual school building and the distance between the virtual building and the building south of it. Third, the participants were made aware of some construction spans in the distance to the north west of the construction site of the school building. Using the AR application, they had to estimate whether the staked out building would be covered by the school building in the future. Following on from this task, the participants had to draw in an aerial photograph of all the buildings that would be occluded by the school building in the future, seen from the current location. Once all these tasks were solved, the participants were free to explore the application as they pleased. The study finished with another digital survey asking 17 questions grouped into the following sub-topics:

Figure 19: Snippet from the post-questionnaire showing questions about the visualisation on a 5-point Likert scale.

1. General questions about visualisation,
2. Accuracy of visualisation,
3. Comparison of AR and construction spans,
4. AR and participation,
5. Individual opinion on the project.

Fourteen questions could be answered on a 5-point Likert scale (1 – strongly disagree, 5 – strongly agree) (Figure 19). One question was a Yes/No question and the remaining two questions were qualitative commentary fields. Additionally to the questionnaires, the GPS positions were logged while the participants used the AR application.

MAIN STUDY

Having tested the study design in a pilot study gives an indication which parts of the study design required improvements. As in the course of the pilot study, participants had to fill in and send a digital consent form beforehand. If a participant forgot to fill in this consent form she/ he had to do so at the beginning of the study. The study started on Spinnereiplatz in Manegg, where the same introduction was given as in the pilot study. The introduction was followed by filling in the same preliminary questionnaire about demographic data and prior knowledge of the participants as in the pilot study. Then, the participants were guided to Allmendstrasse 96 where a construction project was staked out with construction spans (Figure 20). At this location, the participants were asked to estimate the height of the construction spans and estimate how many buildings are staked out.

Figure 20: Construction spans staked out on Allmendstrasse 96 in Manegg, Switzerland.

After this, the participants were guided to Maneggstrasse where the construction site for *Allmend school building* is located. At this location, the participants were asked to estimate the length of a concrete block and the height of the residential building south east of the construction site. Having estimated this baseline for the participants' estimation skills, the AR application was first shown to the participants. Unlike to the pilot study, the AR application was calibrated for the participants in the main study to correctly overlay the virtual object as the calibration process turned out to be difficult. Once calibrated, the users were asked to solve three different tasks using the AR application.

The first task involved estimating height, width and length of the virtual school building and the distance between the school building and the residential building to its south. This task was solved south west of the construction site, in front of a "window" in the barrier walls, which fenced the building site (Figure 21).

Figure 21: Study locations for estimation tasks (I) and occlusion tasks (II) at construction site of *Allmend school building* surrounded by white barrier walls.

The final two tasks had to be solved at another location south of the construction site (Figure 21). There, participants had to draw in all buildings which will be occluded in the future by the school building. Finally, the participants were shown the same construction spans they looked at earlier. The participants had to estimate whether the staked out building will be occluded by the school building in the future.

Once the participants solved all the tasks, they were free to explore the application by walking around the construction site. After a maximum of 10 minutes of free exploring, the participants had to fill in the final questionnaire. The final questionnaire consisted of 21 questions grouped into the same categories as described in the procedure of the pilot study. The questions included a 5-point Likert scale (1 – strongly disagree, 5 – strongly agree) and commentary fields for qualitative feedback. The questions and the participants' answers are described in chapter 4. In addition to the questionnaires, the time elapsed during the tasks was recorded. GPS positions were also recorded during AR application use to get an insight how far around the building site the participants were moving during free exploration. Participants were offered a small bag of chocolate as a return for their participation upon finishing the study.

4 RESULTS

The resulting data from the user study can be divided into qualitative and quantitative data. The quantitative data from the post-questionnaire are available as integer values on a scale of 1–5. The resulting task values are floating values. The statistical analysis was performed with *R*; the data were tested for normal distribution using the Shapiro-Wilk test and Levene's test for testing for homoscedasticity. A significance level of $p>0.05$ was used. If the data were normally distributed and showed a homogeneous variance a one-way analysis of variance (ANOVA) was performed to test if there are statistically significant differences between the *LOD groups*. Next, a pairwise comparison was performed using a pairwise t-test, with Bonferroni as adjustment method. If the data were not normally distributed or did not show homogeneous variances a Kruskal-Wallis test was performed. The groups were compared pairwise with a Wilcoxon test and a significance level of $p<0.05$. It was assumed if $p>0.05$, there are no statistically significant differences between the groups.

The results are outlined in three sections. First, an overview about participants' performance of the given tasks is presented. The task performances enable evaluating how difficult it is for users to interpret the visualisation (research question 2) but also to what extent the effectiveness of the three different levels of detail differ (research question 3). Second, the perceived suitability of the AR application and construction spans was evaluated (research question 1). Third, it was assessed if an AR application is suitable for assisting citizens in their decision-making process and whether their decision outcome is influenced by different degrees of abstraction (research question 4).

4.1 ASSESSING INTERPRETATION DIFFICULTY

This first subchapter describes the results of the tasks solved by the participants during the study session. First, an overview of the statistical analysis is given followed by the qualitative results.

ANALYSIS OF TASK PERFORMANCE

To assess the estimations skills of the participants they had to estimate the length of a concrete block and the height of a residential building. Normal distribution and homoscedasticity can be assumed for the estimates of the length of the concrete block, $W(30) = 0.93851$, $p = 0.08296$, $F(2, 27) = 0.3609$, $p = 0.7003$ (Figure 22). A one-way ANOVA could not show any statistically significant effect, $F(1, 28) = 0.381$, $p = 0.542$. A pairwise t-test showed no significant differences between the three different groups.

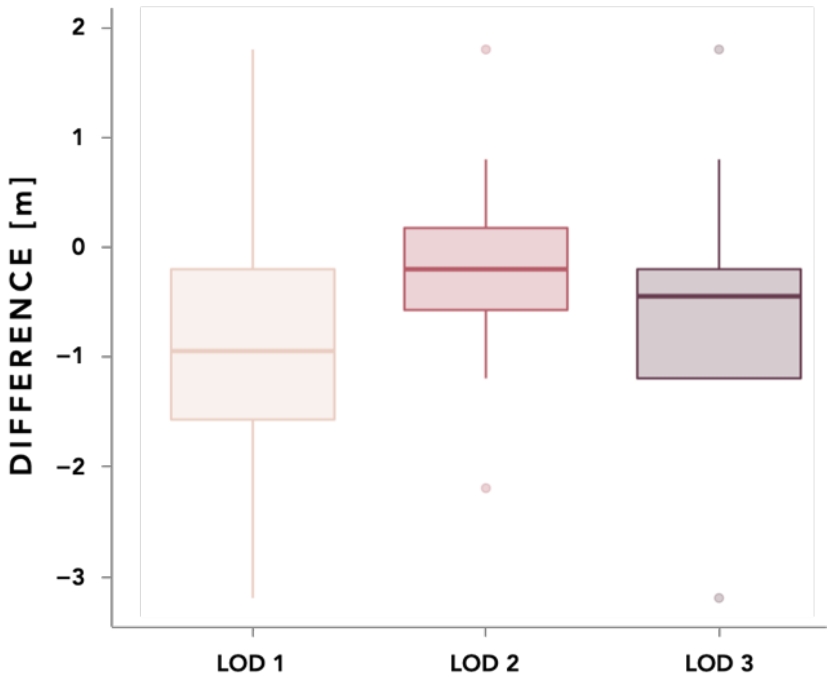

Figure 22: Differences between estimated and actual length of a concrete block to assess the participants' estimation skills.

The estimates for the height of the residential building are not normally distributed, $W(30) = 0.78967$, $p = 0.00004274$ (Figure 23). Homoscedasticity is given for these data, $F(2, 27) = 0.7049$, $p = 0.503$. There are no statistically significant differences between the three groups, $\chi^2(2) = 5.026$, $p = 0.08102$. There is a tendency that the differences are largest between *groups LOD 2* and *LOD 3*, p-value = 0.096.

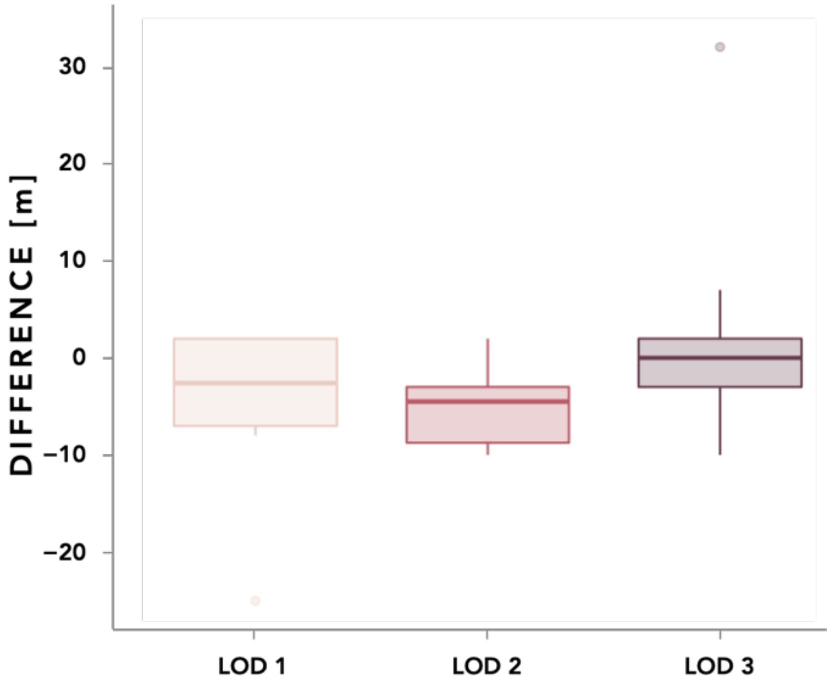

Figure 23: Differences in metres between estimated and actual height of a residential building in Manegg, Switzerland, to assess the participants' estimation skills.

The next task was to estimate the number of buildings staked out at Allmendstrasse 96. The same construction spans were shown to all three groups. The means of the estimated number of buildings staked out are shown in Figure 24. Normal distribution of the data can be assumed, W(30) = 0.9314, p = 0.05349. Further, Levene's test showed that variance homogeneity is given, F(2, 27) = 0.8329, p = 0.4457. A one-way ANOVA was not statistically significant, F(1, 28) = 0, p = 1., and a pairwise t-test showed no differences between the three groups. No differences between the three groups are not surprising as the same construction spans were shown to all three groups.

Next, the participants were asked to estimate the height of the construction spans (Figure 25). Only three participants (*group LOD 1* (2 persons), *group LOD 3* (1 person)) estimated the height of the construction spans correctly, one participant (*group LOD 2*) overestimated the construction spans' height. The other participants underestimated the height of the construction spans. The data for this second task are normally distributed, W(30) = 0.96408, p = 0.392, and can be expected to show variance homogeneity, F(2, 27) = 0.2234, p = 0.8012. A one-way ANOVA showed no statistical significance, F(1, 28) = 0.02, p = 0.887 and, therefore, a pairwise t-test resulted in no differences between the three groups.

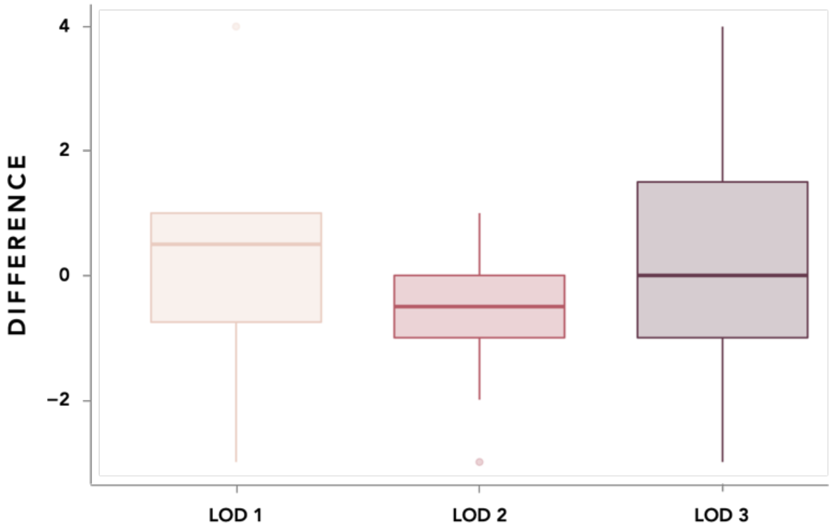

Figure 24: Differences between estimated and actual number of buildings staked out at Allmendstrasse 96 in Manegg, Switzerland according to *LOD groups*.

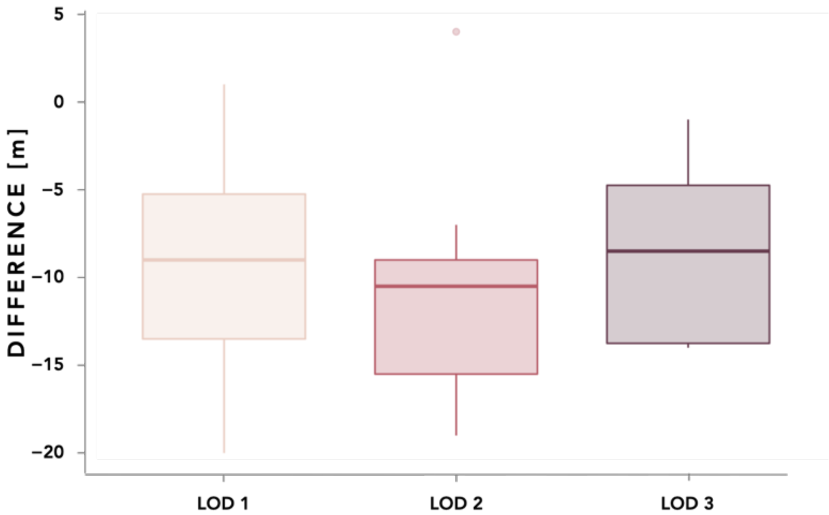

Figure 25: Differences in metres between estimated and actual height of the construction spans at Allmendstrasse 96 in Manegg, Switzerland according to the three *LOD groups*. Negative values indicate that the participants underestimated the height.

ESTIMATES OF DIMENSIONS OF THE AR VISUALISATION

This next task included four sub-questions on the dimensions of the virtual school building. First, the participants were asked to estimate the height of the building using the AR application. The differences between the estimated and real height of the school building is visualised in Figure 26. The data are not normally distributed, $W(30) = 0.7877$, $p = 0.0000944$ but homoscedasticity is given, $F(2, 27) = 2.1965$, $p = 0.1307$. The differences of the groups' means are statistically nonsignificant, $\chi^2(2) = 4.7179$, $p = 0.09452$, however, there is a tendency for differences between *groups LOD 1* and *LOD 2* (p-value = 0.30) and *LOD 1* and *LOD 3* (p-value = 0.18). There is no difference between *groups LOD 2* and *LOD 3* (p-value = 1.0).

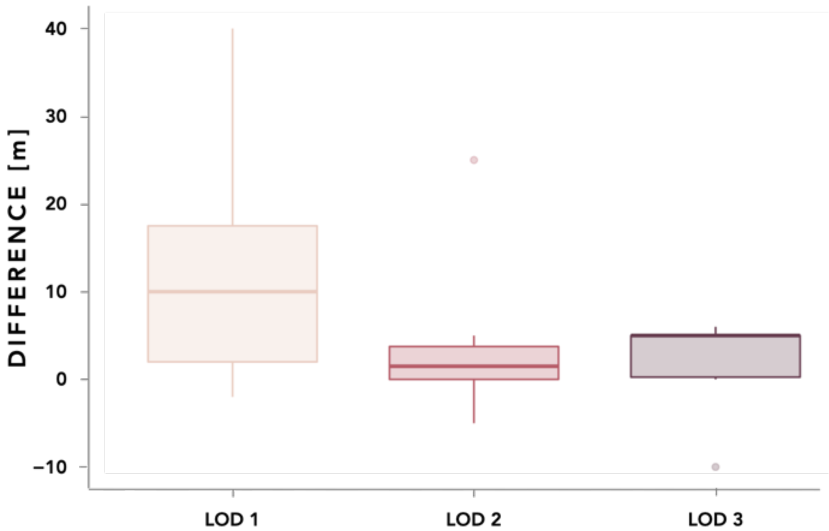

Figure 26: Differences in metres between estimated and actual height of the virtual school building in the AR application according to *LOD groups*.

Second, the participants had to estimate the width of the school building. The difference between the estimated and real width of the school building is visualised in Figure 27. There are more outliers for the width estimates than for the height estimates. The data for the width estimates are not normally distributed, $W(30) = 0.86617$, $p = 0.001378$ but the variances are homogeneous, $F(2, 27) = 0.635$, $p = 0.5377$. A Kruskal-Wallis rank sum test showed differences between the three groups are non-significant, $\chi^2(2) = 0.80414$, $p = 0.6689$.

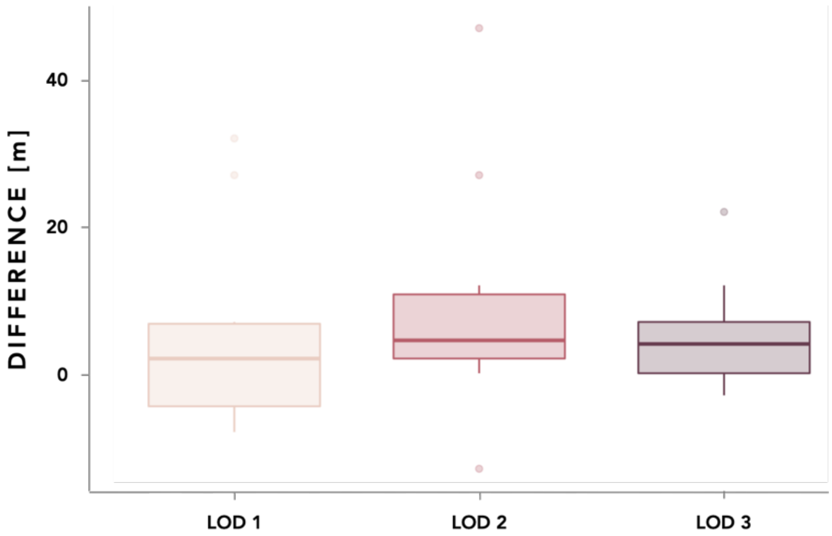

Figure 27: Differences in metres between estimated and actual width of *Allmend school building* in AR application according to *LOD groups*.

Third, the length of the building was the last dimension to estimate (Figure 28). The data follow a normal distribution, W(30) = 0.94054, p = 0.09404 and the variances are homogeneous, F(2, 27) = 0.9523, p = 0.3984. A one-way ANOVA could show there are no significant differences between the three groups, F(1, 28) = 1.754, p = 0.196. The tendencies for the highest group differences are between *groups LOD 1* and *LOD 3* (p-value = 0.61).

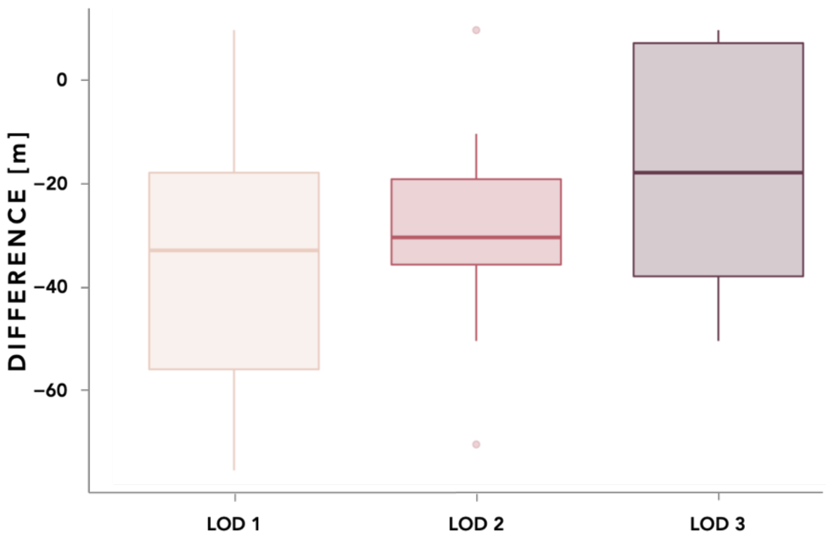

Figure 28: Differences in metres between estimated and actual length of *Allmend school building* in AR application according to *LOD groups*. Negative values indicate that participants underestimated the length of the virtual building.

Finally, the participants had to estimate the distance between the school building and the building to its south (Figure 29). The data are not following a normal distribution, W(30) = 0.82136, p = 0.0001648, but the variances are homogeneous, $F(2, 27) = 2.179$, $p = 0.1326$. There are no significant differences for the estimated values between the three groups, $\chi^2(2) = 2.4869$, $p = 0.2884$. There is no tendency for any differences between *groups LOD 2* and *LOD 3* (p-value = 1.0). However, there is a tendency for a difference between *groups LOD 1* and *LOD 2* (p-value = 0.55) and *groups LOD 1* and *LOD 3* (p-value = 0.57).

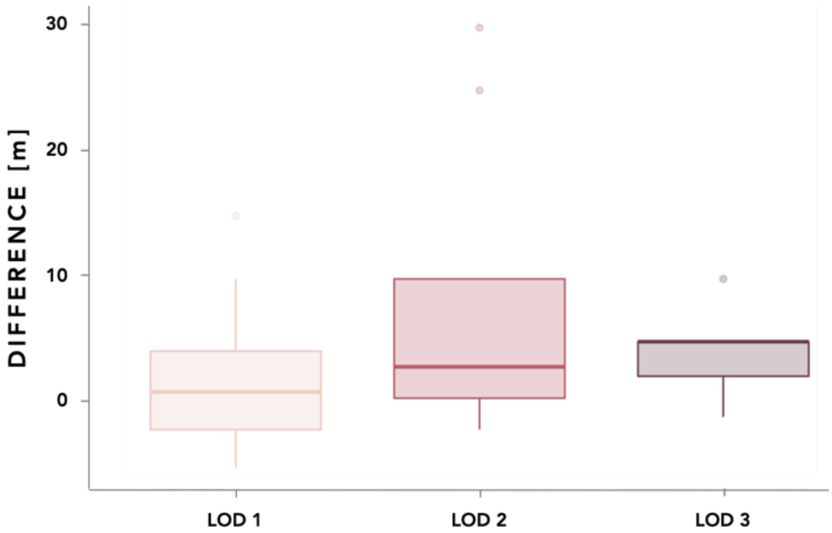

Figure 29: Differences in metres between estimated and real distance between the virtual school building and the building south of the school building according to *LOD groups*.

The time stopped while the participants solved the tasks is visualised in Figure 30. To estimate the height of the virtual building, participants in *group LOD 2* needed 10 seconds longer on average than participants in *group LOD 1* and 7 seconds longer than participants in *group LOD 3*. Participants in *group LOD 2* needed 33 seconds each for estimating the height and width of the building. To estimate the width of the virtual building, participants in *group LOD 3* needed 37 seconds on average, whereas participants of *group LOD 1* only needed 25 seconds. Quickest to estimate the length of the building were participants of *group LOD 2* with an average time of 19 seconds. Participants in *group LOD 3* needed 29 seconds and participants in *group LOD 1* 31 seconds. It took all groups 21 seconds on average for estimating the distance between the virtual building and the building to the south.

Generally, participants who estimated the height of the school building correctly needed between 9 and 44 seconds to answer this question. There are even greater differences in the time elapsed when estimating the width of the building; the participants who correctly estimated the width needed between 17 and 113 seconds. In order to estimate the length, these who underestimated or overestimated the length by 1%–10% needed between 6 and 59 seconds. These who underestimated the length by 50%–80% needed between 6 and 48 seconds to complete the task.

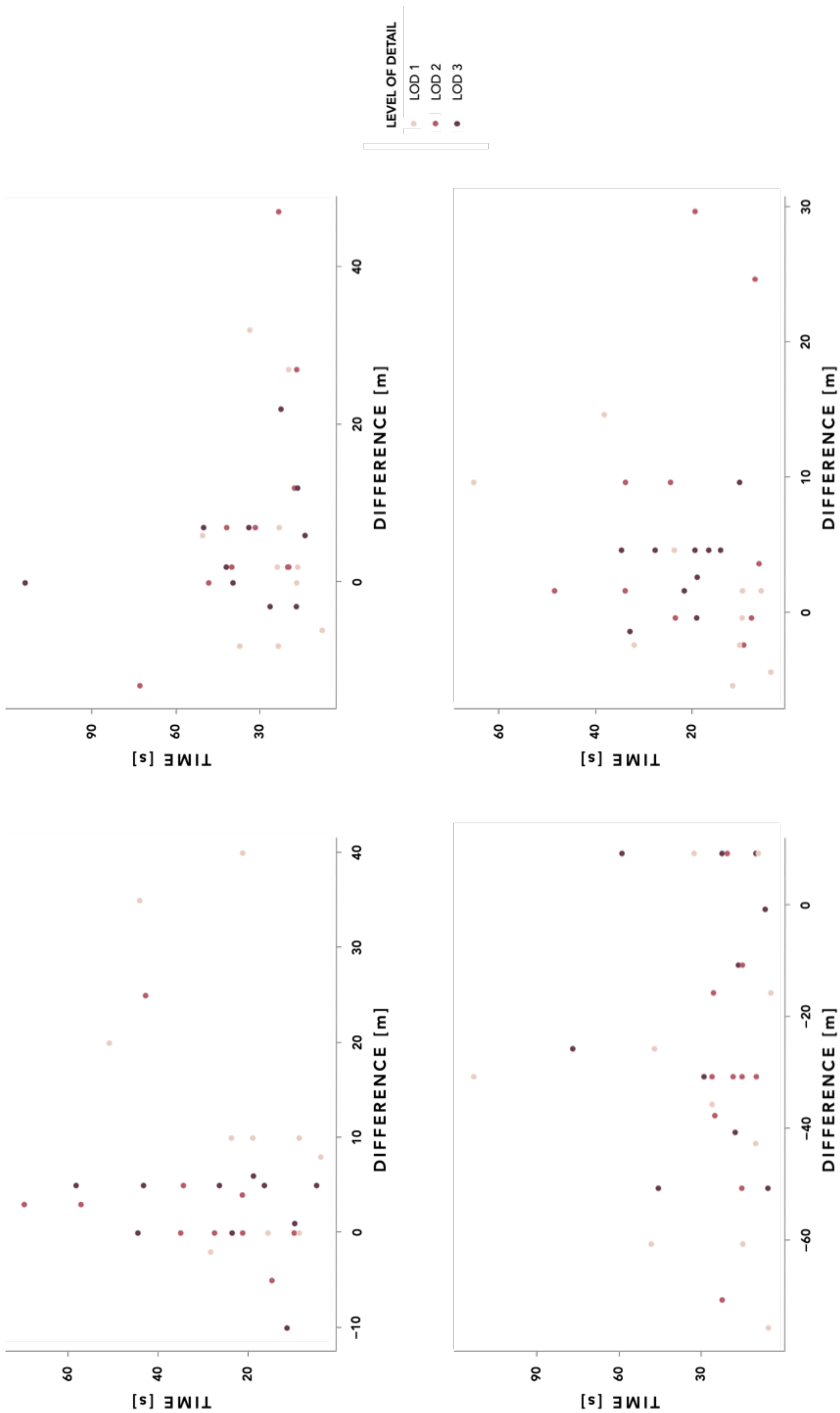

Figure 30: Time spent for estimating the dimensions height (upper left), width (upper right) and length (lower left) of the virtual building and the distance between the virtual building and the building south of virtual *Allmend* school building (lower right) coloured by *LOD groups.*

IDENTIFYING OCCLUDED OBJECTS

For the fourth task, participants were asked to mark all buildings occluded by the virtual school building on an aerial photograph (Figure 31). Five buildings will be covered by the school building. The mean values and standard deviations for the correctly identified, misidentified and unidentified number of buildings are shown in Table 1. The data are not normally distributed but the variances are homogeneous for all three questions. For none of the questions could a significant difference be found between the three groups. The test statistics for all three tests are shown in Table 2. However, there is a tendency for a difference between *groups LOD 1* and *LOD 2* in terms of the correctly identified objects (p-value = 0.18). This could be explained by participants of *group LOD 1* identified more correct objects on average than participants from the other two groups. For the unidentified objects, there is a tendency for a difference between *groups LOD 1* and *LOD 2* (p-value = 0.36) and *LOD 1* and *LOD 3* (p-value = 0.47). These values could be explained by participants of *group LOD 1* have on average fewer buildings not identified as occluded which would actually no longer be visible.

Table 1: Mean and standard deviation for the three groups for the number of correctly identified, misidentified and unidentified objects, which will be occluded by the *Allmend school building*.

	Correctly Identified		**Misidentified**		**Unidentified**	
LOD 1	$\bar{x}$ = 3.8	s = 1.48	$\bar{x}$ = 1.2	s = 3.79	$\bar{x}$ = 1.3	s = 1.49
LOD 2	$\bar{x}$ = 3.2	s = 0.79	$\bar{x}$ = 0.4	s = 0.7	$\bar{x}$ = 1.8	s = 0.79
LOD 3	$\bar{x}$ = 3.5	s = 0.71	$\bar{x}$ = 0.0	s = 0.0	$\bar{x}$ = 1.6	s = 0.52

Table 2: Test statistics for Shapiro-Wilk test, Levene's Test and Kruskal-Wallis test for correctly identified, misidentified and unidentified objects, which will be occluded by the *Allmend school building*.

	Correctly Identified	**Misidentified**	**Unidentified**
Shapiro-Wilk Test	W(30) = 0.84695, p = 0.0005357	W(30) = 0.26027, p = 3.314×10^{-11}	W(30) = 0.83649, p = 0.0003275
Levene's Test	F(2, 27) = 0.3073, p = 0.738	F(2, 27) = 0.7522, p = 0.4809	F(2, 27) = 0.9661, p = 0.3933
Kruskal-Wallis Test	$\chi^2(2)$ = 4.3653, p = 0.1127	$\chi^2(2)$ = 3.5654, p = 0.1682	$\chi^2(2)$ = 3.3515, p = 0.1872

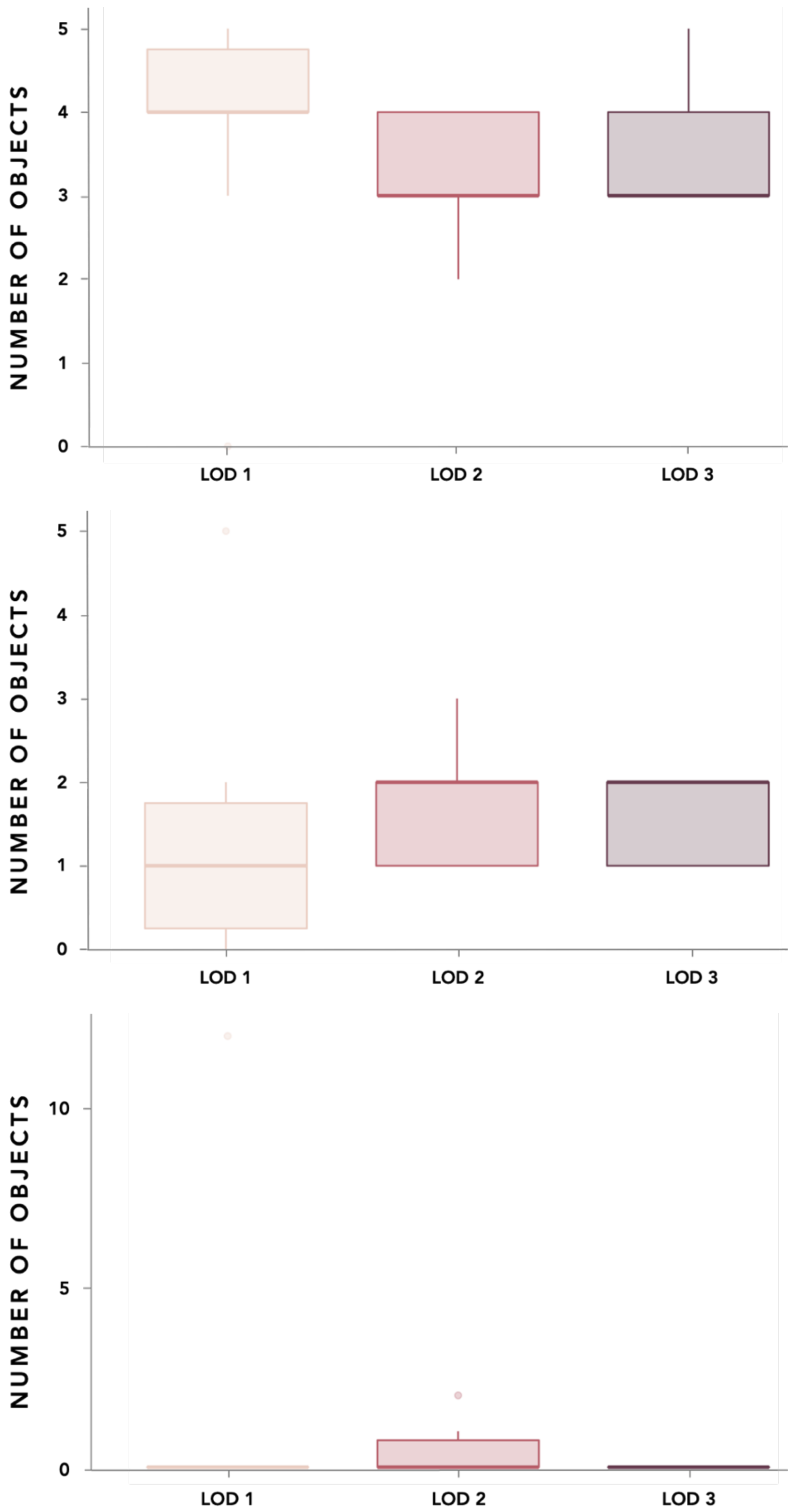

Figure 31: Correctly identified (top), unidentified (middle) and misidentified (bottom) buildings which will be occluded by the school building in the future.

SELF-ASSESSMENT IN QUESTIONNAIRE

The participants were asked in the post-questionnaire whether the visualisation was easy to interpret (Figure 32). The data were found to be not normally distributed, W(30) = 0.77609, p = 0.00002476 but homoscedasticity is given, F(2, 27) = 2.4231, p = 0.1077. A Kruskal-Wallis rank sum test showed that there is no statistically significant difference between the groups, $\chi^2(2) = 2.2109$, p = 0.3311. However, there is a tendency for difference between the *groups LOD 1* and *LOD 2* (p-value = 0.33).

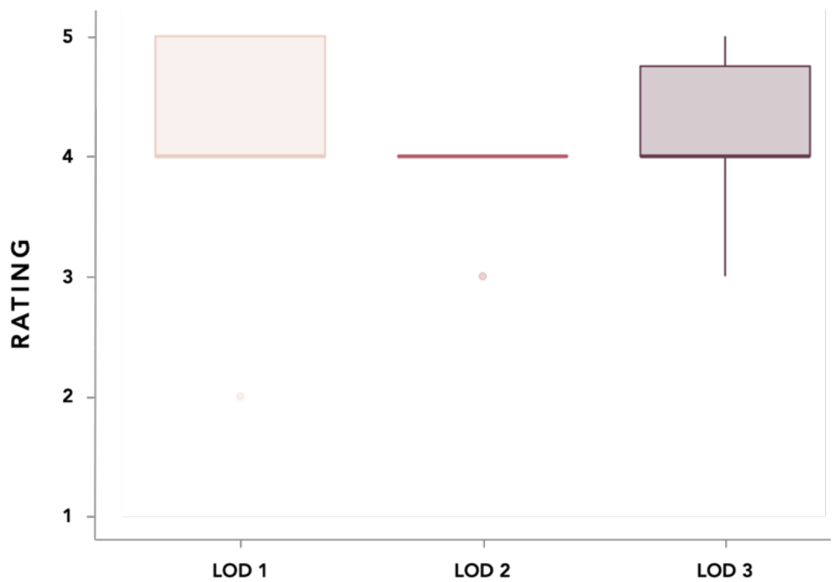

Figure 32: Ratings of the ease of interpretation of the virtual school building in the AR application according to *LOD group*s.

4.2 SUITABILITY OF AUGMENTED REALITY APPLICATIONS AND CONSTRUCTION SPANS

This subchapter evaluates the answers given in the post-questionnaire. First, the visualisation of the school building project in the AR application is evaluated. Second, the construction spans are compared to an AR application.

4.2.1 SUITABILITY OF VISUALISATION WITH AUGMENTED REALITY

EFFECTIVENESS

The participants were asked whether the individual elements of the virtual building are easy to recognise and whether the visualisation is realistic (Figure 33 and Figure 34). The mean values for both questions are similar, whereas the mean values for the rating of the realism of the visualisation are slightly lower (Table 3).

Table 3: Mean values for the three *LOD groups* for the recognisability of the individual elements (left) and the realism of the visualisation (right).

	Recognisability of Elements		**Realism**	
LOD 1	$\bar{x}$ = 4.3	s = 0.67	$\bar{x}$ = 4.1	s = 0.74
LOD 2	$\bar{x}$ = 3.9	s = 0.74	$\bar{x}$ = 3.6	s = 1.07
LOD 3	$\bar{x}$ = 4.4	s = 0.52	$\bar{x}$ = 3.9	s = 0.57

The data of both questions are not normally distributed, $W(30)_{Recognisability} = 0.72246$, $p = 0.000003369$ and $W(30)_{Realism} = 0.85968$, $p = 0.0009955$. The variances for both questions' data are homogeneous, $F(2, 27)_{Recognisability} = 0.3$, $p = 0.7433$ and $F(2, 27)_{Realism} = 1.4016$, $p = 0.2635$. There are no statistically significant differences, $\chi^2(2)_{Recognisability} = 2.8435$, $p = 0.2413$ and $\chi^2(2)_{Realism} = 1.7803$, $p = 0.4106$.

However, there is a tendency for differences between *groups LOD 2* and *LOD 3* (p-value = 0.30) and *groups LOD 1* and *LOD 2* (p-value = 0.68) for the evaluation of the recognisability of the individual elements. This can be explained by the fact that in *groups LOD 1* and *LOD 3* the score 5 on a scale of

1–5 was given four times, whereas in *group LOD 2* the recognisability was only rated 5 once. Moreover, a score of 2 was given once by a participant of *group LOD 2*, whereas, the lowest score was a 3 given by one participant in *group LOD 1*. For *group LOD 3* there were no scores below 4.

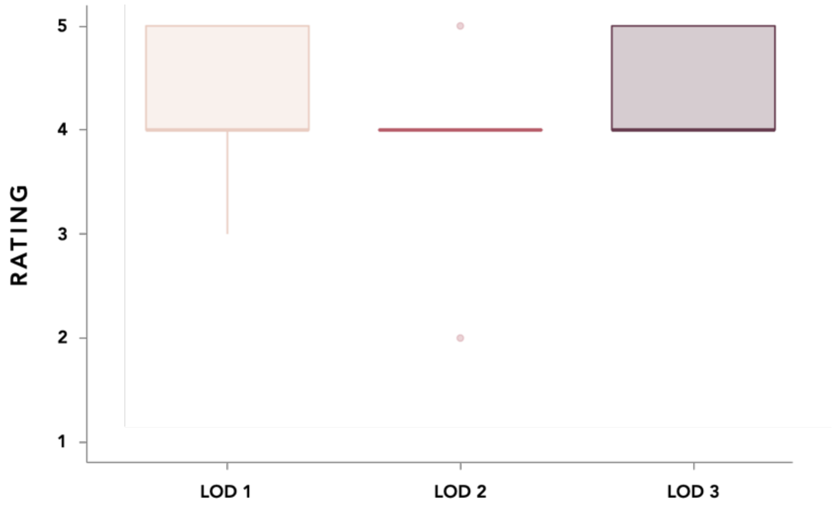

Figure 33: Ratings of the recognisability of the individual elements of the virtual building in the AR application according to *LOD groups*.

The evaluation of the realism of the visualisation showed that there is a tendency for differences between *groups LOD 1* and *LOD 2* (p-value = 0.75). The differences between *groups LOD 1* and *LOD 2* could be explained that more participants of *group LOD 1* gave higher ratings (i.e., a score of 4 or 5) than the participants of *group LOD 2*.

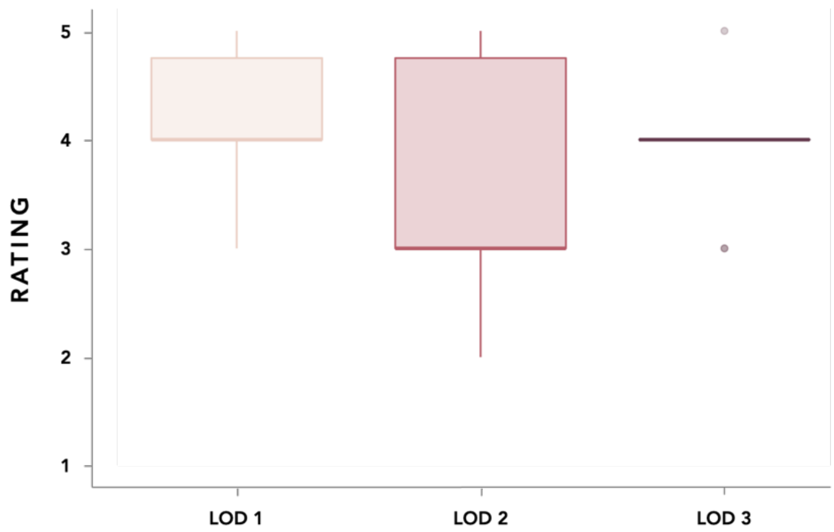

Figure 34: Ratings of the realism of the virtual building in the AR application according to *LOD groups*.

ACCURACY

This block covers the questions regarding the building's size and accuracy. The participants were asked if the real size of the school building is recognisable in the AR application (Figure 35). Participants in *group LOD 1* ($\bar{x}$ = 4.1, s = 0.99) gave on average a higher score than participants in *groups LOD 2* ($\bar{x}$ = 3.8, s = 0.63) and *LOD 3* ($\bar{x}$ = 3.5, s = 0.71). The data are not normally distributed, W(30) = 0.85891, p = 0.0009581, but show homogeneous variances, F(2, 27) = 0.5727, p = 0.5707. There are no significant differences between the groups $\chi^2(2)$ = 3.5123, p = 0.1727. However, a pairwise comparison showed that there is a tendency for *groups LOD 1* and *LOD 3* to differ (p-value = 0.31). The differences could be explained by the fact that in *group LOD 1* four participants gave a rating of 4 and 5 on a scale of 1–5, whereas, in *group LOD 3* only three participants gave a rating of 4 and only one person rated the recognisability a 5.

The perceived accuracy of the visualisation regarding the height and length of the building is visualised in Figure 36. The data were not found to be normally distributed, W(30) = 0.67912, p = 0.00000107. Homogeneity of variance is given for these data, F(2, 27) = 1.5654, p = 0.2281. There are no significant differences between the three *LOD groups*, $\chi^2(2)$ = 3.7003, p = 0.1572. However, there is a tendency for differences between *groups LOD 1* and *LOD 2* (p-value = 0.28) and *groups LOD 1* and *LOD 3* (p-value = 0.37). The differences could be due to the fact that nobody in *group LOD 1* gave a rating below 4 on a scale of 1–5.

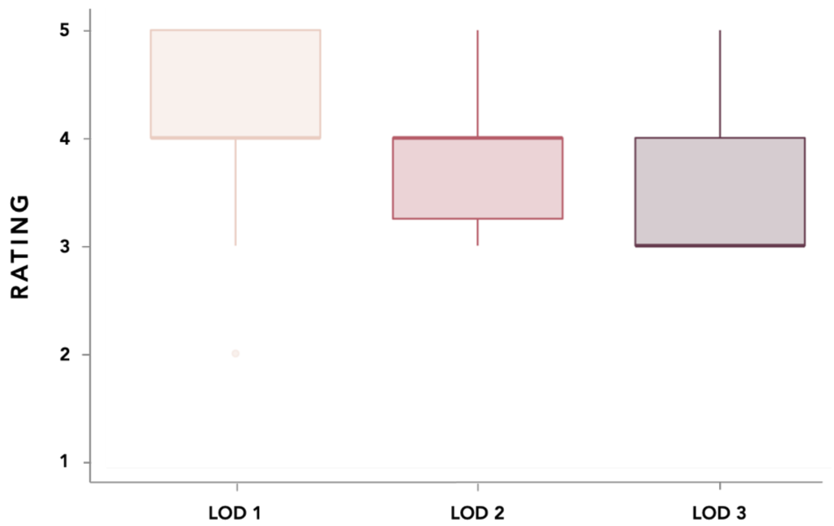

Figure 35: Ratings of the recognition of the real size of the virtual school in the AR application according to *LOD groups*.

Moreover, the above mentioned differences can also be explained by the participants' qualitative feedback. One participant in *group LOD 1* wrote that he thinks that it is an accurate, informative and visualisation. The comments from *group LOD 2* were somewhat more critical. The visualised building floated too firmly in the air for one person. Another person commented that the mobile phone display was too small. He mentioned that only a section of the building was visible on the display at a time. Nonetheless, both participants still rated the accuracy of the visualisation a 4 on a scale of 1–5. As shown in Figure 36, the lowest ratings of the accuracy were given by participants in *group LOD 3*. The three participants who rated the accuracy lower than the others also commented why; the person who rated the accuracy the lowest with a score of 2 remarked that the application is not bad, but some bugs should still be fixed. The other two persons who commented on the accuracy gave a score of 3. One person noted that the visualisation is good but shows often motion lag when walking. A third person commented that it is impossible to imagine exactly where the building extends to. According to them, floor material markings in the app would help.

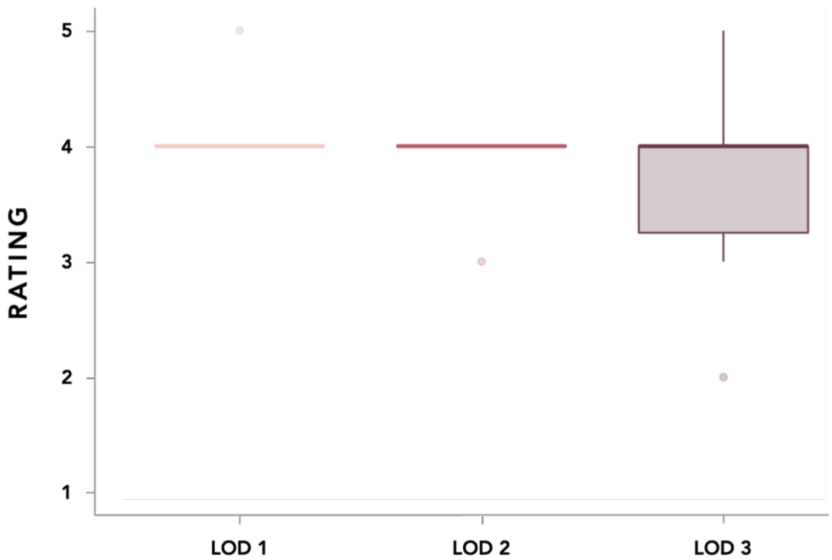

Figure 36: Ratings of the perceived accuracy of the visualisation in the AR application regarding the height and length by *LOD groups*.

FUTURE

Participants were asked whether they have a good idea of what the construction project will look like in the future (Figure 37). The data are not normally distributed, $W(30) = 0.78746$, $p = 0.00003906$, but the variances of the data are homogeneous, $F(2, 27) = 1.2273$, $p = 03089$. A Kruskal-Wallis test showed there were no significant differences between the groups, $\chi^2(2) = 3.3833$, $p = 0.1842$. A Wilcoxon test showed that there is a tendency for differences between *groups LOD 1* and *LOD 3* (p-value = 0.2). This could be explained by the fact that participants of *group LOD 3* answered the question more uniformly than participants of *group LOD 1*.

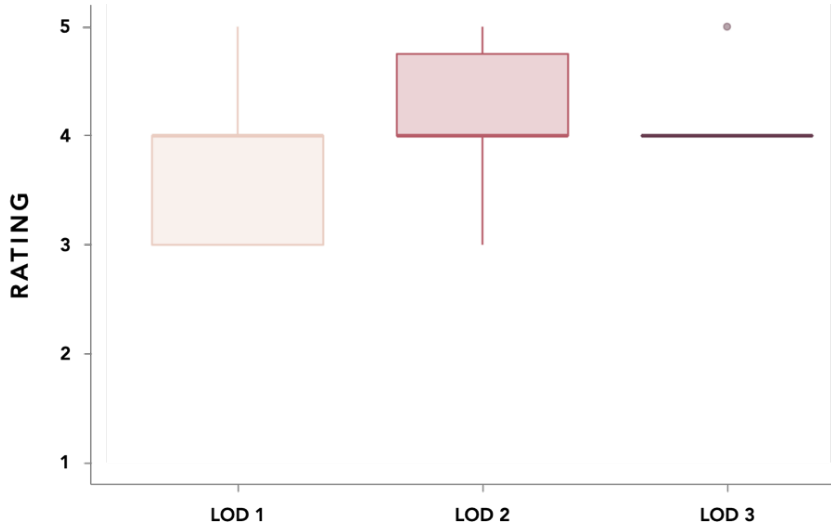

Figure 37: Ratings of the perceived ease of imagination what the construction project will look like in the future once it is finished.

OCCLUDED OBJECTS

The users were asked to evaluate to what extent the AR application helps them to evaluate which buildings are occluded by the virtual school building (Figure 38). The data are not normally distributed, W(30) = 0.75429, p = 0.00001069, but show homogeneous variances, F(2, 27) = 0.7412, p = 0.486. There are no significant differences between the three groups, $\chi^2(2) = 0.43679$, p = 0.8038.

The participants' self-assessment are consistent with the task performance: the participants of *group LOD 1* had on average performed best in the task and distributed on average slightly higher scores for this question than *groups LOD 2* and *LOD 3*.

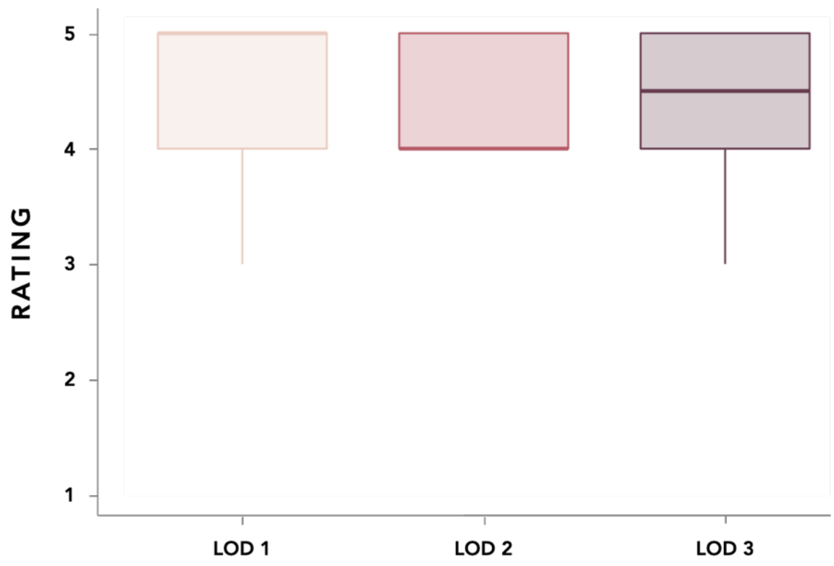

Figure 38: Ratings of the perceived potential to assess whether the AR application helps identifying real-world objects occluded by the virtual building according to *LOD groups*.

QUALITATIVE COMMENTS ON THE VISUALISATION

The participants were asked to provide qualitative feedback on the visualisation in the form of a commentary. When asked what was missing in the visualisation five participants from *group LOD 1* commented that they would have liked to have visualised more external structures of the building such as windows or façades. One person remarked that a coloured building and realistic walls would help evaluating whether the building fits into its surroundings. Another person would like an overall view in the app. In contrast to this, one person commented that everything is there in the app.

There were also five comments from *group LOD 2* on the missing external structures and colours. One person noted that the building looks a bit bulky because windows are missing. One person would like to have the exact height and width measures of the building indicated in the application. Another person would like to have a scale in the application.

From *group LOD 3*, only two participants commented on missing aspects. One person would like stronger contrasts the other person would like to have context such as trees visualised in the application.

4.2.2 AUGMENTED REALITY APPLICATION IN COMPARISON TO CONSTRUCTION SPANS

This next subchapter compares the visualisation of a building with an AR application and construction spans. The comparison of the two methods are first evaluated statistically, then followed by a qualitative evaluation.

The general rating of the potential of construction spans to visualise a construction project is lower than the ratings of the AR application above. The mean values of the ratings of the potential of construction spans are visualised in Figure 39. The data are not normally distributed, $W(30) = 0.87802$, $p = 0.003035$, but variance homogeneity is given, $F(2, 27) = 0.3232$, $p = 0.7267$. There are no significant differences between the ratings of the three groups, $\chi^2(2) = 2.1537$, $p = 0.3407$. There may be no difference between the three groups because the same construction spans were shown to all participants.

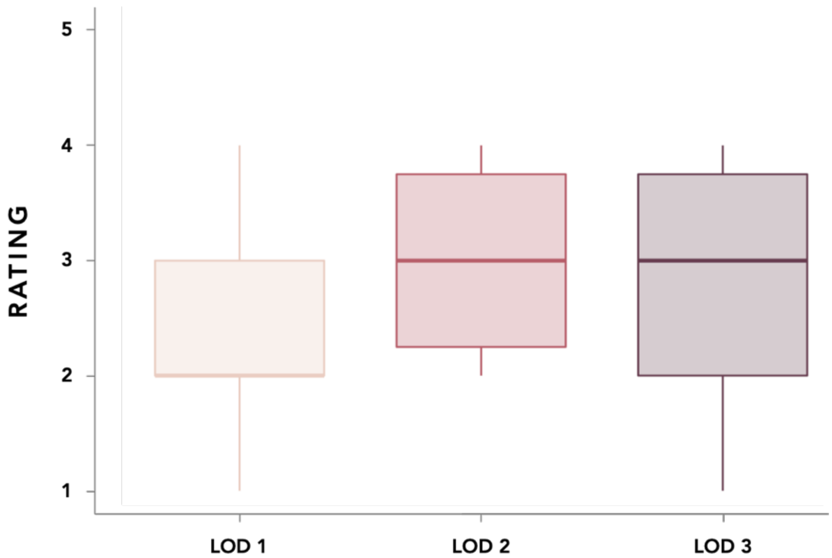

Figure 39: Ratings of the perceived potential of construction spans for visualising a construction project according to *LOD groups*.

Next, the participants had to evaluate three statements to compare the visualisation methods construction spans and AR. First, they had to evaluate the statement that the real size of the future building project is better recognisable in an AR application than with construction spans (Figure 40). The data were not found to be normally distributed, $W(30) = 0.78702$, $p = 0.00004931.$, but homoscedasticity is given, $F(2, 27) = 0.0021$, $p = 0.9979$. There are no significant differences between the three groups, $\chi^2(2) = 1.1758$, $p = 0.5555$.

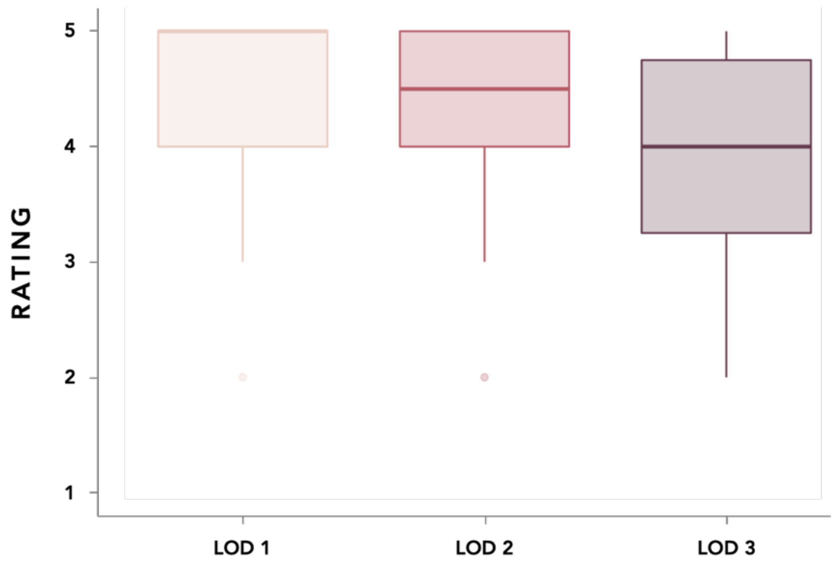

Figure 40: Ratings of the perceived potential to better recognise of the real size of a construction project in an AR application than with construction spans by *LOD groups*.

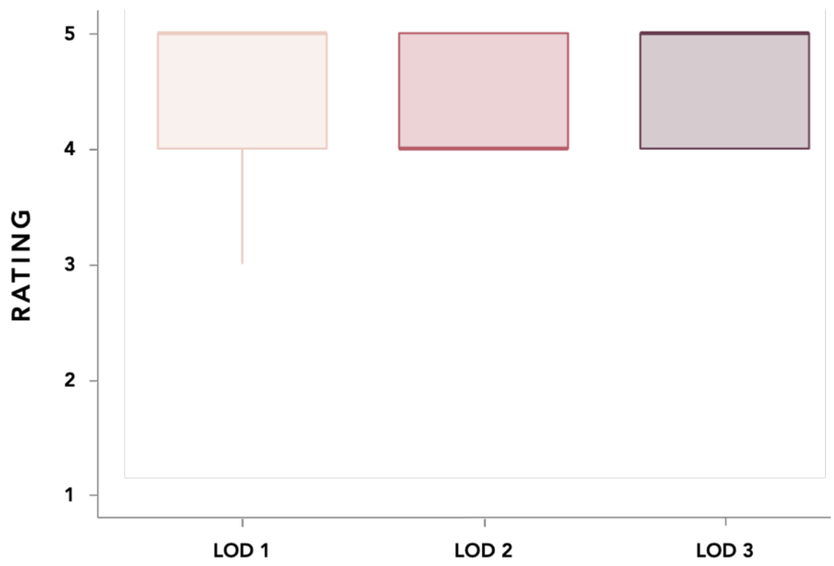

Figure 41: Ratings of the perceived realism of the visualisation in an AR application compared to construction spans according to *LOD groups*.

Then, the participants had to evaluate the statement that the visualisation of a construction project in an AR application is more realistic than with construction spans (Figure 41). The data are not normally distributed, $W(30) = 0.71508$, $p = 0.000003487$, but have homogeneous variances, $F(2, 27) = 0.2164$, $p = 0.8068$. There are no significant differences between the three groups, $\chi^2(2) = 0.7$, $p = 0.7047$.

The last statement to be evaluated in this questionnaire block was that a visualisation of a building project in an AR application is more suitable than with construction spans (Figure 42). The data are not normally distributed, W(30) = 0.76978, p = 0.00002511, because most participants either chose a rating of 4 or 5 on a scale of 1–5. Homoscedasticity is given for the data, F(2, 27) = 1.004, p = 0.3802. There are no significant differences between the answers of the three groups, $\chi^2(2) = 1.569$, p = 0.4563.

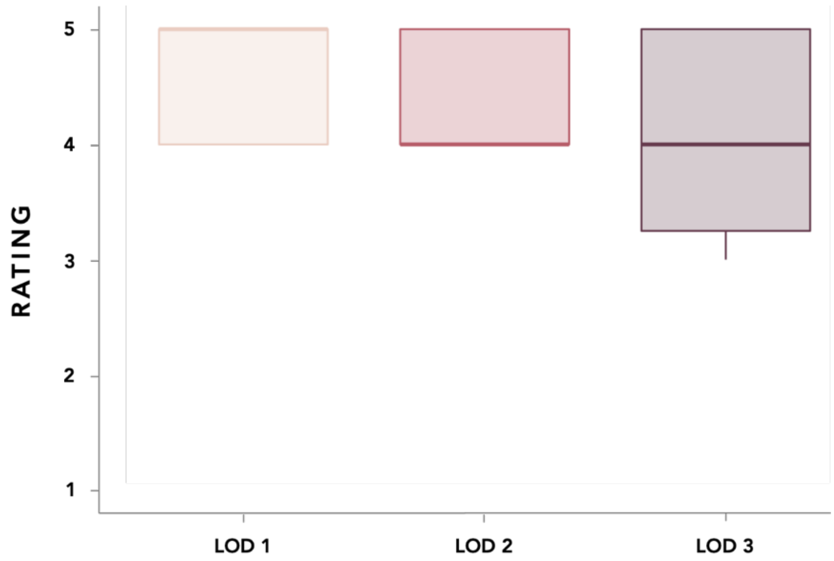

Figure 42: Ratings of the perceived suitability of visualising a construction project in an AR application compared with construction spans according to *LOD groups*.

QUALITATIVE EVALUATION

The above evaluations were partly complemented verbally by the participants. Two participants from *group LOD 1* stated that the building is easier to recognise with an AR application. In contrast, construction spans were confusing and provided an incomplete picture.

Participants in *group LOD 2* commented construction spans were more suitable for representing the height of a building. According to three participants in *group LOD 2*, an AR application has the advantage that the appearance of a building can be better communicated. One person noticed that construction spans are suitable as an announcer because in this way one can perceive that a building is going to be built at this location without having any previous knowledge of this project. For this person, an AR application is suitable if one already knows that a building is going to be constructed at this location and wants to convey the appearance of the building. Contrary to the opinions of these participants, a participant stated that an AR application is more suitable for presenting volume.

The opinions of the participants in *group LOD 3* are mixed. Three participants think that an AR application gives a better picture of the building project. However, the proportions of a building are more recognisable with construction spans. Another person thinks that one has to be able to imagine the building well with construction spans. One participant thinks that the exact positioning of a building is more accurate with construction spans, in all other points an AR application beats the construction spans by a mile. A sixth person believes that AR applications require more effort and may be difficult for people who are not technically experienced. According to this person AR has a huge potential compared to traditional methods. One participant remarked the screen of the smartphone was too small for the AR application. Another participant criticised that the school building was already under construction at the time the study was conducted. This person believes that the potential of AR applications would be much greater if a building was not yet under construction.

4.3 AUGMENTED REALITY AND DECISION-MAKING

DECISION-MAKING IN PLANNING PROCESSES

The results of the statistical analysis of the questions regarding public participation in planning processes are presented in this next block.

The first question assessed whether the availability of an AR application makes participants feel more involved in a planning process (Figure 43). Normal distribution is not followed, W(30) = 0.82227, p = 0.0002152, but the data have homogeneous variances, F(2, 27) = 0.027, p = 0.9734. The differences between the three groups are statistically non-significant, $\chi^2(2) = 3.8721$, p = 0.1443. There is a tendency for differences between *groups LOD 1* and *LOD 2* (p-value = 0.29) or *groups LOD 2* and *LOD 3* (p-value = 0.31).

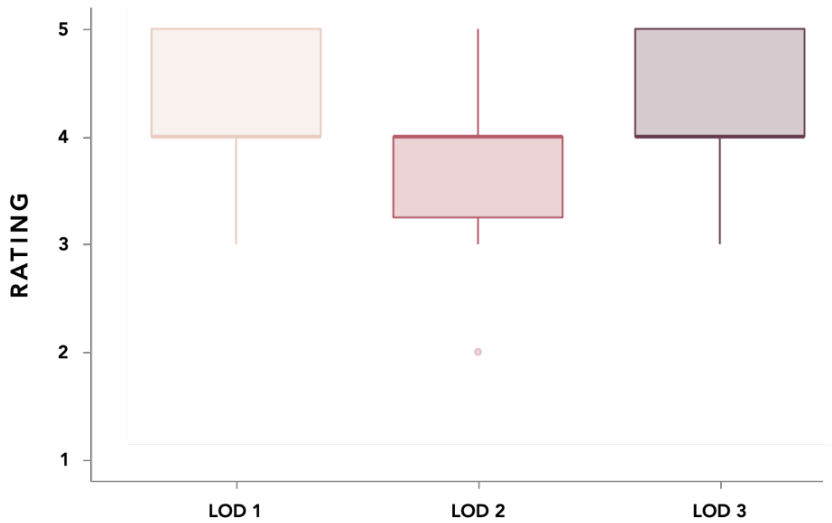

Figure 43: Ratings of the perceived possibility to facilitate involvement in a planning process if an AR application is made available to the public according to *LOD groups*.

The second question asked whether an AR visualisation facilitates encouragement for participating in a realisation process (Figure 44). The data are not normally distributed, W(30) = 0.77033, p = 0.00002564, because the participants often chose the values 4 and 5 on a scale of 1–5. The variances are homogeneous, F(2, 27) = 1.1503, p = 0.3321. There are no significant differences between the three groups, $\chi^2(2) = 3.6992$, p = 0.1573, however, there is a tendency that the differences are greatest between *groups LOD 1* and *LOD 3* (p-value = 0.23).

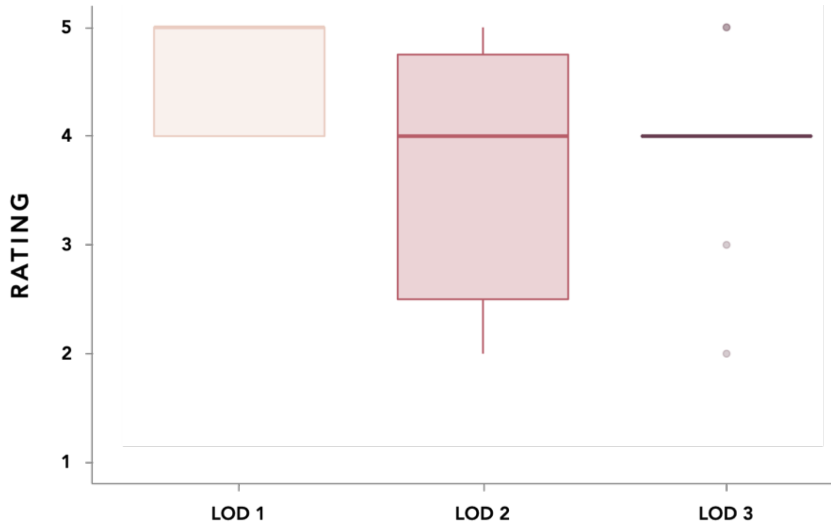

Figure 44: Ratings of the perceived possibility to facilitate encouragement for participating in a realisation process if an AR application is made available according to *LOD groups*.

OBJECTIVE ASSESSMENT AND SELECTION OF ALTERNATIVE SOLUTIONS

Next, the question was asked if an AR application facilitates an objective evaluation and selection of proposed solutions. The answers for the perceived potential to support an objective evaluation is visualised in Figure 45. The data are not normally distributed, $W(30) = 0.70506$, $p = 0.000002488$, because almost all participants chose the value 4 on a scale of 1–5. Variance homogeneity is given for these data, $F(2, 27) = 0.0848$, $p = 0.9189$. There are no significant differences between the groups, $\chi^2(2) = 0.23134$, $p = 0.8908$, because the answers were almost the same for every *LOD group*.

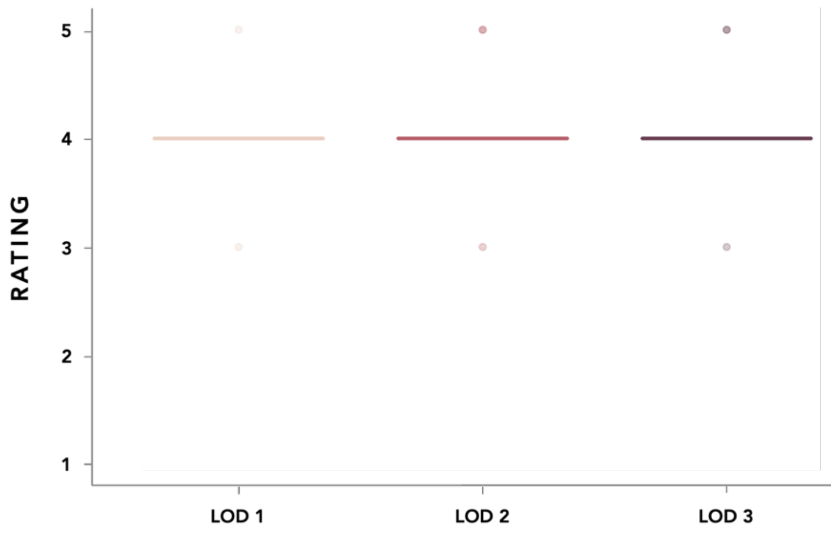

Figure 45: Ratings of the perceived support potential through an AR application for an objective evaluation of a construction project according to *LOD groups*.

Figure 46 visualises the answers to the perceived potential of an AR application to facilitate decision-making. Normal distribution is not followed, $W(30) = 0.6345$, $p = 0.0000002745$ but homoscedasticity is given for these data, $F(2, 27) = 1.2227$, $p = 0.3108$. A Kruskal-Wallis rank sum test showed there are no significant differences between the three groups, $\chi^2(2) = 2.7985$, $p = 0.2468$. The tendency for differences are greatest between *groups LOD 1* and *LOD 3* (p-value = 0.35).

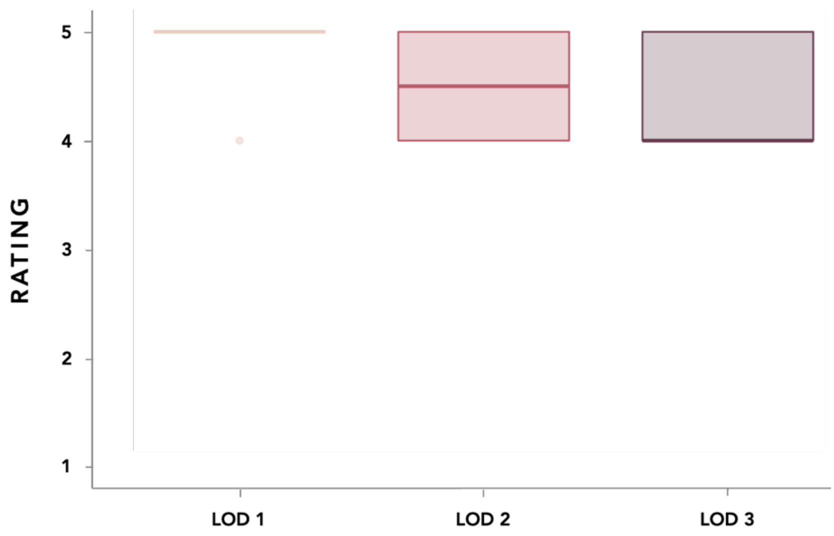

Figure 46: Ratings of the perceived support potential of an AR application to facilitate selection of proposed solutions according to *LOD groups*.

Five participants gave qualitative feedback on this questionnaire block. One participant from *group LOD 1* commented that she wants to know what the façade looks like and another participant commented that it was easier with the AR application. A participant from *group LOD 2* wrote that construction spans alone caused enough of an uproar to encourage participation. Participation should also be possible via an AR application for a participant from *group LOD 3*.

VOTING ON PROJECT ALLMEND SCHOOL BUILDING

In the preliminary questionnaire the participants were asked how they would vote on the project *Allmend school building* (Figure 47). Six persons abstained from voting with one person commenting that he had too little information on the project.

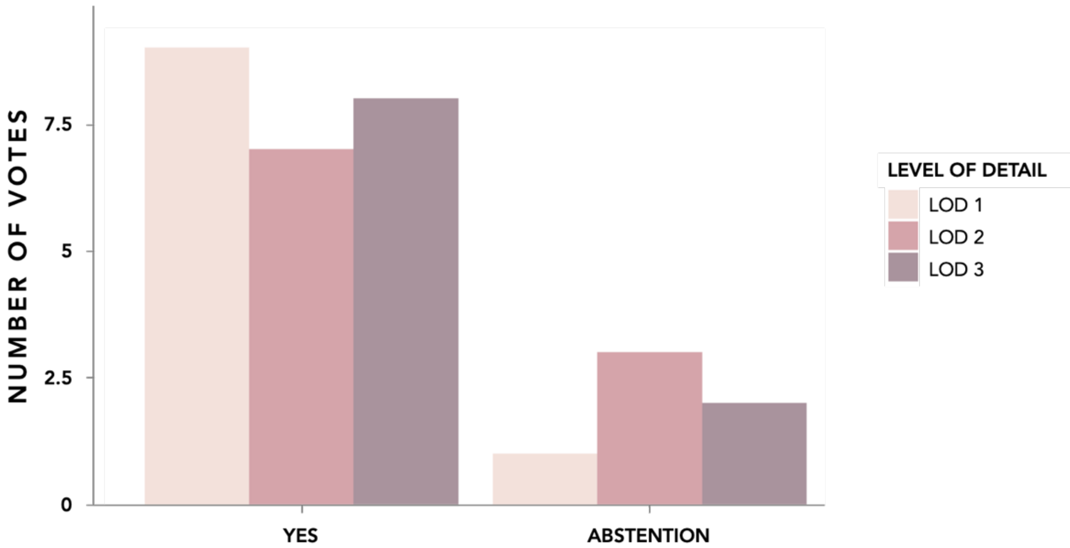

Figure 47: Hypothetical voting results on the project *Allmend school building* according to *LOD groups* before seeing the project in the AR application. The voting on the project was assessed in the preliminary questionnaire.

In the post-questionnaire participants were asked whether their opinion on project *Allmend school building* had changed after viewing the AR application (Figure 48). One of the six participants who abstained at the beginning of the hypothetical vote changed her mind and the other five continued to abstain. One participant commented in the questionnaire that he did not know the construction costs and had not yet read the official arguments. These comments may be a possible explanation for abstaining. Other participants made the same comment orally when filling in the questionnaire. Four participants who initially would have voted for the project have changed their mind and would vote against after seeing the AR application. All other participants remain with their original approval of the project.

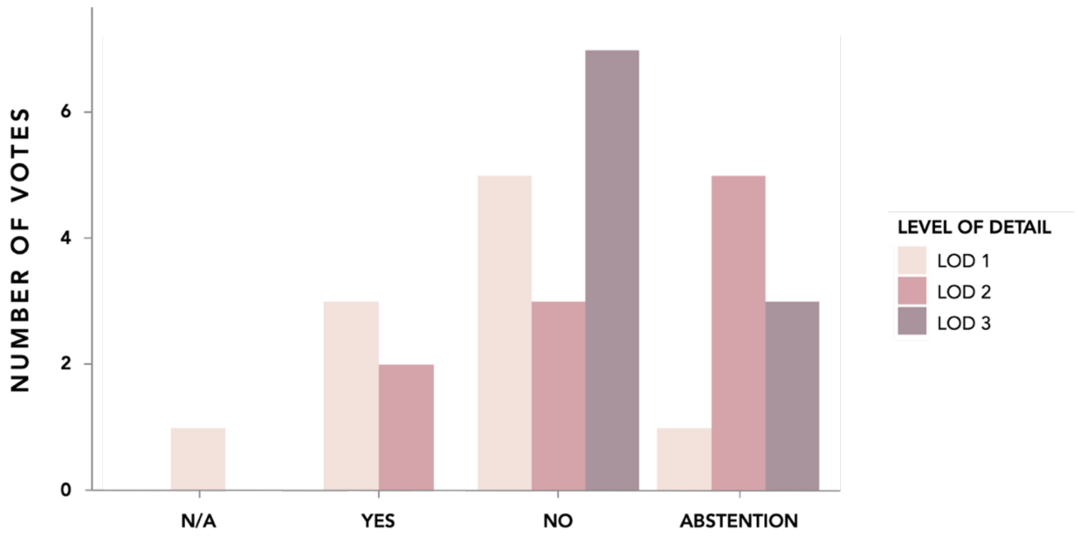

Figure 48: Assessment whether the participants' opinions on the project *Allmend school building* changed after viewing the AR application. Possible choices in the questionnaire were *yes*, *no* and *no answer (= abstention)*. Empty question results are indicated as *N/A* in this bar chart.

5 DISCUSSION

This thesis evaluated the suitability of an AR application compared to the traditional visualisation method with construction spans for displaying a construction project. An assumption of this research was that an AR application is more suitable for visualising a building project, as it would be more effective for visualising the building in a realistic way. The study introduced a prototype AR application, which visualises a building project in the city of Zurich at three different levels of detail. The AR application and the construction spans were compared in a between-subjects study. The results presented in the previous chapter are discussed in the following subchapters in context of the research questions proposed in chapter 1.2. The first subchapter 5.1 compares the suitability of construction spans and the AR application based on the participants' feedback. The second subchapter 5.2 discusses the ease of interpretation of the different LOD based on the results of the tasks introduced in the user study. This is followed by subchapter 5.3, which evaluates the effectiveness of the three LOD. Next, in subchapter 5.4 the suitability of the three LOD are compared in terms of the decision-making of the participants. Finally, uncertainties and limitations of the study are discussed in subchapter 5.5.

5.1 SUITABILITY OF AUGMENTED REALITY APPLICATION AND CONSTRUCTION SPANS

RESEARCH QUESTION 1 *How suitable is an AR application for visualising new building projects in an understandable and realistic way to assist decision-making compared to construction spans?*

HYPOTHESIS 1 An AR application is more suitable than construction spans to visualise new building projects.

The questions regarding the effectiveness and accuracy of the AR application show no statistically significant difference between the three *LOD groups* (Figure 33, Figure 34 and Figure 36). Surprisingly, the participants in *group LOD 1* rated the realism of the visualisation the highest on average, even though the visualisation was the least detailed. Furthermore, these participants rated the accuracy of the visualisation the highest on average. In contrast, previous research found significant differences between different visualisations; the more realistic a visualisation, the higher the rating of the perceived accuracy [13]. This discrepancy could be due to Klausener's (2012) [13] and Zanola, Fabrikant and Çöltekin's (2009) [139] use of visualisations on a screen as opposed to AR technology. Therefore, their visualisations would not show motion lag when walking around the virtual objects as reported by one participant in this study. Thus, the lower rating of the accuracy of *group LOD 3* compared to the other two groups could be explained by the visualised building sometimes randomly showed motion lag, which could be interpreted as inaccurate. The lower average rating of *group LOD 2* compared to the other two groups could be due to their prior knowledge in computer games (Figure 11). As computer games can include very realistic visualisations, these participants might have had much higher expectations of the visualisation's realism. Thus, this could have led to a lower rating compared to the other groups' ratings as the LOD 2 visualisation is missing external structures, such as façade and windows. Participants in *group LOD 1* reported that they wished the visualisation to have more detailed external structures of the building. Nevertheless, they rated the accuracy higher than participants in *group LOD 2*. Furthermore, the discrepancies between the results of previous studies and this study could be due to the choice of study design. In previous research, a within-subjects study design was chosen where the participants were presented all the models, whereas in this study, a between-subjects study design was chosen. This meant that, the participants were only presented one model and answered questions only based on the shown level of detail, without the option to compare different models.

In previous research, participants also remarked that they would like to have a more detailed visualisation and elements such as façades and windows were missing from the visualisation [10], [49]. As a participant in this study also remarked, participants in Allen's (2011) [49] study believe that information about the design a building is important to fully assess how the visualisation would look in the setting of the environment.

Despite the fact that *group LOD 3* rated accuracy, recognisability of the different elements and realism of the visualisation on average lower than the other groups, they rated their ability to imagine what the building would look like in the future the highest (Figure 37). A lower rating of the visualisation's realism compared to the other two groups' ratings could be explained by the fact that the model is detailed but not as realistic as a photorealistic visualisation. The texture of the façade may not give the impression to be realistic and, therefore, participants might have given a lower realism rating. Hence, to receive a higher realism rating, a photorealistic model may be needed, where the difference between reality and virtuality would not be obvious at first glance. It is not surprising that the participants of *group LOD 3* rated their ability to imagine the future building the highest, as the visualisation they viewed was the most detailed. The colouring and the visualisation of the external structures could be a reason for participants having a better idea of what the building would look like in the future. Zanola, Fabrikant and Çöltekin (2009) [139] also found the participants' confidence ratings were higher when being presented with a more realistic visualisation.

Even though the participants' ratings indicate that the recognisability of the real size of the building was higher in the AR application than when visualised with construction spans (Figure 40), their qualitative feedback deviates from this. In particular participants in *groups LOD 2* and *LOD 3* stated that the proportions of a building are better visible with construction spans. They allow communicating more clearly that a new building will be built at this location and facilitate making an initial assessment of the height and shape of a building. None of the participants questioned the accuracy of the construction spans. However, taking a look at the participants' estimates for the height of the construction spans, the majority of participants greatly underestimated the height. After completing this estimation task, most participants wanted to know how high the construction spans actually were. The correct height was given to them, which was often met with surprise. Despite these estimation errors, there is still great confidence in this method. It is probably assumed that construction spans are accurate because this method has been used for many years. As this study suggests, the accuracy of new methods, such as an AR application, are viewed more critically.

As some participants in this study commented, previous research also found that construction spans are a good first indicator for communicating about a construction project in a non-textual form [10]. Nevertheless, there are other means which can be used as a first indicator. For example, a board with information on the construction project could be used as a means of communication (Figure 49). This board could include a Quick-Response code (QR code) or link to the AR application in the app store, with which passers-by could visualise the construction project on site. Moreover, Ilin (2019) [10] suggested that traditional visualisation methods, such as construction spans, can only be used to a limited extent as they always require further visualisations to provide complementary information about the building project. As participants in this study commented, research also pointed out that construction spans leave room for interpretation and, therefore, give an incomplete picture of a building [10]. Construction spans are merely a linear feature, whereas a virtual 3D visualisation has volume. An AR application would be a useful addition to traditional presentation methods, like construction spans, as AR can present much more information [10], [140]. Thus, construction spans could be used as markers for an AR application. The AR application could supplement the missing information, including the external features of a building. Furthermore, the scope of interpretation of construction spans could be reduced by an AR application. If several buildings are staked out on a site, they could be more easily identified using an AR application. However, combining construction spans and an AR application could lead to an even lower rating of the accuracy of the AR application. The perceived accuracy might be lower because the precision of overlaying the construction spans with a virtual building might be low when not calibrated accurately. A low precision would be easily identifiable as the construction spans would not be perfectly aligned with the edges of the virtual building.

Figure 49: Example of a board as a means of communication about a construction project. This board includes information about the *Allmend school building* construction project.

Overall, the ratings of an AR application were very positive, which is in line with previous research [10], [49]. Some of the participants believe that AR applications show great potential for providing information on construction projects. In Ilin's (2019) [10] study, the visualisation of the building project *Allmend school building* with an AR application on a tablet was rated positively by 85% of his study participants. In an overall evaluation of all tools presented in his work, he found that visualisations using AR and VR technology were rated the highest by participants. In contrast, construction spans were rated the lowest [10]. This evaluation behaviour could also be observed in this study; the participants rated construction spans noticeably lower than an AR application. Therefore, this study suggests that an AR application is more suitable for visualising a building project compared to construction spans. Therefore, hypothesis 1 cannot be rejected.

5.2 ASSESSING INTERPRETATION DIFFICULTY

> ***RESEARCH QUESTION 2*** *How difficult is it for users to interpret the visualisation of a building project in an AR application correctly?*

HYPOTHESIS 2 The more detailed the rendering of the object, the easier it is to interpret the visualisation correctly.

As shown by the results of the estimation questions on the height of a residential building and the length of a concrete block, there are no statistically significant differences between the individual groups in their estimation skills (Figure 22 and Figure 23). Hence, the differences of the three groups in the estimation tasks with the visualisation of *Allmend school building* in the AR application cannot be explained by the estimation skills of the participants.

On average, participants in *group LOD 3* estimated the dimensions of the virtual building best. When asked to estimate the height, the participants of *group LOD 3* overestimated the height by about 11%, participants of *group LOD 2* by about 18% and those of *group LOD 1* by about 65%. These differences could be due to the lack of external features of the building. A helpful indicator for the height of the building's floors could be to display the top floor as bars as for *group LOD 2*. Some participants in *group LOD 3* counted the number of floors of the visualised building and, thus, estimated the height. Participants in *group LOD 1* did not have such indicators for the height of individual floors in their visualisation. Moreover, the previous knowledge of urban planning, architecture and GIS could have an impact on the task performance. In all three fields, participants in *group LOD 3* had the most previous knowledge. This may have helped them perform better.

When estimating the width, participants in *group LOD 1* scored better than participants in *group LOD 2*. Participants of *group LOD 1* overestimated the width of the building by only about 30%, whereas those of *group LOD 2* overestimated it by about 52%. Participants in *group LOD 3* were just ahead of those *group LOD 1* with an overestimate of about 28%.

Compared to the height and width, which were overestimated, the length was underestimated by participants in this study. Many other studies have shown that egocentric distances are underestimated in virtual environments [141]–[145]. Grechkin et al. (2010) [143] observed that participants significantly underestimated distances in an AR environment. Furthermore, Cutting and Vishton (1995) [146] suggested that the egocentric distance perception is not the same for the three subspaces in which the observer's visual environment can be divided into. The visual environment can be divided into personal space (≤ 2m), action space (2m–30m) and distant space (≥ 30m) [146]. Previous research found that participants underestimated egocentric distances in action and distance spaces, however, overestimated egocentric distances in personal spaces [145]. Egocentric distance estimations can be improved when providing feedback to the observer, for example, by letting her/ him walk half as the distance they are asked to estimate [141]. Hence, the task performance in this study could have been improved by letting participants walk around while estimating the distances.

Kälin (2015) [107] observed that the accuracy of estimates deteriorated with duration for which a dynamic AR application was used. However, in this study, no correlation between accuracy and duration of usage could be observed between the accuracy of estimates and length of time used for the estimations (Figure 30). Therefore, the time spent for estimating dimensions of the virtual building is probably not the reason for the underestimates and overestimates. One reason for the underestimations and overestimations could be the size of the display of the device used. Some users felt that the display of the mobile phone was too small to view the visualisation. Therefore, moving the mobile phone around to view the virtual object could be a source of error for the dimension estimates. When moving around the device, a motion lag could occur because the objects were re-positioned [147]. These drift-effects could lead to misinterpretations of the size of the presented building [107].

To conclude, hypothesis 2 cannot be rejected, as a more detailed model could indeed help to estimate the volume of a building. Façade elements, such as windows or floors, could help to better estimate dimensions. Furthermore, previous knowledge of architecture, GIS and urban planning may have an influence on task performance.

5.3 EFFECTIVENESS OF DIFFERENT DEGREES OF ABSTRACTION

RESEARCH QUESTION 3 *What is the most effective degree of abstraction for visualising a planned building project in an AR application?*

HYPOTHESIS 3 The lower the degree of abstraction of the object, the easier to make decisions.

In the post-questionnaire, the different aspects of the AR application rated slightly higher by participants in *group LOD 1* than participants in the other two groups. Participants in *group LOD 2* gave the lowest ratings on average. Also, the comments of participants in *groups LOD 2* and *LOD 3* on the AR application were more sceptical than the remarks of participants in *group LOD 1*. Although the differences in ratings are not statistically significant, one reason for the lower ratings of *groups LOD 2* and *LOD 3* could be the participants' previous knowledge. The participants in *group LOD 3* had the most previous knowledge in urban planning, architecture, GIS, and 3D visualisation. Participants in *group LOD 2* had the most previous knowledge in computer games. In all these areas the participants of *group LOD 1* had comparatively the least previous knowledge. Therefore, the expectations of the AR application could have been different, which resulted in a higher evaluation of the statements in the post-questionnaire. Previous research suggests that the effect of novelty of AR applications could have positively impacted the given answers in the post-questionnaire [111], [148]. Hence, participants with no previous knowledge of AR applications could have been biased by a temporary wow-effect, which may have led to higher ratings in the post-questionnaire.

However, when looking at task performance, as described above, participants in *group LOD 3* scored better on average than the other participants. Participants in *groups LOD 1* and *LOD 2* are comparable in task performance. Therefore, a more detailed model and previous knowledge in relevant fields, such as urban planning and architecture, could assist users in tasks which involve estimating distances and volumes.

In conclusion, no level of detail for visualising a planned building is most effective for all purposes. Different steps in urban planning may require different visualisations. For example, a more simplistic and abstract visualisation might be more useful to inform citizens about a future construction project in the early stages of its planning process. Previous research suggested that sketches give people the impression that the model can still be modified [13]. Additionally, Drettakis et al. (2007) [117] suggested that an artistic visualisation might be appropriate when designers or authorities do not wish to make a definite commitment. Therefore, a simpler LOD, such as LOD 1, could facilitate the involvement of citizens in planning processes. A more detailed model, such as LOD 3, may be more useful for advanced stages of planning processes. For example, an AR application with a detailed visualisation of the project could be a useful method for providing citizens with additional information ahead of a vote. The application could be used combined with the voting documents to get a more in-depth picture of a project and assist citizens in their decision-making process. As earlier research suggested, AR technology could be an important communication platform to make public participation more accessible to citizens and facilitate their decision-making process [72].

5.4 AUGMENTED REALITY AND DECISION-MAKING

RESEARCH QUESTION 4 *How is the decision outcome of the citizens influenced by the different degrees of abstraction?*

HYPOTHESIS 4 The more realistic the visualisation, the higher the acceptance of the project.

The participants were asked at the beginning of the study to fictionally vote on the project *Allmend school building*, where 80% of all participants voted for the project. This high rating is not surprising because in the actual vote on the budget for the construction of the *Allmend school building* on 17th November 2019 the percentage of yes votes was 86.6% after excluding invalid votes [149]. Compared to the voting result, the empty votes were higher in the fictional voting during the study: on 17th November 2019, 1.7% of all votes were empty [149], compared to 20% in this study. This difference might be explained by the fact that citizens had more time and resources to form an opinion on the project before the 2019 vote. In this research, one participant commented in writing that he has not enough information to vote on the project. Other participants commented verbally during the study that they would need more information than the short introduction given to make a decision on what to vote.

At the end of this study, it was assessed whether participants would vote differently on the project after having used the AR application. Even though the average rating of the perceived potential of the AR application to support the selection of alternative solutions and ratings of the perceived potential to be more encouraged in the realisation process was highest for *group LOD 1*, more participants in *group LOD 1* would reconsider their opinion of the project. The lowest average rating of the perceived potential to facilitate the selection of alternative solutions was given by participants in *group LOD 3*. Apart from three persons who abstained from the voting, all participants in *group LOD 3* stated that they would not change their opinion. Furthermore, across all groups, 10% more participants abstained than in the hypothetical vote in the pre-questionnaire. The reasons for a change of opinion or abstention could be due to the degree of realism of the presented visualisations. As LOD 1 and LOD 2 are less realistic than LOD 3, they could cause uncertainty. Uncertainty could lead people to abstain or vote against a proposal, as the results of a vote in Switzerland are binding. Citizens are aware that the acceptance of a proposal by vote brings about a change and, therefore, uninformed people are less likely to vote because of the linked costs [150]. According to Krishnakumar and Müller

(2007) [150], citizens only participate in a voting if the cost of voting is smaller than the expected benefit from voting. Therefore, the cost of voting for a building project might be too high if an unrealistic, undetailed visualisation is presented to the citizens. Klausener (2012) [13] suggested that the acceptance of the project increases with increasing degree of realism. This is in alignment with the results of this study as more participants would change their opinion (i.e., vote against the project) or abstain from voting as the degree of realism decreases.

Although the perceived potential to facilitate an objective evaluation through an AR application is the same for all three groups, the average perceived potential of an AR application to facilitate decision-making is highest for *group LOD 1*. Research found that platforms such as AR have potential for bringing communities together and empower citizens by providing a framework for an interactive decision-making process [72]. Being able to interact with a virtual visualisation could help the citizens in their decision-making process [151], [152]. These findings are in line with this study, as the participants gave the perceived potential of an AR application to support the selection of an alternative solution a rating of 4 or a5 on a scale of 1–5 (Figure 45).

Participants in *group LOD 1* rated the perceived potential to be more encouraged in the realisation process by an AR application higher than participants in *groups LOD 2* and *LOD 3* (Figure 44). The perceived encouragement might be lower when the model is more realistic, which could be explained by more photorealistic representations by being regarded as more unalterable: Schumann et al. (1996) [153] found that more realistic models appear to be final. In contrast, sketches appear to be incomplete, which give a scope for change to the viewer. This observation was also supported by Klausener (2012) [13]. Even though there were no sketches used in this study, a less realistic visualisation such as LOD 1 could be regarded as incomplete and, therefore, people might be more encouraged to participate in planning a building project.

The perceived involvement in planning processes with an AR application was statistically non-significant, however, there is a tendency that the participants of *group LOD 2* feel less involved in the planning process than participants in *groups LOD 1* and *LOD 3* (Figure 43). However, an issue with measuring perceived involvement is that construction work for *Allmend school building* has already started. Some ratings could therefore be lower, as the question about the perceived involvement in planning processes with an AR application is hypothetical and the participants can consequently no longer be involved in the planning process.

Regarding research question 4, it can be concluded that there is a tendency that people might change their opinion about a project when shown a lower LOD an AR application. Therefore, hypothesis 4 cannot be rejected. This change of opinion could be attributed to the fact that a simplified representation of a building (i.e., LOD 1) lacks information about the appearance of the building. This could lead to a situation where voters are more likely to vote against a project because they are indecisive and the cost of participating in the voting is too high. Nonetheless, a less realistic visualisation could facilitate the involvement of citizens in processes of a project. Previous research found a significant increase in the participants' willingness to participate in urban planning processes when an AR application was available that served as a communication means in the participatory processes [49], [72].

5.5 UNCERTAINTIES AND LIMITATIONS

This study has limitations because it took place outdoors, under direct sunlight, some participants had difficulty seeing the content on the screen of the mobile device used. Direct sunlight caused reflections on the screen, which resulted in a low contrast and, therefore, content could not be displayed brightly enough to see it clearly. This has also been an issue in previous research [96], [101].

Another issue with the present study is that construction works for the school building under consideration had already started at the time the study was. The construction site was surrounded by white barrier walls and foundation construction was already underway. This caused two separate issues. First, the white barrier walls were an issue for participants in *groups LOD 1* and *LOD 2*, as the virtual object in the AR application was also visualised in white. Therefore, some participants trouble distinguishing between the white barrier walls and the white virtual object. Second, the already existing foundation of the actual building was used by some participants as an aid for estimating the dimensions of the virtual school building. In addition, the fact that the project was already under construction may have reduced the effect of the AR application. For the tasks with the AR application, participants viewed the construction site through a window in the white barrier walls. On some days, a vehicle parked was behind this window, which obscured the participants' view. To avoid these issues it would be ideal if such an AR application were be available before constructions have started. This would allow a direct comparison between construction spans and AR application. Moreover, this would allow freer movement around a site, whereas the participants in the present study could only walk around the barrier walls. Additionally, if a location were not yet fenced off, and the interior of a building were modelled, citizens would have the possibility to view the building from the inside.

Another difficulty was the correct use of the AR technology itself. One participant unconsciously covered the camera of the mobile device with his fingers at times, which resulted in the camera live feed being temporarily displayed in black. Other participants accidentally touched the screen, causing the visualisation to reposition itself accordingly, whereupon it had to be re-calibrated. To avoid this issue, future AR applications should feature an option for moving the virtual scene, which prevents the repositioning of virtual objects when disabled.

An additional issue with the virtual scene was that the building started rotating from time to time. The cause for this random rotation is not clear, as neither the screen was touched, nor was a continuous tracking update mode chosen for the positioning of the objects. In addition, the height of the building in the far distance rather unrealistic because the height of the building was rendered too low in the far distance.

A major issue with the AR prototype was occluding virtual objects with physical objects detected in the camera feed. There exist various approaches for occluding virtual content, such as the use of depth maps or existing 3D models of surrounding objects [154]. Two-dimensional depth maps can be created with ARKit, which can detect horizontal and vertical planes in physical spaces [155]. The detected planes can then be assigned an empty material and be rendered in the foreground and, thus, occlude other virtual objects. However, these sensors have a limited reach and can only detect planes up to 4 metres away [156]. Therefore, vertical planes for objects taller than 4 metres cannot be detected. The approach based on plane detection is not suitable for the present AR application as the buildings around the *Allmend school building* are higher than 4 metres. Another approach would be to use a 3D layer with the virtual copies of the surrounding buildings. This building layer could be visualised with transparent colour and used as an occluding layer. However, these methods are not suitable for the project used in this study as transparent layers were not rendered in the foreground and, therefore, were not occluding the virtual school building.

The pilot study showed that the initial calibration process to position the virtual object at the correct location was too complicated. Therefore, the scene had to be calibrated for the study participants. For future AR applications, the calibration process should be made easier such that users can calibrate the scene themselves without any difficulty. Moreover, providing an imagery basemap for the calibration process within the application did not suffice. Therefore, markers on the ground for indicating the corner points of the building would perhaps help participants when calibrating the scene. The calibration process relates to a big challenge for mobile AR systems, which is the tracking of the virtual objects itself. Various studies have shown that both a marker-based and a marker-less approach for tracking need some improvement [72], [96], [157].

There are not only technical limitations present but also limitations in terms of the participants' previous knowledge. Participants in *group LOD 3* had the most previous knowledge in architecture, GIS and urban planning, whereas, participants in *group LOD 2* had the most experience with computer games. This previous knowledge could bias participants' task performance as well as their expectations of an AR application.

Lastly, a deeper understanding of long-term implications of such an AR application remain to be investigated. Were participants positively affected by the novelty effect of seeing such an AR application for the first time? As Olsson et al. (2013) [148] suggested, longitudinal research is still necessary to find out whether the user experience changes over time and if participants would rate the suitability of an AR application for participatory processes in urban planning differently after using the application over an extended period of time in real scenarios.

6 CONCLUSION

ACHIEVEMENTS

With the recent advancements of AR technology, new ways for visualising and, therefore, communicating construction projects are made possible. The first aim of this research was to find out whether an AR application is suitable for visualising a construction project and what level of detail of the virtual visualisation is the most appropriate. The traditional visualisation method construction spans were compared to an AR application (Figure 42). Participants of the conducted field study rated the perceived potential of construction spans rather low on a 5-point Likert scale (Figure 39). A statistical analysis on effect and accuracy of the AR visualisation did not suggest any statistically significant differences between the three *LOD groups* (Figure 33–Figure 36). However, participants who were assigned either LOD 1 or LOD 2 reported they wished to see external structures such as windows in the visualisation. This research suggests that visualising external structures helps viewers to imagine what a building will look like in the future and better evaluate whether a building fits into its surrounding environment. These observations are in line with Ilin (2019) [10]. Participants rated the suitability of construction spans as visualisation method lower than an AR application. According to the participants the suitability of both methods depends on context; construction spans are suitable as announcers, whereas, an AR application can be used to communicate more details about the design of the project.

The second aim of this research was to assess participants' interpretation difficulty of a building project visualised in an AR application. In self-report measure, participants indicated that the visualisation was rather easy to interpret (Figure 32). The ease of interpretation was also tested with several estimation tasks including estimating dimensions of construction spans and virtual building in an AR application. Generally, participants underestimated construction spans' height by about 34%, whereas they overestimated the height of a virtual building by about 31%. In particular participants who viewed the AR visualisation in LOD 2 or LOD 3 estimated the height of the AR visualisation more accurately than the height of construction spans (Figure 25 and Figure 26). This study confirmed earlier findings by Grechkin et al. (2010) [143] that real-world distances are underestimated when using AR. Participants who were shown LOD 1 or LOD 2 performed generally worse in estimating dimensions.

The results of the estimation tasks were also used to investigate whether a certain LOD is more suitable than others to represent a building project in an AR application. This research suggests that no LOD is most effective for all purposes. Depending on intention a different LOD should be chosen. A less detailed visualisation of a project may give viewers a less definite and less unchangeable impression, whereas, a more detailed LOD may be used for purposes where authorities wish to make a definitive commitment. In addition, an AR application would make it possible to view a planned high-rise building from a distance. In contrast to construction spans which can be seen through an AR visualisation of a building clearly communicates how the planned building impacts the view from a certain point and what effect it has on the appearance of a neighbourhood or skyline. This research suggests that if time and other resources are limited they best be spent in producing a more detailed model as there were no statistically significant differences found between the three LODs and most participants who viewed LOD 1or LOD 2 remarked they wished to see a more detailed model which showed features like façade and windows.

Finally, it was assessed how the decision outcome of participants is influenced by different LODs. The involvement of citizens in public participation processes can be facilitated by providing an AR application as an additional source of information for a construction project. Participants rated on average the perceived potential by an AR application to facilitate objective evaluation a 4.1 on a scale of 1–5. The perceived potential by an AR application to support decision-making was given an average rating of 4.5 on a scale of 1–5. Participants' may also reconsider their opinion about a project after viewing an AR application, as 16.6% of the participants in this study reported.

As an overall conclusion, providing the citizens with an AR application to visualise a building project could increase their willingness to be involved in public participation processes. AR is a new communication method to visualise past and future buildings and facilitates the transition from traditional to smart city.

RECOMMENDATIONS AND FURTHER RESEARCH

This study could show that participants had a positive attitude towards the presented AR technology. Participants of this study see potential in AR technology for urban planning and public participation processes. It is suggested to complement existing best practices for visualising construction projects with new visualisation methods like AR. Integrating AR technology provides an additional information source which could support citizens in their decision-making, for example with regard to a voting.

However, long-term implications of the usage of AR in participatory processes remain to be investigated. There is a need to understand if participants' responses are influenced by the novelty effect of seeing an AR visualisation of a building project for the first time. Furthermore, future research should investigate whether participants' age has a significant influence on the perceived suitability of an AR application as 60% of all participants in this study were in their twenties and only 16% of the participants were forty years old or older. Additionally, this research is limited to the city of Zurich, a rather progressive city on the political map and one of the smartest cities in Switzerland [8], [158]. Therefore, the question arises how new visualisation methods are perceived in rather conservative areas or cities that would be classified as traditional.

Based on the collected feedback, an AR application is useful for assisting in selection processes of alternative solutions, for example in regards to a popular vote. As the construction work on the project used in this study already started, it would be interesting to see what feedback participants give when providing such an AR application before an actual popular vote. Moreover, future research is needed to investigate how participants would react after construction work is finished. Would participants be satisfied with the decision they made for the popular vote? Would they change their decision if they could?

Previous knowledge was not accounted for the LOD group allocation in this study. It remains to be investigated whether the performance of participants viewing a project in LOD 3 actually perform better because of the more detailed version or if their previous knowledge influences their performance.

Future research could investigate what impact photorealistic visualisations in an AR application have on participants' decision-making and, whether, they would perform better in estimation tasks than with a visualisation in LOD 3.

Finally, the prototype AR application was only developed for iOS devices. Therefore, an application should be made available which is platform independent in the future. Based on the discussion in this research, additional functionalities should be implemented in an AR application to guarantee a better user experience. For example, unintentional touches of the mobile device's screen should not move a virtual scene so that the calibration does not have to be performed again. Additionally, the prototype application did not occlude virtual objects by the surrounding physical objects. Implementing occlusion is especially important when viewing a virtual object from further away and, therefore, having other objects in the field of vision, which occlude parts of the virtual object.

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8 APPENDIX

8.1 CONSENT FORM

Studieninformation und Einverständniserklärung

Dieses Dokument dient als Einverständniserklärung für die Studie. Bitte lesen Sie diese Informationen sorgfältig durch.

Teilnahmenummer*

Bitte geben Sie die Ihnen genannte Teilnahmenummer hier an.

Datum/ Uhrzeit*

Datum und Zeit des Ausfüllen der Einwilligungserklärung

2020-09-29 14:23

Zweck der Studie

Zweck der Studie ist, herauszufinden inwiefern eine *Augmented Reality* (Erweiterte Realität) Applikation geeignet ist, um ein Bauvorhaben für die Bevölkerung zu visualisieren. Weiter wollen wir Informationen zur Eignung von verschiedenen Abstraktionsstufen der Visualisierung gewinnen.

Gerne laden wir Sie ein, an dieser Studie teilzunehmen, in der die Visualisierungen von Bauvorhaben in *Augmented Reality* Applikationen untersucht werden.

Diese Studie wird im Rahmen der Masterarbeit *"Open Communication in Augmented Reality Experiences in Urban Planning"* von Ursina Boos durchgeführt. Die Masterarbeit wird von Dr. Tumasch Reichenbacher (Geographisches Institut Universität Zürich), Christian Sailer (ETH Zürich), Dr. Peter Kiefer (ETH Zürich), Matthias Schenker (Esri Schweiz) und Christian Hürzeler (Stadt Zürich) betreut.

Ablauf der Studie

Um an der Studie teilzunehmen zu können, müssen Sie das Schweizer Stimmrecht besitzen. Ausserdem müssen Sie Erfahrungen mit dem iOS Betriebssystem (z.B. Apple's iPhone) haben.

Während der Studie werden Sie eine Visualisierung eines geplanten Gebäudes in einer *Augmented Reality* Applikation (AR App) betrachten. Mit Hilfe dieser Applikation sollen Sie eine kurze Aufgabe lösen. Anschliessend werden Sie gebeten einen Onlinefragebogen, mit Fragen zur Applikation und der darin dargestellten Visualisierung, ausfüllen. Im Fragebogen sollen Sie ausserdem Fragen zu Ihrer Person beantworten. Die Studie dauert ungefähr 45 Minuten.

Vertraulichkeit der Daten

Die während der Studie erfassten Daten werden vertraulich behandelt und nur mit Ihrem ausdrücklichen Einverständnis an Dritte weitergegeben.

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

Bekanntgabe der Ergebnisse

Wenn Sie an den Ergebnissen der Studie interessiert sind, können Sie uns Ihre E-Mailadresse hinterlassen. Eine Kopie der zukünftigen Veröffentlichung kann Ihnen so digital zugestellt werden.

Covid-19

Die Teilnahme an dieser Studie besteht auf eigenes Risiko. Während der Studie sind Sie verpflichtet eine Maske zu tragen, die von uns gestellt wird. Wir stellen auf Wunsch Latexhandschuhe zur Verfügung. Während der Studie wird ein Sicherheitsabstand von 2m gewährleistet.

Falls Sie sich momentan nicht gesund fühlen oder eines der nachfolgenden Symptome aufweisen, dürfen Sie nicht an der Studie teilnehmen: Husten, Fieber, Atembeschwerden, Störungen des Geruchs- oder Geschmackssinns.

Die Studienleitung hat das Recht, die Studie jederzeit ohne Begründung abzubrechen, sollten die Hygienemassnahmen nicht eingehalten werden.

Entscheiden Sie sich an der Studie teilzunehmen, steht Ihnen jederzeit frei, die Teilnahme ohne Begründung abzubrechen.

Einwilligung

Ihre Entscheidung, an der Studie teilzunehmen, beeinträchtigt Ihre zukünftigen Beziehungen mit den beteiligten Parteien (Universität Zürich, ETH Zürich, Esri Schweiz und Stadt Zürich) nicht.

Sollten Fragen zu einem späteren Zeitpunkt aufkommen, wird Ursina Boos (ursinachristina.boos@uzh.ch) oder Dr. Tumasch Reichenbacher (tumasch.reichenbacher@geo.uzh.ch) diese gerne beantworten.

Schäden

Dies ist eine Studie mit geringem Risiko, und wir sind nicht gegen Schäden versichert, die Ihnen während des Experiments entstehen können. Wenn Sie jedoch der Studie jegliche Form von körperlicher oder geistiger Beeinträchtigung zuschreiben möchten, kontaktieren Sie uns bitte umgehend. Wir werden Ihnen so gut wie möglich helfen und Ihnen bei Bedarf eine klinische Beratung anbieten.

Einverständniserklärung*

Mit Ihrer Unterschrift bestätigen Sie, dass Sie die oben stehenden Informationen sorgfältig durchgelesen haben. Sie bestätigen damit Ihr Einverständnis zu den Studien- und Hygienebedingungen und dass Sie momentan nicht wissentlich krank sind.

Bitte unterzeichnen Sie oberhalb der Linie

Submit

8.2 PRE-QUESTIONNAIRE

AR Manegg Vorumfrage

Teilnahmenummer*
Bitte geben Sie die Ihnen genannte Teilnahmenummer hier an.

[123]

Studienbedingung*
Geben Sie die Ihnen genannte Studienbedingung (1, 2, oder 3) hier an.

[ ]

Wie würden Sie bei einer Volksabstimmung über das soeben vorgestellte Projekt "Schulhaus Allmend" abstimmen?

- ○ Ja
- ○ Nein
- ○ Keine Antwort

Teil 1: Personenangaben

In diesem Teil der Vorumfrage bitten wir Sie, uns einige Angaben zu Ihrer Person zu machen.

Geschlecht

- ○ W
- ○ M
- ○ X

Alter

[123]

Sehvermögen

- ☐ Brille/ Kontaktlinsen
- ☐ Eingeschränktes Sehvermögen
- ☐ Farbenblindheit

1.1 Ausbildung

Höchst abgeschlossene Ausbildung

- ○ Obligatorische Schulzeit
- ○ Berufslehre
- ○ Matura/ BMS/ Seminar
- ○ FH/ HF
- ○ Bachelor
- ○ Master
- ○ PhD/ Dr.
- ○ anderes

Beruf

____

Semester (Studenten)

123

Fachrichtung des Studiums (Studenten)

[ ]

1.2 Wohnsituation

In welchem Stadtkreis (Zürich) wohnen Sie?

[123]

In welchem Quartier (Zürich) wohnen Sie?

[ ]

Seit wie vielen Jahren leben Sie in Zürich?

[123]

Sind Sie Wochenaufenthalter in Zürich?

- ○ Ja
- ○ Nein

Wo sind Sie aufgewachsen?

- ○ Stadt Zürich
- ○ andere Stadt
- ○ Agglomeration
- ○ Land

Teil 2: Erfahrungen

In diesem Teil möchten wir gerne Erfahren was für Erfahrungen Sie bereits im Bereich Augmented Reality (AR) haben. Weiter möchten wir Sie bitten uns weitere Angaben zu Ihren Kenntnissen zur Umgebung in der das Experiment stattfindet zu geben.

Ich kenne mich in der Manegg gut aus.

○ trifft nicht zu ○ trifft eher nicht zu ○ teils/ teils ○ trifft eher zu ○ trifft zu

Ich bin positiv gegenüber AR-Technologie eingestellt.

AR = Augmented Reality

Beispiele AR Anwendungen: Pokémon Go, IKEA Place

○ trifft nicht zu ○ trifft eher nicht zu ○ teils/ teils ○ trifft eher zu ○ trifft zu

Haben Sie bereits Erfahrungen mit AR-Applikationen gemacht?

◉ Ja

○ Nein

Wie oft brauchen Sie AR-Applikationen?

○ nie ○ 1 - 2 Mal pro Jahr ○ 1 - 2 Mal pro Monat ○ 1 - 2 Mal pro Woche ○ täglich

Haben Sie bereits Erfahrungen mit VR-Applikationen gemacht?

VR = Virtual Reality

Beispiele VR Anwendungen: VR Games (z.B. Beat Saber, Star Trek: Bridge Crew), Google Cardboard, YouTube VR

◉ Ja

○ Nein

Wie oft brauchen Sie VR-Applikationen?

○ nie ○ 1 - 2 Mal pro Jahr ○ 1 - 2 Mal pro Monat ○ 1 - 2 Mal pro Woche ○ täglich

Wie viel Erfahrung mit Computergames haben Sie?

1 * = keine Erfahrung
2 * = jährlich
3 * = monatlich
4 * = wöchentlich
5 * = mehrmals in der Woche
6 * = täglicher Gebrauch

☆ ☆ ☆ ☆ ☆ ☆

Wie viel Erfahrung haben Sie mit 3D-Visualisierungen?

1 * = keine Erfahrung
2 * = jährlich
3 * = monatlich
4 * = wöchentlich
5 * = mehrmals in der Woche
6 * = täglicher Gebrauch

☆ ☆ ☆ ☆ ☆ ☆

Haben Sie Vorwissen in Geographischen Informationssystemen (GIS)?

1 * = kein Vorwissen
2 * = fast kein Vorwissen
3 * = wenig Vorwissen
4 * = durchschnittliches Vorwissen
5 * = viel Vorwissen
6 * = professionell

☆ ☆ ☆ ☆ ☆ ☆

Haben Sie Vorwissen in der Architektur?

1 * = kein Vorwissen
2 * = fast kein Vorwissen
3 * = wenig Vorwissen
4 * = durchschnittliches Vorwissen
5 * = viel Vorwissen
6 * = professionell

☆ ☆ ☆ ☆ ☆ ☆

Haben Sie Vorwissen in der Bau-/ Städteplanung?

1 * = kein Vorwissen
2 * = fast kein Vorwissen
3 * = wenig Vorwissen
4 * = durchschnittliches Vorwissen
5 * = viel Vorwissen
6 * = professionell

☆ ☆ ☆ ☆ ☆ ☆

Haben Sie die ausgesteckten Metallstangen für geplante Bauten schon einmal gesehen?

Für Bauvorhaben werden in der Schweiz auf dem Gelände, wo das Gebäude gebaut werden soll, Metallstangen ausgesteckt.

- Ja
- Nein

Haben Sie sich mit dem Projekt "Schulhaus Allmend" in der Manegg bereits beschäftigt?

1* = ich kenne das Projekt nicht
2 * = ich habe vom Projekt gehört
3 * = ich habe mich wenig mit dem Projekt auseinandergesetzt
4 * = ich habe mich mit dem Projekt auseinandergesetzt
5 * = ich habe mich viel mit dem Projekt auseinandergesetzt

☆ ☆ ☆ ☆ ☆

Wie oft nehmen Sie an Abstimmungen auf Bundes-, Kantonal- oder Gemeindeebene teil?

Pro Jahr gibt es vier Abstimmungen.

- Nie
- 1x pro Jahr
- 2x pro Jahr
- 3x pro Jahr
- 4x pro Jahr

Submit

8.3 POST-QUESTIONNAIRE

AR Manegg Meinungserfassung

Teilnahmenummer*

Bitte geben Sie die Ihnen genannte Teilnahmenummer hier an.

Studienbedingung*

Geben Sie die Ihnen genannte Studienbedingung (1, 2, oder 3) hier an.

Studienevaluation

Bitte beurteilen Sie die nachfolgenden Aussagen.

1.1 Visualisierung

Die Visualisierung in der AR Applikation ist einfach zu interpretieren.

trifft nicht zu | trifft eher nicht zu | teils/teils | trifft eher zu | trifft zu

Die einzelnen Elemente des Gebäudes sind in der AR Applikation zu erkennen.

trifft nicht zu (nicht erkennbar) | trifft eher nicht zu | teils/teils | trifft eher zu | trifft zu

Die Visualisierung des Gebäudes in der AR Applikation empfinde ich als realistisch.

trifft nicht zu | trifft eher nicht zu | teils/teils | trifft eher zu | trifft zu

Gibt es etwas das an der Visualisierung des Bauprojektes fehlt?

1000

1.2 Genauigkeit der Visualisierung

Ich kann mir gut vorstellen, wie das Bauprojekt in der Zukunft aussehen wird.

trifft nicht zu	trifft eher nicht zu	teils/teils	trifft eher zu	trifft zu
○	○	○	○	○

Die Genauigkeit der Visualisierung des Bauprojekts (Länge/ Höhe) in der AR Applikation ist hoch.

trifft nicht zu	trifft eher nicht zu	teils/teils	trifft eher zu	trifft zu
○	○	○	○	○

Die reale Grösse des zukünftigen Bauprojekts ist in der AR Applikation zu erkennen.

trifft nicht zu	trifft eher nicht zu	teils/teils	trifft eher zu	trifft zu
○	○	○	○	○

Die AR Applikation hilft mir, zu unterscheiden, welche Objekte vom Gebäude verdeckt beziehungsweise nicht verdeckt werden.

trifft nicht zu	trifft eher nicht zu	teils/ teils	trifft eher zu	trifft zu
○	○	○	○	○

Kommentare zur Genauigkeit der Visualisierung

1000

1.3 Gegenüberstellung AR Applikation und konventionelle Visualisierung*

* auf dem zukünftigen Baugebiet ausgesteckte Metallstangen

Wie schätzen Sie das Potential der ausgesteckten Metallstangen ein?

ungeeignet	eher weniger geeignet	neutral	eher geeignet	sehr geeignet
○	○	○	○	○

Die reale Grösse des zukünftigen Bauprojekts ist in der AR Applikation besser erkennbar als mit ausgesteckten Metallstangen.

trifft nicht zu	trifft eher nicht zu	teils/teils	trifft eher zu	trifft zu
○	○	○	○	○

Die Visualisierung des Bauprojekts in einer AR Applikation ist realistischer als die Visualisierung des Projekts mit ausgesteckten Metallstangen.

trifft nicht zu | trifft eher nicht zu | teils/teils | trifft eher zu | trifft zu

Die Visualisierung des Projekts in einer AR Applikation is geeigneter als die Visualisierung des Projekts anhand von ausgesteckten Metallstangen.

trifft nicht zu | trifft eher nicht zu | teils/teils | trifft eher zu | trifft zu

Kommentare zur Gegenüberstellung AR Applikation und konventionelle Visualisierung*

* auf dem zukünftigen Baugebiet ausgesteckte Metallstangen

1000

1.4 Partizipation

Die Verfügbarkeit einer AR Applikation die ein geplantes Bauprojekt darstellt führt dazu, dass ich mich besser in den Planungsprozess einbezogen fühle.

trifft nicht zu | trifft eher nicht zu | teils/ teils | trifft eher zu | trifft zu

Das Modell regt zur Mitsprache im Realisierungsprozess an.

trifft nicht zu | trifft eher nicht zu | teils/teils | trifft eher zu | trifft zu

Die AR Applikation hilft mir eine sachliche Bewertung zum Projekt zu bilden.

trifft nicht zu | trifft eher nicht zu | teils/ teils | trifft eher zu | trifft zu

Kommentare zur Partizipation

1000

1.5 Persönliche Meinung zum Projekt

Die AR Applikation kann mir bei der Auswahl von Lösungsalternativen (z.B. bei einer Abstimmung) helfen.

trifft nicht zu	trifft eher nicht zu	teils/ teils	trifft eher zu	trifft zu
○	○	○	○	○

Hat die AR Applikation Ihre Meinung zum Projekt geändert bzw. würden Sie anders abstimmen als am Anfang angegeben?

- ○ Ja
- ○ Nein
- ○ Keine Antwort

Sonstige Kommentare

1000

Submit

8.4 TASK QUESTIONNAIRE

Manegg – Aufgabe

Bitte geben Sie hier die Antworten zur gestellten Aufgabe an.

Teilnahmenummer*

Bitte geben Sie die Ihnen genannte Teilnahmenummer hier an.

Studienbedingung*

Geben Sie die Ihnen genannte Studienbedingung (1, 2, oder 3) hier an.

Task 1

a) Wie viele Gebäude werden hier gebaut?

Schätzen Sie die Anzahl Gebäude anhand der ausgesteckten Metallstangen ab.

[Ursina] verstrichene Zeit 1a

b) Wie hoch (in Meter) sind die Metallstangen?

Schätzen Sie die Höhe (m) der Metallstangen.

[Ursina] verstrichene Zeit 1b

Task 2

a) Wie lange (in Meter) ist der mittlere orange Block?
Schätzen Sie die Länge (m) des Blockes.

[123]

[Ursina] verstrichene Zeit 2a

[123]

b) Wie hoch (in Meter) ist das Gebäude hinter dem Schulhaus Allmend?
Schätzen Sie die Höhe (m) des Gebäudes.

[123]

[Ursina] verstrichene Zeit 2b

[123]

Task 3

a) Wie hoch (in Meter) wird das geplante Gebäude sein?
Schätzen Sie die Höhe (m) des Gebäudes.

[123]

[Ursina] verstrichene Zeit 3a

[123]

b) Wie breit (in Meter) wird das geplante Gebäude sein?
Schätzen Sie die Breite (m) des Gebäudes.

[123]

[Ursina] verstrichene Zeit 3b

[123]

c) Wie lang (in Meter) wird das geplante Gebäude sein?

Schätzen Sie die Länge (m) des Gebäudes.

123

[Ursina] verstrichene Zeit 3c

123

d) Wie weit (in Meter) ist das bereits bestehende Gebäude (rechts) vom virtuellen Gebäude entfernt?

Schätzen Sie die Entfernung (m) zwischen den beiden Gebäuden.

123

Task 4

Welche Objekte werden vom geplanten Gebäude verdeckt?

Bitte laden Sie hier das Bild mit den umkreisten (= verdeckten) Objekten hoch.

Tryck här för att välja en bild-fil. (<10MB)

[Ursina] verstrichene Zeit 4

123

Task 5

Wird das ausgesteckte Gebäude von diesem Sichtpunkt aus vom Schulhaus Allmend verdeckt?

- Ja
- Nein

[Ursina] Verstichene Zeit 5

123

Submit

8.5 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.

Ursina Boos, 30th September 2020