Location-based Augmented Reality Visualization of 3D Models using a Mobile Application - izanagiXR

Master Thesis

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«Chew, if only you could see what I've seen with your eyes».
- Roy Batty, Blade Runner (1982)

Executive Summary

Introduction

The increasing use of AR in practical applications such as education, design, manufacturing, and construction shows enormous promise for upgrading existing technology and improving quality of life. Meanwhile, the construction industry is well known for falling behind in the implementation of IT even though the digitalization is already transforming the industry across the entire lifecycle. A peculiarity in Switzerland is that in most cantons, projects still must be marked with physical metal poles called construction spans.

Methodology

The aim of this research is to investigate an effective method for visualizing 3D models using location-based Augmented Reality. This paper seeks to identify the necessary steps for developing an application to accurately visualize 3D buildings using location-based AR for replacing construction spans and to find out what the benefits and challenges are. For this purpose, an AR artifact is being developed and five interviews with industry experts are being conducted to gain a better understanding of the current practice.

Findings

The costs of erecting and maintaining such construction spans can amount to 0.1% or more of each construction project depending on its height and the complexity of the terrain. AR represents an enabling technology for customer engagement. It can be reasoned that by externalizing the visualization of construction projects, AR can reduce the mental effort customers need to participate in a productive discourse. AR technology has been improving dramatically and together with hybrid localization methods it is able to display information accurately and reliably in the physical world.

Recommendations

In light of the findings of this research, developers, and public bodies such as municipalities alike should evaluate the use of AR applications for replacing construction spans and digitize the construction span industry to save significant investment amounts and opportunity losses. This paper recommends the above-mentioned stakeholders to explore the potential of AR applications additionally to using construction spans to gain important experience and to get an idea how their industry could look like once construction spans are not legally required anymore and AR hardware has overcome current limitations.

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List of abbreviations

AEC/FM	**-**	Architecture, engineering, construction, and facility management
AR	-	Augmented Reality
BVU	-	Department of construction, transport, and environment
CAD	-	Computer-Aided Design and Drafting
CAGR	-	Compound Annual Growth Rate
CDO	-	Chief Digital Officer
CNN	-	Convolutional Neural Network
DSR	-	Design Science Research
EFV	-	Federal Finance Administration
FoV	-	Field of View
GIS	-	Geographic Information System
GT	-	Grounded Theory
HMD	-	Head-mounted Display
MR	-	Mixed Reality
ORB	-	Oriented FAST and rotated BRIEF
PBG	-	Planning and Building Law
PCI	-	Problem-centered interview
SDK	-	Software Development Kit
SFSO	-	Swiss Federal Statistics Office
SLAM	-	Simultaneous localization and mapping
UX	-	User Experience
VPS	-	Visual Positioning Service
VR	-	Virtual Reality
XR	-	Mixed Reality / Extended Reality

1 Introduction

1.1 Background

The fast development of extended reality (XR) technologies such as augmented reality (AR) and virtual reality (VR) has sparked widespread interest in recent years (Shoker, 2020). More and more internationally renowned research institutions, universities and enterprises have been investing in XR research, resulting in the publication of numerous scientific papers and research findings (Yunqiang Chen et al., 2019, p. 1). Significant advances have been made on AR components such as in localization and hardware (Jiao, Zhang, Li, Wang, & Yang, 2013, p. 37). From a lab experiment to military and eventually industrial uses, augmented reality has come a long way. With specialized and urgent needs and budget constraints, military, industrial, and scientific customers accepted the constraints of early AR systems (Peddie, 2017, p. 1). However, this emerging technology for projecting data onto the physical world has recently begun to impact the daily lives of the public (Chi, Kang, & Wang, 2013, p. 116).

The increasing use of AR in practical applications such as education, design, manufacturing, construction, and entertainment shows enormous promise for upgrading existing technology and improving quality of life (Chi et al., 2013, p. 116). Since 2019 Augmented Reality has officially left Gartner's Hype Cycle (Panetta, 2021) and has never returned since, while experts in 2011 predicted that AR could take another 5-10 years to become a mature technology (Herdina, 2020).

Meanwhile, the construction industry is well known for falling behind in the implementation of information technologies even though the digitalization is already transforming the industry across the entire lifecycle, from design to operation and maintenance (Hautala, Järvenpää, & Pulkkinen, 2017, p. 340). Organizations who can take advantage of the opportunities presented by digital advancements stand to earn significant benefits (Hautala et al., 2017, p. 340). The state of the art varies by geographical region and in several European countries: the United Kingdom, the Netherlands, Denmark, Norway, and Finland, for example, have already implemented digital planning and building guidelines (Hautala et al., 2017, p. 340) while Switzerland is still lagging behind (Bürgi, 2020).

Before this evolution of the AR technology, construction CAD software has evolved from simple 2D drawing applications to complicated 3D solid modelling systems that enable structural analysis, project management information systems, collaborative environments, and work scheduling throughout the last two decades (Lipman, 2002, p. 1). Mainframes have given way to desktop computers and laptops (Lipman, 2002, p. 1) and eventually smartphones as the hardware on which such applications operate. Computer memory and storage have grown from megabytes to gigabytes. Client-server communication has progressed from dial-up modems to always-on broadband and wireless networks (Lipman, 2002, p. 1). Previously exclusive to the engineer's office, software programs are now available mobile directly on the construction site (Lipman, 2002, p. 1). They provide access to project information saved locally on the mobile device or obtained via a wireless Internet connection from a server (Lipman, 2002, p. 1).

Now, with augmented using a mobile device, a person may merge a 3D item into a conventional viewing position while retaining all of the benefits of object movement and individual mobility in real-world surroundings (Xiangyu Wang, Truijens, Hou, Wang, & Zhou, 2014, p. 96). AR is expected to become the primary medium for delivering 3D models to building sites (Xiangyu Wang et al., 2014, p. 96). Recent advancements in computer interface design and hardware power have spawned a large amount of notable AR research prototypes or test platforms in the construction industry (Xiangyu Wang et al., 2014, p. 96). AR can transform how site managers, building workers, residents, and others interact with and obtain information from the 3d model as a class of easy-access interfaces (Xiangyu Wang et al., 2014, p. 97). Because information may be made easily available in real-time and in context, AR can be utilized to expedite operations, such as information retrieval, more efficiently and effectively (Lei Hou & Wang, 2013, p. 40ff.). By integrating the essential information into activities and therefore reducing the time and energy associated with recurrent switching, AR should minimize the frequency of switching between information resources (paper drawings or computers) and work piece tasks (Xiaodu Wang, Giri, & Almer, 2013, p. 37ff.).

1.2 Problem statement

In June of 2020 the project "eBaugesucheZH-Volldigital" has started ("Elektronische Baugesuche," n.d.). Since then, a building application can be submitted electronically in 32 Zurich municipalities ("Elektronische Baugesuche," n.d.). The integration of several municipalities is being planned and other cantons such as Schwyz, Aargau and Bern are also in the process of setting up a platform for fully electronic building applications (Bürgi, 2020). With a total of 162 municipalities in the canton of Zurich alone and 2'215 municipalities in Switzerland, there is still a long way to go (*Statistisches Jahrbuch des Kantons Zürich 2020*, 2020, p. 10).

A peculiarity in Switzerland, however, is that in most municipalities and cantons, building applications legally still have to be staked out with physical metal poles called construction spans (Bürgi, 2020). Their purpose is to draw attention to the fact that a construction project is open to the public and that the plans can be inspected by interested parties (Walker Späh, 2010, p. 5). This should make it clear to all those affected on site whether and to what extent the new construction project will affect the surrounding area. Although in most cases it is sufficient to express the building cube with its horizontal and vertical extension in a simplified way (Walker Späh, 2010, p. 6), the erection of metal poles leads to a disfigurement of the landscape. Furthermore, a building structure must be erected prior to the submission of the building application and must generally remain in place until the building permit and any appeal proceedings have been legally resolved (Bösch, 1993, p. 481ff.). During this period, the owner must bear the cost of delivery and installation, as well as the cost of rent for the period of standing of the construction spans (Arcangioli, 2017). The costs of erecting and maintaining such construction spans can cost each commissioner of a construction project roughly 0.1% of the total construction project's costs and even much more for high or complex construction projects (Martinu, 2008). Now, in the case of augmented reality, information is immediately integrated into a person's real-world view allowing for more efficient retrieval and visualization of data (Xiangyu Wang et al., 2014, p. 97). Technically, augmented reality may place digital information in the physical setting of a working area, in this case inside the predetermined construction area, in real time (Xiangyu Wang et al., 2014, p. 97). AR therefore has the potential to replace construction spans while offering interested parties the opportunity to visualize the construction project easily and accurately.

1.3 Objectives

The aim of this research is to investigate an effective and accurate method for visualizing 3D models using location-based augmented reality. This paper seeks to identify the necessary steps for building an application to visualize 3D buildings using location-based AR for replacing construction spans and to find out what the benefits and challenges are. In this paper, a mobile android device is being used as the platform to enable AR.

Furthermore, this paper aims to bring into knowledge the current state of the architecture, engineering, construction, and facility management (AEC/FM) industries regarding their degree of digitalization and especially regarding their use of Augmented Reality (AR) in projects or their everyday business. For this, a literature search as well as five interviews with experts in the field are being conducted over the course of this research.

Lastly, a projection of the cost of a construction span measured against the total investment for a construction project is being put into context and finally recommendations are presented to the reader.

1.4 Research question

This thesis investigates how to easily create an application that allows users to visualize 3D models using location-based augmented reality. The aim is to find out what the benefits and challenges are and what requirements should be implemented to make this solution useful. Furthermore, this paper aims to find out for which stakeholders this application would be the most useful.

RQ1: What are the benefits and challenges when utilizing an application to visualize 3D building models using AR for replacing construction spans and which steps are necessary?

rq1.1: Which stakeholders will benefit from this app?

rq1.2: What are the potential cost savings when using this app?

rq1.3: Which technical components are necessary for the realization of this app?

rq1.4: What conditions are attached to the usability of the app?

1.5 Relevance of the work

Enabling a mobile app-based alternative to expensive construction spans which obstruct the land- and cityscape in Swiss localities, could offer the commissioners of construction projects the chance to potentially save a substantial amount of money each year. In the case of the public sector these finances could be spent on education and research, welfare, or other purposes. For private investors these potential cost savings could be reinvested in constructing more sustainable and often times more expensive buildings which however outperform conventional non-sustainable buildings in numerous performance areas (Dwaikat & Ali, 2016, p. 1). According to Dwaikat and Ali (2016, p. 1ff.) the cost premium of more sustainable buildings is oftentimes the biggest hurdle to a widespread adoption of sustainable building. Construction spans not only cost a significant amount of money, which can be invested elsewhere and are responsible for the disfigurement of the landscape but also accidents with construction spans occur repeatedly. These accidents most frequently occur when construction spans overturn because of storms ("Luzern LU - Strassensperrungen durch Orkan „Petra“," 2020). These construction spans could potentially hit buildings or people.

The usage of AR to visualize construction projects instead of using construction spans could lower the price and risk for projects and therefore lower the above-mentioned hurdles. However, these aspects of sustainable building or safety are not further explored in this paper. This research focuses more on their costs and the development of an artifact.

1.6 Delimitation

This paper will not discuss the whole building approval process but only the step where construction spans are being erected and taken down again. Also, when talking about 3D models in combination with the construction industry, building information models (BIM) models are frequently mentioned. This paper will not discuss BIM models or their visualization with the help of AR since BIM itself is a broad topic.

A clear focus lies on the current state of digitalization and use of AR in the Swiss construction industry. Also, the topic of construction spans is very much Switzerland specific and therefore only a brief overview of how different countries visualize construction projects is provided. For the same reason, the calculation of the cost of a construction span against the total investment for a construction project is only considered for Switzerland.

1.7 Structure of the work

After the introduction, the theoretical framework follows, which starts with the research design. The research design gives an overview of which research methods are utilized to get which insights and how the gathered knowledge is being analyzed. Then the state of the art follows, which describes the definition of the different XR technologies. Also, it is stated in this part how the visualization of building or extension projects is managed in Switzerland and other countries around the world. After that it will be analyzed what use cases there are for AR in the construction sector. Lastly, it is analyzed how 3D models could be visualized with AR and what types of tracking can be used for it.

Following the theoretical framework, the methodology will be defined. The different steps in conducting the expert interviews as well as developing and evaluating the artifact will be explained in detail. Furthermore, a projection of the cost of a construction span measured against the total investment for a construction project is put into context and finally recommendations are presented to the reader. Before composing the conclusion, all insights and findings are being analyzed and evaluated in the results and discussion parts and an extrapolation in the form of a model calculation is to be created based on the information found during literature research and provided by the experts as well as the Swiss Federal Statistics Office (SFSO).

2 Theoretical framework

2.1 Research Design

This paper consists of three parts. The development of the artifact, the conduct of the expert interviews as well as calculation of the cost of construction spans. The research follows practice-oriented research and fits into the methodology of design science. Specifically the research conducted in this paper follows the design science research (DSR) cycle introduced by Hevner (2007) as seen in figure 1.

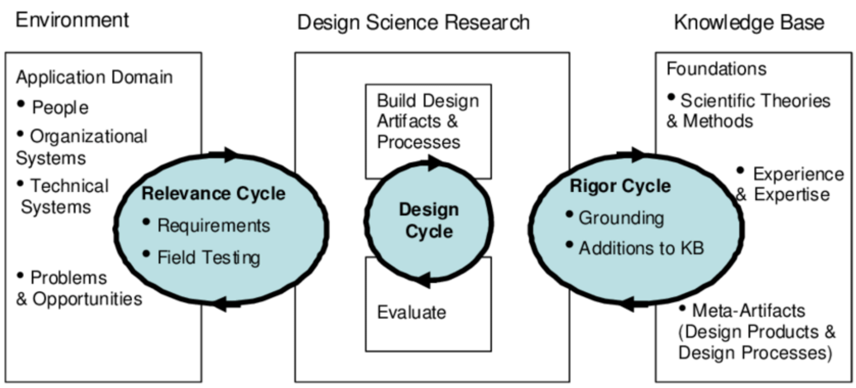

Figure 1: Hevner's Design Science Research Cycles (Hevner, 2007, p. 88)

This paper follows a qualitative methods research approach. Existing knowledge is investigated as well as new knowledge is generated through interviews and the creation of an artifact. Thus, deductive as well as inductive reasoning is used in this research project. In the DSR, business informatics research develops IT artifacts for problem classes, evaluates them, and develops them further. These are often so-called instantiations, usually not completely executable systems, but prototypes or sections of complete systems (Robra-Bissantz & Strahringer, 2020). In view of the increasing degree of abstraction and maturity, Hevner and Gregor (2013, p. 341) refer to instantiations as level 1 artifacts and to constructs, models and methods as level 2 artifacts. In this research an artifact of level 2 is aimed at. The formulation of open research questions allows to follow a qualitative research approach. To provide an overview of the topic, desk research is conducted. This is done deductively by identifying requirements for the artifact from theory and checking them against the artifact later. This desk research falls into the rigor cycle of Hevner's DSR cycle. It comprises the knowledge and experiences that define the state-of-the-art (Hevner, 2007, p. 89ff.).

As part of the relevance cycle (Hevner, 2007, p. 89), five structured problem-centered expert interviews with open questions are being conducted to be able to gather additional requirements directly from domain experts as to how the artifact should look like or be improved. Subsequently, with this feedback a further development iteration of the artifact is being started. Four experts from the domains of construction spans, 3D models of buildings and visualization with AR can be identified through already existing relations. The fifth person must be an expert from the construction office of a bigger municipality in Switzerland. This person is searched for by contacting several big municipalities directly. The results of the interviews are interpreted by creating an encoding guide. For this, a transcript of the interviews is being written down after Mayring (2010). Therefore, this encoding guide follows an inductive approach. Text sections from the interviews are being imported into a table where the section is being encoded and allocated to a category of topics. A frequency analysis is being conducted to find out which are the most important topics and from these, additional requirements for the artifact can be extracted.

Another DSR cycle is the design cycle. One of the most distinguishing characteristics of design science research as a technique is that it is focused on solving specific issues to arrive at a satisfying solution for the scenario (Dresch, Lacerda, & Antunes Jr, 2015, p. 68). Despite the scientific approach, one core requirement of design science research remains to create results that are relevant for practice (Robra-Bissantz & Strahringer, 2020). The design of IT artifacts is therefore always based on requirements, needs or even problems of practice, in the interaction of people, organization, operational task and technology (Robra-Bissantz & Strahringer, 2020). The design cycle is a crucial part of this research project. In this research project, this cycle especially consists of the development part of this paper. According to Hevner: «This cycle of research activities iterates more rapidly between the construction of an artifact, its evaluation, and subsequent feedback to refine the design further» (Hevner, 2007, p. 90). Therefore, also the expert interviews are part of the design cycle as well. The development of the artifact in this paper is following the rapid prototyping for software projects with user interface principles from Tizkar and Tabatabaei (2009). After analyzing the proposed system, identifying initial requirements, object and actions as well as putting those objects and actions together a first prototype is put together with the help of which initial feedback can be generated. Lastly, in the results part a simple extrapolation in the form of a model calculation is to be created based on the information provided by the experts.

2.2 State of the art

2.2.1 Definition of XR technologies

In the beginning of this paper, it is required to specify numerous technologies since their names are mistakenly used interchangeably. The Metaverse, created by the merger of digitally augmented physical reality and physically persistent virtual space, is a combination of both of these things, while enabling users to experience it as one or the other (Peddie, 2017, p. 10). In his novel "Snow Crash," Neil Stephenson created the term Metaverse in 1992, describing how humans interact with each other and artificial agents in three-dimensional space as avatars (Peddie, 2017, p. 10). While the Metaverse as it is known today also spans across video games such as Minecraft and Roblox where Gamers create completely virtual worlds and where they interact with each other, there was Milgram's reality-virtuality continuum, which illustrates the whole spectrum of realities.

2.2.1.1 Mixed Reality and the reality–virtuality continuum

The whole continuum of realities is also just simply described as Mixed Reality (XR or MR). The word XR can also be understood as Extended Reality. In Mixed Reality (XR), as in Augmented Reality, virtual objects are transferred into the real world. Due to the many similarities between XR and AR, mixed reality is also referred to as enhanced augmented reality (Milgram, Takemura, Utsumi, & Kishino, 1994, p. 282). XR leverages the best features of VR and AR to create an even more immersive and interactive virtual world (Billinghurst & Kato, 1999, p. 2ff.). The graphic below shows that XR extends from the real world to the completely virtual world to create a virtual world that is almost indistinguishable from the real world (Milgram, Takemura, Utsumi, & Kishino, 1995, p. 283).

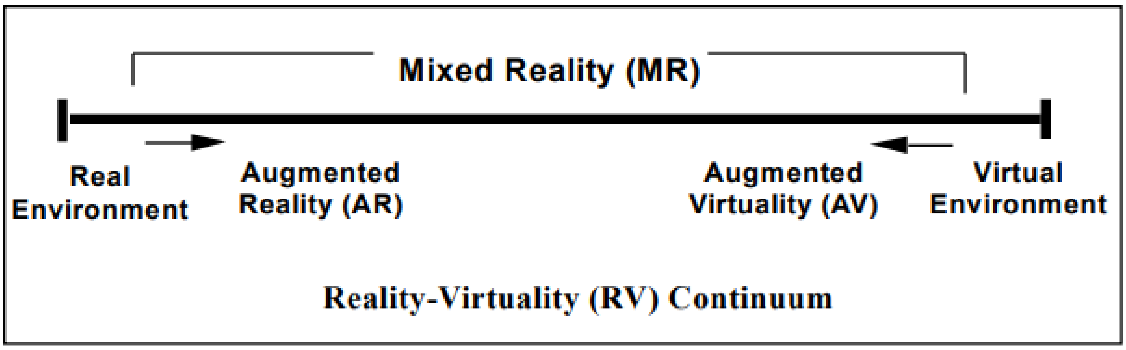

Figure 2: Simplified representation of a RV Continuum (Milgram et al., 1995, p. 283)

To use XR applications, users also require a headset like VR applications (Venkatesan et al., 2021). The goal in developing XR applications is to create a system where users can seamlessly switch between fully virtual environments and their own environment, which can be augmented (Gong, Fast-Berglund, & Johansson, 2021, p. 24796ff.). An example of an XR application is the repair of vehicles or machines. The mechanic can view the machine from different angles and find out where the damage is without being on site. For example, if the mechanic is standing behind the vehicle, it is not possible to call up information about a part that is in the front area of the car.

Because XR simulations offer more information and better display capabilities than AR, the technology is also known as the next generation of augmented reality (Herur-Raman et al., 2021). There are several advantages to employing XR in for example the medical education, and an increasing number of research supporting XR as an instructional tool are published each year (Herur-Raman et al., 2021). The use of XR to visualize information spatially has been shown to improve memory recall (Krokos, Plaisant, & Varshney, 2019). In comparison to other approaches, research has demonstrated that XR can improve knowledge of complicated 3D structures and boost educational engagement and satisfaction with the learning experience (Alfalah et al., 2019). The greater interaction provided by XR aids in active learning and increases student motivation by further deepening learner immersion and enjoyment with the virtual experience (Hudson, Matson-Barkat, Pallamin, & Jegou, 2019).

2.2.1.2 Virtual Reality

VR is described as: «The use of real-time digital computers and other special hardware and software to generate a simulation of an alternate world or environment that the users believe to be real or true» (Lu, Shpitalni, & Gadh, 1999, p. 475). The VR system is located on the right-hand side of the reality-virtuality continuum and is entirely made up of computer-generated material (Gong et al., 2021, p. 24797). Users are completely immersed in the virtual environment, with no way of seeing or interacting with the actual world (Gong et al., 2021, p. 24797). VR systems' complete immersion and high level of presence provide for a lot of freedom when it comes to playing what-if scenarios (Sin & Zaman, n.d.). VR systems are often set up in one of two ways. The first is a standalone headset, which may be used with a smart phone and cardboard or as part of an integrated system to give a virtual experience (Gong et al., 2021, p. 24797). The second method involves using a head-mounted display (HMD) that is connected to a separate computer (Gong et al., 2021, p. 24797). This arrangement has been increasingly popular in recent years (Gong et al., 2021, p. 24797) as it has gotten more inexpensive while still providing a decent VR experience. Figure 3 shows three distinct levels of reality. The first image shows a normal real world with real objects (cars). In image two, AR is depicted. Here, virtual objects are in the real world. Finally, the last image shows virtual reality, where the objects as well as the world they are in have been virtually simulated.

Figure 3: From reality to virtual reality (Mekni & Lemieux, 2014, p. 206)

The goal in the development of VR applications is to create a virtual world that is indistinguishable from the real world (Gutiérrez, Vexo, & Thalmann, 2008, p. 2). This allows excellent conditions for training, entertainment and design purposes (Gutiérrez et al., 2008, p. 2).

To describe VR, there is a physical and a psychological point of view (Mütterlein & Hess, 2017, p. 1ff.). In the physical view, we speak of immersion (Mütterlein & Hess, 2017, p. 2). The idea here is to completely isolate the user from the real world and lead them into the virtual world (Gutiérrez et al., 2008, p. 2). During complete immersion in the virtual world, users may even experience motion sickness, which in this context is called "cybersickness" (Stanney, Lawson, & McMaster-Oman, 2020). One of the most important concepts that help us understand the psychology of VR experience is the so-called Presence, which forms the psychological point of view (Gutiérrez et al., 2008, p. 3). Presence is a subjective concept, which is related to the psyche of the user (Price & Anderson, 2007, p. 2). Presence is the situation in which the user processes various stimuli such as images, sounds, and haptic feedback and thus understands the virtual world as a coherent and interactive world (Gutiérrez et al., 2008, p. 3). Thus, people may feel deeply involved in the VR simulation and therefore feel a variety of emotions (Gutiérrez et al., 2008, p. 4). A detailed virtual world has the potential to change our emotional state and can give us a feeling of sadness, happiness or fear (Gutiérrez et al., 2008, p. 4).

2.2.1.3 Augmented Reality

This form of virtual reality is closest to the real world. AR superimposes virtual objects onto the real environment (Azuma, 1997, p. 2). It is worth noting that this concept of AR is not limited to a specific display technology, such as a head-mounted display (HMD) (Yin et al., 2021, p. 1). In some AR applications, in addition to introducing virtual things, real objects must be removed from the seen environment. For example, an AR visualization of a building that once stood in a particular location could be used to remove the current structure (Azuma, 1997, p. 2). The task of removing real objects is referred to by some researchers as mediated or diminished reality, although it is considered to be a subset of AR (Azuma, 1997, p. 2). AR connects the real world with the virtual world and allows people to interact with virtual elements in real time (Nabiyouni, Scerbo, Bowman, & Höllerer, 2017). People's perception and interaction with the real world can be enhanced through augmented reality, as the virtual objects provide the user with information that they would not be able to pick up with their own senses (Nabiyouni et al., 2017).

Augmented reality blends the physical with the simulated or digital and superimposes images and information in the user’s field of view (Peddie, 2017). The advantage of Augmented Reality versus other technologies lies in the fact that it allows users to interact with their digital content in a more natural way thanks to the effective integration of the two realities (Xiangyu Wang & Dunston, 2006a, p. 314).

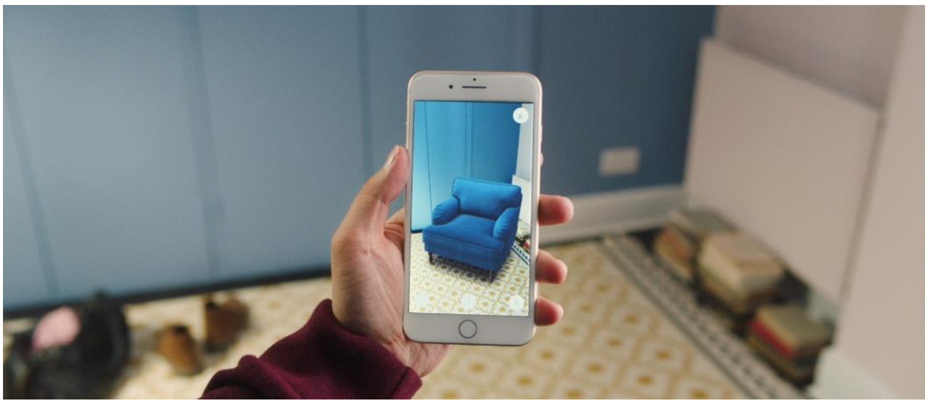

Figure 4: IKEA AR application (Rotzinger, 2019)

Figure 4 shows one way in which AR is used today. With the help of the IKEA AR app "Place", it is possible to project one's desired piece of furniture (virtual object) into one's room (real world) and thus obtain information. The most popular application areas for AR are in medicine, manufacturing, and education (Mekni & Lemieux, 2014).

2.2.2 Different tracking methods for visualizing content in AR

This section discusses types of tracking techniques. Tracking is described as acquiring the portion of an image that includes the object to be identified (Smeulders et al., 2014, p. 1442; Yilmaz, Javed, & Shah, 2006, p. 2). The tracking task is similar to extracting the camera pose given the 3D model of the targeted item (Paulo Lima et al., 2017, p. 101). It learns where the camera is and what direction it is pointing to build a direct link between the camera and the object (Paulo Lima et al., 2017, p. 101). This connection may be utilized to find out not just where an object is in the frame, but also its distance from the camera and orientation (Paulo Lima et al., 2017, p. 101). However, there are some considerations for using a tracking solution in an AR application (Marchand, Uchiyama, & Spindler, 2016, p. 2633). To allow the user to observe and engage with the augmentation naturally, the camera position must first be acquired in real time (Paulo Lima et al., 2017, p. 101). Furthermore, precision is necessary so that the augmented content does not go misplaced on the scene, supplying the user with inaccurate or unclear information (Paulo Lima et al., 2017, p. 101). There are sensor-based tracking and vision-based tracking techniques (Ashwini, Patil, & Savitha, 2020, p. 474). Sensor-based tracking can be further subdivided into different sensor types (Ashwini et al., 2020, p. 474). Marker-based and markerless tracking are two types of vision-based tracking. The tracking technique's use is determined by the AR application (Ashwini et al., 2020, p. 474).

This paper will solely focus on vision-based tracking since these methods are commonly used in application nowadays and for the creation of the artifact of this research paper. In the field of augmented reality, a lot of research is being conducted on vision-based tracking (Zhou, Duh, & Billinghurst, 2008, p. 195). Different computer vision algorithms are utilized in this form of tracking to calculate the viewpoint to the camera as well as interpret the real-world object (Bajura & Neumann, 1995). The tracking technique to be used is determined by the AR applications to be used. In the following the marker-based, markerless as well as the location-based tracking will be explained. The location-based tracking will be used in the mapper as well as in the visualizer scene of the artifact. The markerless tracking will be used in the planner scene. Firstly, the marker-based tracking method will be explained because together with the markerless tracking, it is the most used tracking method for AR since they are both rather simple and standard functions in numerous AR software such as the Unity AR Foundation ("AR Tracked Image Manager," n.d.), Vuforia Engine ("Image Targets," n.d.) or Zappar ("Image Tracking," n.d.).

2.2.2.1 Marker-based Augmented Reality

Tracking and registration were formerly done with marker-based tracking toolkits (e.g., ARToolkit) (Chi et al., 2013, p. 117). The marker that must be identified is stored in advance in the database in marker-based tracking. A picture or an image can be used as a marker. AR software and a camera are used to detect augmented reality markers as virtual object locations. These markers feature a recognition library that calculates the rotation and translation of the marker in relation to the device's camera in the actual world (Chi et al., 2013, p. 117). The system provided by Naimark & Foxlin (2002) enables for thousands of different codes to be used, allowing for continuous database tracking at a minimal cost. Most AR tracking systems necessitate the use of expensive hardware (Ashwini et al., 2020, p. 477). The camera is the only source of tracking for marker-based tracking, which is based on mobile phone technology (Maidi, Didier, Ababsa, & Mallem, 2010, p. 365). Marker-based tracking is a valid option for developers who want to keep an application as cost-effective and simple as feasible (Ashwini et al., 2020, p. 477). For markerless tracking it becomes difficult to distinguish between environments that are identical, have shiny surfaces, or have repeated patterns (Ashwini et al., 2020, p. 477).

However, when markers are added to the environment in such instances, tracking becomes considerably simpler and easier (Ashwini et al., 2020, p. 477). Furthermore, tracking in a dynamic environment is significantly more difficult because the locations of the elements change (Ashwini et al., 2020, p. 477). In this type of situation, a tracking system can avoid some of these issues by attaching markers, therefore a marker-based system is typically a superior alternative (Ashwini et al., 2020, p. 477). In such scenarios, a markerless tracking system will also lose track, hence only a marker-based tracking system can be employed (Ashwini et al., 2020, p. 477).

Figure 5: Video playing on top of QR code (Gherghina, Olteanu, & Tapus, 2013)

If an application requires further information, the marker can supply it which is something that isn't there in any other form of tracking (Gherghina et al., 2013). A marker-based system is ideal for applications where the focus is not on the tracking implementation but on a quick demonstration of the application concept (Ashwini et al., 2020, p. 477).

2.2.2.2 Markerless Augmented Reality

According to Paulo Lima et al. (2017) it is recommended to finish the tracking stages without having to place markers on the scene in several cases. Because they are less obtrusive and usually need little or no setup effort from the end user, markerless trackers are anticipated to broaden their applicability range (Paulo Lima et al., 2017, p. 101). Natural feature tracking approaches for AR require 3D object knowledge, often known as a model of the item (Paulo Lima et al., 2017, p. 103). This model can be encoded in a variety of ways, including computer-aided design (CAD), point clouds, and plane segments, depending on the method (Paulo Lima et al., 2017, p. 103). While a wide range of tracking systems are commercially available, most of them are designed to be utilized in well-defined environments where the variables that impact tracking can be easily controlled (Barandiaran, Paloc, & Graña, 2010, p. 129ff.). However, ideally the tracking method should work in an uncontrolled environment without modifying the 3D objects or the surroundings to be monitored.

Optical sensors have been extensively investigated for markerless tracking for many years (Lepetit & Fua, 2005). Natural characteristics retrieved from camera pictures, such as edges, corners, and texture patches, are used in optical markerless tracking (Barandiaran et al., 2010, p. 130). The utilization of natural characteristics avoids the need of artefacts such as QR codes or images, allowing the system to be more adaptable and function under less-than-ideal situations (Barandiaran et al., 2010, p. 130). Natural plane surfaces are typical structures in both indoor and outdoor settings, which are used in the Planner scene of the proposed artifact of this paper (Barandiaran et al., 2010, p. 130). Planes include the ground, building faces, and walls, so in the case of the artifact it must be specified that only the ground or other horizontal surfaces get tracked. Optical markerless tracking is based on image processing and uses a digital camera as the primary data input source (Barandiaran et al., 2010, p. 130). Figure 6 shows the interaction between the camera, the object, and the environment in markerless tracking.

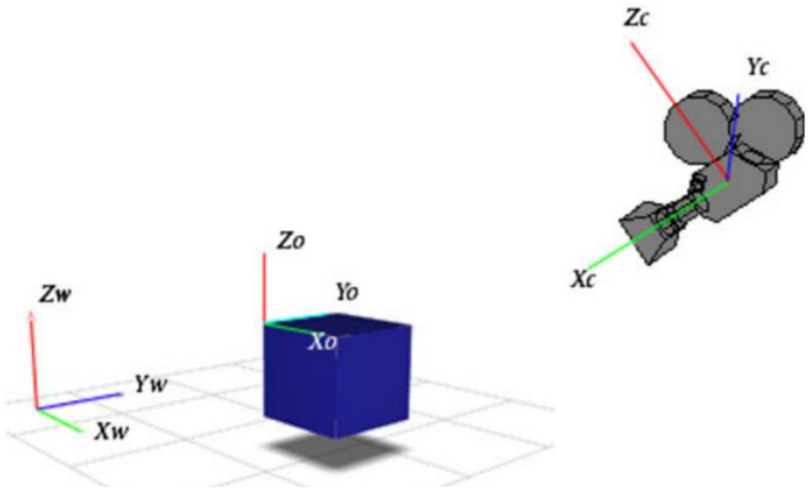

Figure 6: Camera, object and environment coordinate systems (Barandiaran et al., 2010, p. 130)

Images from the globe are captured by a camera (environment) (Barandiaran et al., 2010, p. 130). These photos are then sent to a computer workstation, where they are analyzed to obtain relevant information like camera pose transformation (Barandiaran et al., 2010, p. 130). The transformation, translation, and orientation between the objects or environment coordinate system and the camera coordinate system is referred to as camera pose (Barandiaran et al., 2010, p. 130). During the tracking process, this transformation should be approximated dynamically and as quickly as feasible to accurately integrate virtual items amongst actual ones (Barandiaran et al., 2010, p. 130). This calculation must be extremely precise in order for virtual things to look solidly attached to the actual environment (Barandiaran et al., 2010, p. 130).

2.2.2.3 Location-based Augmented Reality

Location-based AR is defined by Kyza & Georgiou as: «Those mobile technologies that take advantage of technological advancements like geospatial reference and the Global Positioning System (GPS) to enable the dynamic amplification of the here and now with digital information» (Kyza & Georgiou, 2019, p. 212). Location-based AR, unlike marker-based AR, does not require special markers to define the location of a virtual object (Kuprenko, 2021). It primarily relies on GPS, digital compass, accelerometer, and other comparable technologies to accurately determine the user's location (Kuprenko, 2021). Given that these modules are present on every modern phone, AR apps are a product that is accessible to everyone (Kuprenko, 2020). Location-based tracking is valuable because it can be used outdoors using GPS data or indoors using computer vision or visual simultaneous localization and therefore make it a valuable option when creating accurate outdoor and indoor navigation systems (Bostanci, Kanwal, Ehsan, & Clark, 2013, p. 93). These characteristics may enable users to learn by engaging with their surroundings (Kyza & Georgiou, 2019, p. 212). Such experiences, according to Santos (2016, p. 5), can encourage students and adapt to just-in-time learning demands.

AR technologies may be deployed indoors or outdoors as well as on stationary machines or mobile devices (Kyza & Georgiou, 2019). To register and monitor the user's position in the actual world, AR developers employ both marker-based and markerless approaches (Chi et al., 2013). The capacity of various AR technologies to be registered in three dimensions is demonstrated through marker-based and markerless augmentation techniques (Kyza & Georgiou, 2019). Two other conditions for AR applications next to the three-dimensional registration mentioned by Azuma (1997) are that the technology combines the real and virtual world and that it is interactive in real time. As mentioned before, marker-based tracking implies that the user searches for and scans the marker in order for reality to be augmented. Outdoor conditions, on the other hand, are often more difficult to monitor, and markerless systems provide the user more freedom in their movement while also providing information about their environment (Carmigniani et al., 2011; K.-H. Cheng & Tsai, 2013).

This study focuses on location-based augmented reality technologies for visualizing 3D models of buildings on mobile devices such as tablets and smartphones. The artifact of this paper utilizes a hybrid tracking method with GPS, and a visual positioning service (VPS). At runtime of the experience, the VPS allows the application to figure out where the AR user is in real space (latitude and longitude) by collecting pictures through the camera and checking them against the georeferenced point cloud created prior to the use. The point cloud can be created by capturing photographic data of the desired location and stitching them together into a so-called map. For this process, this paper utilized the VPS of Immersal. Immersal hosts public servers which take georeferenced RBG PNG files from the user as input and return them as a point cloud to the user. These point clouds are then saved to and made accessible through the user’s account. GPS is being utilized to display all the point clouds that lie within a predefined range of the user’s location for quicker access to the relevant locations.

2.2.3 AR in architecture, engineering, and construction

AR and XR are two visualization technologies that are frequently cited (Guo, Yu, & Skitmore, 2017, p. 138). Unlike VR, which isolates the display from the actual world and adheres to solely synthetic settings, AR and XR combine the real and virtual worlds (Haller, Billinghurst, & Thomas, 2007, p. 43). In AR and XR, computer-generated visual materials (e.g., texts, images, and 3D models) are superimposed on the real-world physical environment to enhance learners' view of the actual world using cameras or head-mounted displays (HMDs), such as Microsoft's HoloLens (Andujar, Mejias, & Marquez, 2011, p. 493). Whereas AR overlays virtual contents on real-world items, XR ties virtual contents to the actual world and allows users to interact with the virtual contents (Gao, Gonzalez, & Yiu, 2019, p. 103).

2.2.3.1 AR in the construction space

Due to the rapid improvement of computer software and technology more intuitive visualization systems are required for better use of digital information as the architecture, engineering, construction, and facility management (AEC/FM) industries migrate towards (Chi et al., 2013, p. 116). The most pressing challenges in the field of construction are generally missing or insufficient information for field workers (Chi, Chen, Kang, & Hsieh, 2012, p. 643; Schall et al., 2008, p. 284; 2010, p. 38), gaps between planned solutions and actual solutions (Shin & Dunston, 2008, p. 889), and inadequate communication among project participants (Hammad, Wang, & Mudur, 2009, p. 421; B. Kim, Kim, & Kim, 2012, p. 333; Rui & Schnabel, 2009, p. 1). AR technologies are highly suited for these industries because they have shown the ability to tackle these challenges while researchers and industry practitioners are focused on how to effectively use augmented reality technologies to address the above-mentioned concerns (Chi et al., 2013, p. 116).

AR has touched people’s daily life thanks to the development of robust AR applications like the ARToolkit (Kato, Tachibana, Billinghurst, & Grafe, 2003), Blippar (Striuk, Rassovytska, & Shokaliuk, 2018), Snapchat filters (Rios, Ketterer, & Wohn, 2018) and Pokémon GO (Chong, Sethi, Loh, & Lateef, 2018). The initial stage in augmented reality is tracking and registration, which decides where digital content should be displayed (Flavián, Ibáñez-Sánchez, & Orús, 2019, p. 549). The media contents, are the second phase in AR (Chi et al., 2013, p. 117). The technological capabilities of augmented reality have dramatically improved during the last decade (K. Kim, Billinghurst, Bruder, Duh, &

Welch, 2018, p. 2952). Attempts have been made in certain research projects to mimic and gather feedback on specific construction operations (Chi et al., 2013, p. 117). This approach, on the other hand, only allows for the visualization of actions in a virtual environment and bears no relation to real-world work (Chi et al., 2013, p. 117). This difficulty can be solved with augmented reality. Previous research has demonstrated that augmented reality can improve visualization and user comprehension (Dunston & Wang, 2005, p. 1307), as well as aid in the visualization of three-dimensional settings (Xiangyu Wang & Dunston, 2006b, p. 438).

2.2.3.2 AR in the engineering space

The use of augmented reality in engineering has been the subject of numerous research investigations. AR was used by Yabuki and Li (2007) to build a support system for cooperative reinforcing bar arrangements. AR was utilized by Wang (2007) to help train heavy machinery operators. Golparvar-Fard et al. (2009) employed augmented reality to show 4D models for project management. AR was used by Schall et al. (2008) and Talmaki et al. (2010) to visualize the location and structure of subsurface infrastructure as well as to increase security in the field. In simulated activities, licensed crane operators outscored unlicensed crane operators, according to Chi et al. (2012), who examined an AR remotely operated crane interface. As a result, they concluded that incorporating augmented reality into the user interface of construction machinery had a favorable impact on crane operators (Chi et al., 2012, p. 651). AR is a practical and effective strategy for merging virtual reality with the real world since virtual worlds and 3D models have grown (Kamat et al., 2010, p. 9).

2.2.3.3 Technologies enabling the use of AR

However, there are significant barriers to the development of useful AR applications. In the industry of AEC/FM, for example, the devices hosting AR applications must be portable (Chi et al., 2013, p. 117). Furthermore, to use AR on building sites, convenient methods, or databases for obtaining large and heterogeneous volumes of data are required (Chi et al., 2013, p. 117). AR applications should have intuitive user interfaces that can be operated with natural human movements such as hand gestures (Pintzos, Rentzos, Papakostas, & Chryssolouris, 2014, p. 133). Due to safety concerns, users are not able to direct their attention to how they control AR apps in a working environment (Chi et al., 2013, p. 119). For example, Yeh et al. (2012) created the iHelmet, a construction helmet with an AR display that may be used for construction maintenance. Future research efforts are expected to focus on establishing how the human brains interact with AR devices (Putze et al., 2020) intended for use in the disciplines of AEC/FM.

2.2.4 Future developments of AR

After giving an overview about the use of AR in AEC/FM this section discusses probable future trends for the application of AR in AEC/FM.

2.2.4.1 Hybrid localization

Hybrid localization methods may be future solutions to accommodate for sensor uncertainty and detector accuracy, especially in dynamic construction environments, such that AR applications may deliver reliable and high-quality tracking results for superimposing messages (Yadav, Chugh, Jain, & Baneriee, 2018). As a result, more technologies should be combined to widen the application of AR and continue its development path (Chi et al., 2013, p. 117). It may be useful to investigate hybrid localization algorithms that combine data from various sensors to provide solid localization findings and, therefore, improve AR application performance (Akula et al., 2011, p. 641). In a dynamic environment such as a building site, combining the findings of GPS (Talmaki et al., 2010) and simultaneous localization and mapping (SLAM) (Bailey & Durrant-Whyte, 2006; Klein & Murray, 2007) may ensure the continual identification of a location even if one of the sensors fails or GPS services are unavailable (Chi et al., 2013, p. 119). The way SLAM works is, that it retrieves the camera position and creates an unstructured point cloud (Chen, Tang, John, Wan, & Zhang, 2018, S. 137). 3D geometric information is then built, and a camera space transformation is used to match the compact surface mesh with the input image sequences (Chen et al., 2018, S. 137). Hybrid approaches may also help field personnel do their tasks more quickly by speeding up localization and providing more geometrical reference information (Chi et al., 2013, p. 119). Furthermore, the integration of sensor data might help with other applications like materials maintenance (Behzadan, Aziz, Anumba, & Kamat, 2008, p. 738) and construction schedule monitoring (Golparvar-Fard, Pena-Mora, et al., 2009, p. 132).

The prospects of SLAM for positioning have received a lot of attention (Munoz-Montoya, Juan, Mendez-Lopez, & Fidalgo, 2019, p. 2455). The Metaio SDK was utilized by Rehman and Cao (2015) for indoor tracking which is a system for marker and SLAM tracking. They scanned the surroundings for visual elements (point clouds) and saved them as trackables using the Metaio SDK (Munoz-Montoya et al., 2019, S. 2454). These trackables were linked to their respective locations as well as navigational data (Munoz-Montoya et al., 2019, S. 2454). SlidAR, a 3D positioning approach for SLAM-based handheld AR, was introduced by Polvi et al. (2016). SlidAR was much faster than handhelds without SLAM, needed significantly less device movement, and received significantly superior subjective assessments from the subjects, according to their findings (Munoz-Montoya et al., 2019, S. 2454). For real-time AR applications on mobile devices, Piao and Kim (2017) introduced a SLAM tracking approach (Munoz-Montoya et al., 2019, S. 2454). Their findings revealed the efficacy of their recommended strategy for improving performance up to 18.8 %. Egodamage and Tuceryan (2018) introduced a networked visual SLAM-based collaborative AR system. Chen et al. (2018) established a framework for intra-operative surgical surface reconstruction that was both efficient and successful. They tested the camera tracking accuracy by comparing the camera tracking results to recordings (Munoz-Montoya et al., 2019, p. 2455). Their findings demonstrate that SLAM-based AR even has the ability to be employed in minimally invasive surgery (Munoz-Montoya et al., 2019, p. 2455).

2.2.4.2 Portable AR devices

The devices that host AR apps will become portable and ubiquitous to increase usability and sustain operation in the field (Dey, Billinghurst, Lindeman, & Swan, 2018). Future research efforts might focus on producing natural user interfaces that are simple to use, tiny display devices, and enhanced microchips (Chi et al., 2013, p. 119). Due to high pricing and stringent safety norms, professionals in the construction field typically lack appropriate information and communication tools (Hammad et al., 2009). Furthermore, information materials such as graphics are massive in size and include data that is difficult to compare to data collected in real-life settings (Chi et al., 2013, p. 119). AR-enabled devices are getting smaller, more intelligent, and even wearable (Kerr et al., 2011, p. 210), making them easier to transport onto building sites. Wearable augmented reality computing and display systems, which do not obstruct the field workers field of view while providing consistent and relevant location-based information, are a future research trend (Kerr et al., 2011, p. 210). Most professions in the disciplines of construction and engineering, will experience advantages in their daily work from adopting such smart AR systems (Chi et al., 2013, p. 119).

2.2.4.3 Location-specific information

BIM is a recent trend that delivers location-specific information and necessitates incorporation with augmented reality technology (Chi et al., 2013, p. 119). Construction timelines, cost measures, 3D virtual objects and facility maintenance data simulations may all be found in a BIM (Lakaemper & Malkawi, 2009). As a result, users can get the most out of the model if they can conveniently obtain the elements they need during the various stages of assembly (Chi et al., 2013, p. 119). However, because modern building projects suffer information gaps between the planning and execution stages (Salman, Khalfan, & Maqsood, 2012, p. 16), communication tools are critically needed (Chi et al., 2013, p. 119). Information originating from BIM during construction should be used to determine if activities and tasks are performed on time and schedule, and that the appropriate quality and safety requirements are satisfied (Salman et al., 2012, p. 19).

AR enables not only a visualization of an architects or developers idea on-site but also boosts the likelihood of successfully finishing a construction project (Gu, Singh, & Wang, 2010; L. Hou & Wang, 2011) since it has the potential of merging planned information with real-time information (Chi et al., 2013, p. 119). By employing AR's on-site viewing capabilities, BIM might be enhanced as a novel geographic information system (GIS) that provides architectural elements that can be used throughout urban planning (Chi et al., 2013, p. 119). Integration and utilization of this data should be examined further, as it may become a future research trend (Singh, Gu, & Wang, 2011, p. 134).

2.2.4.4 Using online services to get real-time data

AR applications may be used with cloud computing technology to provide more versatile information (M. Chen, Ling, & Zhang, 2011, p. 569). BIM and other large volumes of field data may be dynamically given according on the current location and time (Chi et al., 2013, p. 119). AR currently has several capabilities, one of which is the capacity to give rich virtual information (Cipresso, Giglioli, Raya, & Riva, 2018). Users may utilize a web connection to update and synchronize the information in AR apps from anywhere (Yuan Chen & Kamara, 2011, p. 11). Consequently, construction data such as schedules, and blueprints may be accessed and changed from any location, including the office and the construction site (Chi et al., 2013, p. 119). Users can utilize AR display devices to view and alter this data, as well as interact with other users in various places using similar devices (Lukosch, Billinghurst, Alem, & Kiyokawa, 2015).

2.2.4.5 Context-aware AR

Context-aware AR may be done in the AEC/FM areas by giving relevant construction information at the proper time and location (Chi et al., 2013, p. 120). In general, context-aware AR relies on contextual factors including time, location, and domain-specific activities to determine what information should be delivered to users (Burrell & Gay, 2001, p. 232). It provides field workers with essential information by considering their specific location and time (Burrell & Gay, 2001, p. 231). As a result, they don't have to filter through a significant amount of data and will be more productive since they will be better informed about relevant data (Chi et al., 2013, p. 120).

Mobile devices, robust localization technology, and intuitive user interfaces are necessary to achieve context-aware AR (Burrell & Gay, 2001, p. 232). A database that may be accessed through an internet connection is also required, which allows for access of various types of building information as needed (Chi et al., 2013, p. 120). There are currently AR applications that can deliver location-specific and time-specific information to field employees (Akula et al., 2011; Aziz, 2012; Behzadan et al., 2008).

2.2.5 Visualization of building or extension projects outside Switzerland

The physical setting up of construction spans is a Swiss particularity (Bürgi, 2020). No other country requires building project contractors to setup construction spans. Rarely, construction spans can be seen in Germany (Jansen, 2016). In Germany construction spans are not required but are sometimes being constructed for demonstration purposes (Jansen, 2016). By foreigners to Switzerland, the construction spans are normally seen as an exceptionality (Tietz, 2017). Opinions, however, can be positive, as construction spans are seen as the tracing of building projects through construction spans as part of a building cultural participation and acceptance (Tietz, 2017).

Many countries are working on submitting the entire building application electronically and monitoring and visualizing the entire project digitally using BIM (Hautala et al., 2017, p. 340). As mentioned in section 2.2.2, in many respects, the Swiss construction industry is lagging. For example the UK, the Netherlands, Denmark, Norway and Finland, have already applied rules for digital planning and construction (Hautala et al., 2017, p. 340). There are several advantages to information modelling. Early in the design process, visualizations may be done rapidly with the use of modelling, and the geometry information can be employed in structural analysis later (Hautala et al., 2017, p. 340ff.). The digital models are used to create traditional drawings (Hautala et al., 2017, p. 340ff.). They make it simple to check structural correctness and match components accordingly (Demian & Walters, 2014, p. 2). The models include information transfer and communication (Demian & Walters, 2014, p. 2). All of this has increased the work's efficiency and precision (Hautala et al., 2017, p. 340ff.). As mentioned in the introduction part this paper will not further discuss building information modelling (BIM) since this is a very extensive topic on its own.

2.2.6 Visualization of building or extension projects in Switzerland

In June of 2020 the project "eBaugesucheZH-Volldigital" has started ("Elektronische Baugesuche," n.d.). Since then, a building application can be submitted electronically in 32 Zurich municipalities ("Elektronische Baugesuche," n.d.). The integration of several municipalities is being planned and other cantons such as Schwyz, Aargau and Bern are also in the process of setting up a platform for fully electronic building applications (Bürgi, 2020). With a total of 162 municipalities in the canton of Zurich and 2'215 municipalities in Switzerland, many have yet to join (*Statistisches Jahrbuch des Kantons Zürich 2020*, 2020, p. 10).

A peculiarity in Switzerland, however, is that in most municipalities and cantons, building applications have to be staked out with physical metal poles called construction spans (Bürgi, 2020). Their purpose is to draw attention to the fact that a construction project is open to the public and that the plans can be inspected by interested parties (Walker Späh, 2010, p. 5). This should make it clear to all those affected on site whether and to what extent the new construction project will affect the surrounding area. Although in most cases it is sufficient to express the building cube with its horizontal and vertical extension in a simplified way (Walker Späh, 2010, p. 6), the erection of metal poles leads to a disfigurement of the landscape. Furthermore, a building structure must be erected prior to the submission of the building application and must generally remain in place until the building permit and any appeal proceedings have been legally resolved (Bösch, 1993, p. 481ff.). During this period, the owner must bear the cost of delivery and installation, as well as the cost of rent for the period of standing of the construction spans (Arcangioli, 2017).

Construction spans do not have to be erected in every Swiss canton and not in all cases. For example, the Planning and Building Law (PBG) of the Canton of Zurich requires in

§ 311 (1) that presentable projects are to be marked out ("Planungs- und Baugesetz (PBG)," n.d.). Whether a project is presentable is not decided by the expense it causes, but by the technical feasibility of measuring and erecting construction spans (Walker Späh, 2010, p. 6). Variations in the terrain are difficult to present, such as those that occur when creating hiking trails. Pegs can be used to mark out the railing in this situation (Blutbacher, 2022). Internal conversions and modifications, on the other hand, are impossible to mark out (Walker Späh, 2010, p. 6). Although it is not required to show every detail of the structure, the building profile should give people seeking justice enough information (Walker Späh, 2010, p. 6). The building's exact shape is documented in publicly accessible plans (Walker Späh, 2010, p. 6).

Within the framework of the preliminary inspection, the local building authority reviews the layout prior to the public announcement (§ 313 (1) PBG). In this case, in addition to adequate visualization, it must also examine the measurements of the construction span, where the needed precision is in the range of decimeters rather than centimeters (Blutbacher, 2022). In the ordinary procedure (§ 319 - 321 PBG), the approval authorities generally make their decisions within 2 months of the preliminary examination ("Baueingabe & Bewilligungsverfahren," n.d.). In the case of new buildings and major conversion projects, a period of 4 months from the preliminary examination is available ("Baueingabe & Bewilligungsverfahren," n.d.). In any appeal proceedings, especially in the case of an on-site inspection, a correct assembly is essential for the assessment of legal issues, which is why the restoration of the alignment can be ordered (§ 313 (2) PBG). In line with § 83 PBG, the quantity, location, external dimensions, as well as the use and purpose of buildings are all specified for a specific region within the scope of design plans. Even though the external measurements are given, no building profiles are necessary (Walker Späh, 2010, p. 8). They are only defined in the context of the subsequent construction permit process, which is not covered in depth in this paper (Walker Späh, 2010, p. 8). Although the design plans must be made available to the public so that third parties can protect their rights, it is not obvious that they will be informed of the design plan procedure without a building permit or that they will be able to form a sufficient picture of the external dimensions to protect their interests (Walker Späh, 2010, p. 8ff.).

If the staking out is incorrect or incomplete, there is a significant flaw in the building permit process, because it renders an accurate assessment of the structure's impact on a neighboring property impossible, or at the very least much more difficult (Walker Späh, 2010, p. 9). The defect in the layout, on the other hand, cannot be objected to in the appeal processes if the kind and scope of the construction measures can be determined with certainty from the plan papers (Walker Späh, 2010, p. 9). Affected third parties now face the tough burden of demonstrating that the poor layout is impeding their interests (Walker Späh, 2010, p. 9). The objection procedure can be used for smaller construction projects, where no interests of third parties are affected and the processing period is 30 days ("Baueingabe & Bewilligungsverfahren," n.d.). The objection procedure is not permissible for building projects outside of building zones and in federally protected sites ("Baueingabe & Bewilligungsverfahren," n.d.). Buildings in urban areas are becoming taller, which might make it challenging to stake out and erect construction spans (Walker Späh, 2010, p. 10). Because of the building's height, third-party interests could only be jeopardized in extreme circumstances, such as for security concerns, with full height profiling (Walker Späh, 2010, p. 10). With the help of a pneumatic crane and a helicopter, one of Switzerland's highest buildings, the Prime Tower in Zurich, was stretched to its full height of 126 meters (Hodel, 2021). After that, the construction spans stood for three months (Hodel, 2021).

Today, however, almost everything is technically conceivable, making staking out practically always possible and, thus, required by law (Walker Späh, 2010, p. 10). With construction spans, it's far more difficult to visualize specific buildings (Walker Späh, 2010, p. 10). Human creativity and fancy are essential because only the clearance profile is to be exhibited (Walker Späh, 2010, p. 10). Special roofs, curves, or materials can't be depicted, and a building's real proportions are only recorded once it's been built (Walker Späh, 2010, p. 10ff.). AR however is capable to show all of this and even more features such as the shadows the building will throw once it is built (Jakl, 2004, p. 4). Staking out such high buildings is not just a lot of work but costs exponentially more than average buildings due to their height and therefore complex construction (Blutbacher, 2022).

3 Methodology

The methodology part presents in detail the expert interviews, the development of the artifact as well as the estimation of the cost of a construction span measured against the total investment for a construction project. As the literature research covers the relevance cycle according to Hevner (2007), the methodology part will cover the design as well as the rigor cycle of this research as described in the following sections.

3.1 Expert interviews

As part of the relevance cycle (Hevner, 2007, p. 89) and also part of the design cycle in collecting requirements for the artifact, five structured problem-centered expert interviews with open questions are being conducted. The aim is to be able to show off the first iteration of the artifact to the experts in the field and therefore gather additional requirements for the artifact directly from domain experts. In this paper expert interviews as a method of qualitative empirical research have been chosen. Expert interviews are conducted with the goal of learning more about a certain subject or gathering information (Gläser & Laudel, 2009; Kaiser, 2014; Meuser & Nagel, 2002; Van Audenhove & Donders, 2019). The expert interview, according to Meuser and Nagel (2009, p. 18), is a qualitative interview based on a guide that focuses on the expert's expertise, which is widely defined as specific knowledge in a given field of work. In order to gain a better understanding, qualitative interviewing stresses the importance of exploring the expert's experiences and opinions (Edwards & Holland, 2013; Flick, 2017).

Expert interviews in this paper are conducted to evaluate the analyzed contents of the scientific literature for their relevance and topicality in practice. The option of interview type falls on qualitative interviews for the interview partners to not only appraise the subject to be addressed as honestly and completely as possible, but also to contribute their own ideas and experiences. A qualitative interview, according to Döring and Bortz (2016, p. 365), is characterized by open-ended questions and the interviewees' responses in their own words.

3.1.1 Interview method and procedure

Bogner and Menz (2009) define three types of expert interviews. The exploratory expert interview is the first form, and it's commonly used to gather expertise and orientation in new or unfamiliar topics (Döringer, 2021, p. 266). The systematizing expert interview, which is similar to the exploratory expert interview, is the second type (Döringer, 2021, p. 266). This sort of expert interview tries to collect expert knowledge in an organized and complete manner to attain a high level of data comparability (Gläser & Laudel, 2009, p. 263). The third kind, identified by Bogner and Menz (2009) as a theory-generating expert interview, serves as a basis for the development of problem-centered expert interviews (Döringer, 2021). Experts are people with specific expertise who occupy a managerial role in a specific sphere of activity, according to the theory-generating expert interview (Bogner & Menz, 2009, p. 44). As a consequence, their actions, knowledge, and assessments help to shape the circumstances of other individuals' actions (Bogner & Menz, 2009, p. 54). Expert knowledge has a socially important component, because it essentially molds and determines an area of action (Döringer, 2021, p. 267). The expert interview is appropriate for the study of this work since it employs an analytical and interpretive approach in order to highlight interconnections in empirical data and build theoretical approaches (Döringer, 2021, p. 267). It emphasizes empirically based inductive theory building to disclose interpretative knowledge (Bogner & Menz, 2009, p. 44), which is described as subjective opinions, or perspectives that professionals draw on when deciding on their actions. The majority of this knowledge is hidden, and it includes things like decision-making strategies and action orientations (Döringer, 2021, p. 267). The process of abstraction and systematization of qualitative interview data produces interpretative knowledge, which does not exist a priori (Bogner & Menz, 2009, p. 53).

The theory-generating interview approach of this paper is combined with the problem-centered interview (PCI) approach. PCI necessitates the use of a specific study design and interviewing tools (Döringer, 2021, p. 269). In general, it uses an interview guide that starts with sounding questions and a story and ends with detailed follow-up questions in the second phase (Döringer, 2021, p. 268). Rather of developing a predefined question-answer structure, its goal is to offer the researcher a framework that acts as a direction to the predetermined research topics (Döringer, 2021, p. 268). To promote a narrative shaped by the individual's concerns, the interviewer begins with an open-ended inquiry (Scheibelhofer, 2008; Witzel & Reiter, 2012). Following the conclusion of the narrative episode, the interviewer moves on to general explorations and impromptu questions (Döringer, 2021, p. 268). Ad hoc questions are based on prior knowledge or information that emerges during the narrative portion (Döringer, 2021, p. 268). Because these questions may disturb the topic of the interview, it is recommended to ask them near the end

(Döringer, 2021, p. 268). Coupling an open storyline introduction with a more structured interview component enables the researcher to stay open to the information gathered since it allows interviewees to express other points of view, clarify previous claims, and correct the interviewer's incorrect assumptions (Döringer, 2021, p. 268).

Both the theory-generating interview and the PCI strive to develop new theories by systematizing and interpreting individual utterances, highlighting the interviewee's perspectives and ideas (Döringer, 2021, p. 269). The purpose of the expert interview is thus to open up and analytically recreate subjective expert knowledge (Bogner & Menz, 2009, p. 48). Despite the fact that the interview pushes for an inductive method, Bogner and Menz (2009) emphasize the idea of combining inductive and deductive components. Both approaches can be connected to the Grounded Theory methodology in this context, which attempts to develop theories based on qualitative interview data (Glaser & Strauss, 2017; Strauss & Corbin, 1997).

This interview follows the problem-centered interview procedure by Mayring (2016) as shown in figure 7. Figure 7 was translated from German to English by the author of this paper.

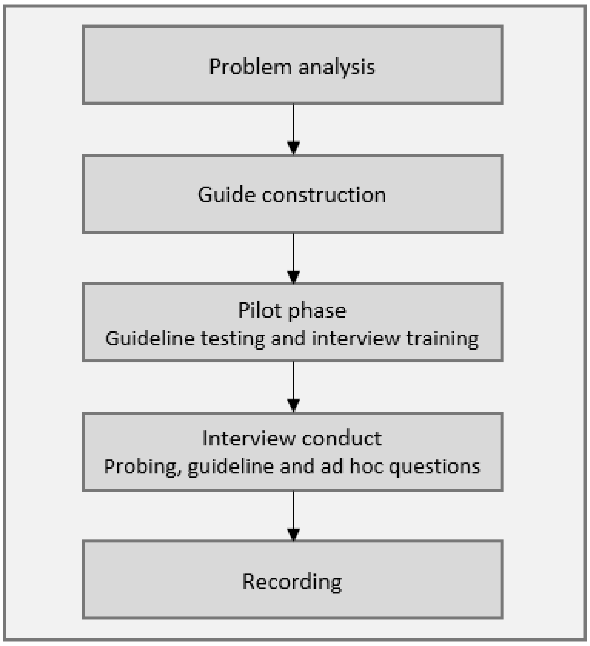

Figure 7: Procedure of the problem-centered interview (Mayring, 2016, p. 71)

Before the interview is being conducted a few steps must be completed. The problem is being analyzed and a guide with questions is being constructed by the interviewer. When everything is prepared the guide and the procedure of the interview is being assessed first. The length of the expert interviews is set at around 60 minutes, as recommended by Döring and Bortz (2016, p. 373), for guideline-based interviews, among others.

The aim of this qualitative, semi-structured expert interview is to find out what the state of research is in practice, what is already in use or in the process of being digitized. The goal is to find out how a digital solution for visualizing construction spans is received by the experts and where they are most likely to see a use for such a solution. In general, the experts are asked where they see digitization potential or a use of augmented reality in their industry and how they themselves see how digitization could be achieved. This research project aims to find out what the experts think the conditions are for digitization or change in their industry. Finally, the technical implementation and visual design of the artifact of this work is to be explained to the experts and to find out what they think of it, what they like or dislike about the solution, how they would change the artifact or what would have to be implemented so that they would use it at their own work. The guiding questions and full structure of the expert interviews can be found in the appendix of this paper.

3.1.2 Expert selection

This research paper has three underlying topics: Construction spans, the digitalization of the Swiss construction industry and the use of AR in construction. As part of the preparation of the interview experts from each topic as well as experts with expertise in several of the mentioned topics are approached to get as many different insights as possible. Since the expert interview is just one of three methodologies used in this research, the number of experts for the expert interviews is limited five.

Existing contacts of the author could be contacted to find experts. This includes experts from Keller+Steiner AG, one of the most well-known companies in Switzerland, which sets up construction spans, an expert from Nomoko, a digital twin start-up, which plans to digitalize the real estate industry in Switzerland and an XR expert from BearingPoint AG, a consulting firm, which applies VR and AR in various industries including the construction industry in Switzerland. An Expert from Luucy AG, a Swiss company offering an online platform for spatial design based on 3d models, was mediated by the supervisor of this research paper. The final expert from the department of construction, transport, and environment (BVU) of the canton of Aargau was approached directly by E-Mail.

- [***E1***] Joel Blutbacher: CDO at Keller+Steiner AG
- [***E2***] Christian Hutter: XR Team Lead at BearingPoint AG
- [***E3***] Mathias Blaser: Project Manager at Civil Engineering Department Aargau
- [***E4***] Gonzalo Rezola de Vargas: Group Product Manager at Nomoko AG
- [***E5***] Mark Imhof: Co-Founder at Luucy AG

3.1.3 Evaluation of the expert interviews

The interviews will not be transcribed in their entirety to open up more time for the creation of the artifact itself. However, a summary of each interview is created, which describes the most important findings. From the texts thus produced, research question two is to be posed as well as answered. In this paper, qualitative interviews with open questions are analysed with the help of a structuring content analysis according to Mayring (2010). The answers are assigned to specific categories by the coding guide. In this way, one can establish connections between the individual answers. The inductive categorization approach is being used. This is therefore a summary, and the content of the interviews is reduced to the essentials. The interview guide, the presentation used for the interviews, and the interview coding guides are shown in appendices A, B, C and D. The interviews of *E1, E2, E3* and *E5* are translated from Swiss-German to English by the Author.

According to Mayring (2010) there are seven steps to conduct a inductive categorization of an interview.

1. **Determining the analysis unit**: Any complete statement by the experts on the visualization of construction spans and the use of augmented reality for visualizations as well as benefits and disadvantages of the current procedure for construction spans and of the proposed technical AR solution.
2. **Paraphrasing statements**: Delete the unnecessary and concentrate on the essentials (Mayring, 2010, p. 70). In this research the interviews will not be paraphrased entirely and only the most essential statements are being written down.
3. **Setting the level of abstraction**: This research moves from a sentence to encodings and finally to the individual categories. So, the level of abstraction is raised step-by-step in two stages.
4. **First level of abstraction**: Moving from the statement of the expert to encodings.
5. **Second level of abstraction**: Moving from keywords to high-level categories.

6. **Summary as a system of categories**: Now categories are gradually formed from the keywords. Each additional statement is checked to see if it already fits into an existing category (Mayring, 2010, p. 70).
7. **Review**: The author goes through all categories again here and summarizes them in case of similarities (Mayring, 2010, p. 71).

Question 16 “Which existing similar solutions do you know?” as well as question 17 “What would be your preferred way of gathering data for the proposed solution?” are not being categorized since the answers to these questions are rather a list of solutions rather than topics to be considered in the artifact. The alternative solutions are briefly being analyzed in section 3.2 after presenting the artifact of this research paper.

In chapter 3.2.3, these results are important for collecting requirements and suggestions for improvements for the artifact. In the chapter results the findings of the expert interviews are being presented and subsequently discussed in the chapter discussion.

3.2 Development of the artifact

The development of the artifact, which is the heart of this research, is part of the design cycle of this research. The design of IT artifacts is always based on requirements, needs or even problems of practice, in the interaction of people, organization, operational task and technology (Robra-Bissantz & Strahringer, 2020). The design cycle of this research iterates between the construction of the artifact and its evaluation in order to constantly improve the architecture as well as the design.

3.2.1 Enabling technologies related to the artifact

AR employs a variety of techniques to merge the virtual and real worlds. Instead of being a single technology, it is a concept (Chi et al., 2013, p. 117). The applicability and usability of AR are directly influenced by several evolving and upcoming technologies. Figure 8 shows the architecture of a typical AR application according to Chi et al. (2013, p. 118).

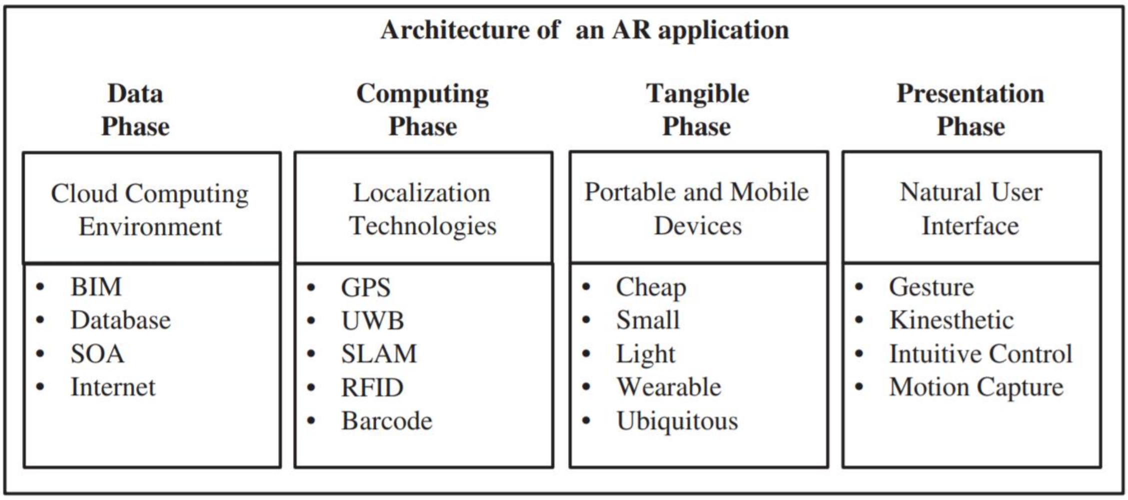

Figure 8: Architecture of an AR application (Chi et al., 2013, p. 118)

The interaction of all components for the artifact of this paper is explained in chapter 3.2.2. The artifact is developed with the game engine Unity, a popular software for developing XR experiences or 2D and 3D games.

3.2.1.1 Localization technologies and tracking methods

Identification of subject postures necessitates the use of localization technologies. They're an integral aspect of AR's fundamental functioning, and they're likely to have a big impact on how AR apps evolve in the future (Chi et al., 2013, p. 117). Because of the precision of the localization process, AR apps are limited in their ability to superimpose virtual information onto the actual world (Yadav et al., 2018).

Behzadan et al. (2008) have presented a mobile AR framework that incorporates GPS for construction purposes. Hammad et al. (2009) also used GPS to design a distributed AR for visualizing collaborative construction jobs (DARCC), which they used to improve communication and highlight intractability. Other outdoor localization systems, such as radiofrequency identification (RFID) (H.-S. Lee, Lee, Park, Baek, & Lee, 2011; Pea-Mora, Thomas, Golparvar-Fard, & Aziz, 2012; Razavi & Haas, 2011), ultra-wide band (UWB) (T. Cheng, Mantripragada, Teizer, & Vela, 2012; Shahi, Aryan, West, Haas, & Haas, 2012; C. Zhang & Hammad, 2012), and barcoding, combine numerous sensors and give comparable capabilities.

As mentioned previously, for augmented reality, localization is critical to the algorithm that determines where the information from the virtual environment should be placed (Chi et al., 2013, p. 117). The accurate geolocated information for AR applications is retrieved mostly devices, such as cameras or laser sensors (Chi et al., 2013, p. 117). To present AR, the methods for determining geometric attributes from collected pictures or point clouds are critical (Bosché, 2010, p. 110; Golparvar-Fard, Bohn, Teizer, Savarese, & Peña-Mora, 2011, p. 1145). If a subject's posture could be reliably predicted, AR could show the right information, and AR users in the field might get meaningful information (Chi et al., 2013, p. 118). Similarly, AR would be able to give more information with steady quality if sensor fusion technologies (Razavi & Haas, 2012; Shahi, Cardona, Haas, West, & Caldwell, 2012), localization algorithms, and equipment such as SLAM (Castle, Klein, & Murray, 2008), UWB, and GPS were employed. Environmental noise and sensor faults would have little impact on the accuracy of AR localization (Chi et al., 2013, p. 118). Maintaining the accuracy level of AR is tough for developers because all existing localization algorithms are constrained by ambient complexity, signal quality, ranges of sensors and uncertainty (Chi et al., 2013, p. 118).

The artifact of this research paper is using a hybrid localization method utilizing GPS as well as visual positioning. Visual positioning services (VPS) are mainly used for indoor navigation (Anup, Goel, & Padmanabhan, 2017; Ruizhi & Liang, 2017; Yadav et al., 2018). VPS as a localization method have emerged around 2016 as a solution for devices to navigate indoors (Lomas, 2017). Visual positioning can be achieved using markers, however, unfolds its full potential when combined with computer vision. VPS makes effective use of visual information for dynamic target tracking, model reconstruction, and real-time processing (He et al., 2021, p. 1). VPS use convolutional neural networks (CNN) to extract features from images (Yujin Chen et al., 2018) taken in this instance with a smartphone camera. Figure 9 shows the process of when the image is submitted to the cloud servers of the VPS and then being processed to calculate the pose of the camera of the user.

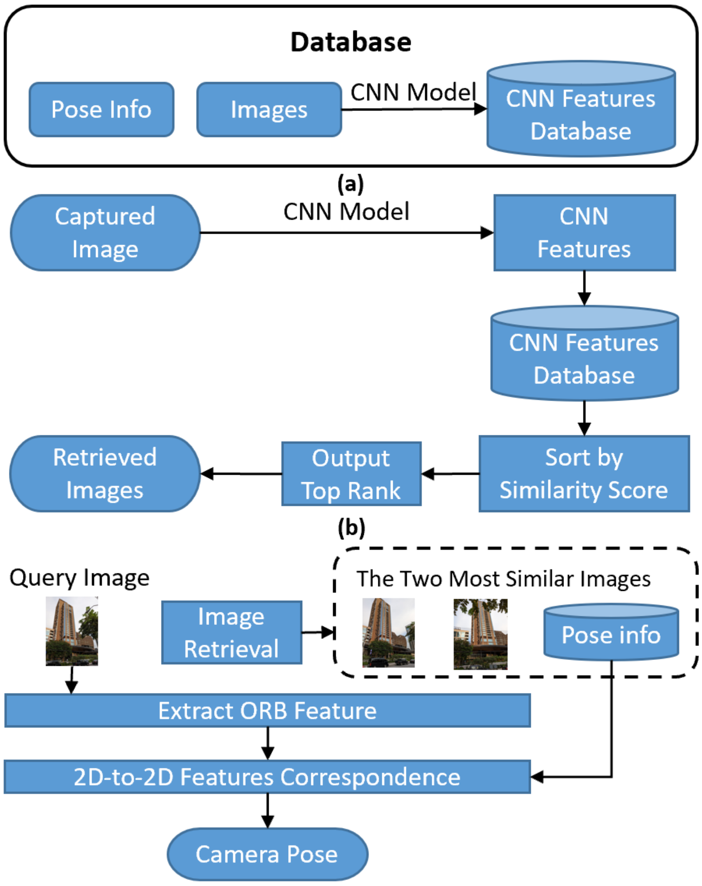

Figure 9: Visual positioning using computer vision (Chen et al., 2018, S. 4)

The figure shows in section (a) how the VPS has a database of images and the corresponding pose information of each image. To extract as much features as possible from each captured image VPS utilize pre-trained CNN models (Chen et al., 2018, S. 2692). The database then sorts the images by a similarity score. When then an image is being retrieved during the runtime of the application, the database can provide the top ranks of the similarity score for each retrieved image and their poses and therefore get the most accurate position of the user when matching the images against the database (Chen et al., 2018, S. 2692). Section (b) of figure 9 more closely shows how image information is being retrieved. A query image is being taken by the user during runtime and the image retrieval process gets triggered (Chen et al., 2018, S. 2692). It retrieves two of the most similar images to the query image (Chen et al., 2018, S. 2692). The VPS then extracts the feature points from the query image using Oriented FAST and rotated BRIEF (ORB), a fast robust local feature detector (Luo, Yang, Huang, & Zhou, 2019). Now, to compute the pose of the query image a 2D-to-2D feature correspondence is applied, with the main purpose of retrieving as many correct correspondences from the initial query image as possible (Zhao, Yang, Xiao, & Cao, 2019, p. 1). Figure 10 illustrates how similar images are ranked next to each other in "Metashape", a photogrammetry software, which is also based on their location where they have been taken from.

Figure 10: Photogrammetry model and camera poses ("Custom Images," n.d.)

For this research, a VPS provider is utilized to achieve the desired functionality. The VPS provider Immersal ("Digital and Reality AR Ready to Merge – Immersal," n.d.) is chosen because they provide open and free software for their visual positioning service. Furthermore, they provide a seamless Unity integration which is crucial in developing the artifact. Immersal therefore allows the user to take images with their smartphone and submit them and later download them as a map. This map gets converted to a point cloud which includes all the visual features of the environment which has been photographed. The point cloud can then be downloaded during runtime according to the user's GPS location. When the user has downloaded the point cloud, 3D models can be accurately placed in the environment by means of the visual features that have been extracted by the computer vision algorithm of the VPS cloud servers earlier. The GIBSON city walking system from

Takeuchi et al. (2021) is using the Immersal VPS to align the locations of users between the VR space and the real space (Takeuchi et al., 2021, p. 14). According to Takeuchi et al. (2021, p. 14) the VPS allows them to expect higher accuracy than with other localization methods.

3.2.1.2 Mobile devices

The success of AR applications is directly influenced by the size, weight, performance, and cost of hardware (Chi et al., 2013, p. 119). AR applications may be used in the field because mobile devices are growing smaller, cheaper, more powerful, and provide accessible displays (Chi et al., 2013, p. 119).

AR portability is determined by how much mobility a hardware device can give while still meeting AR's displaying and operating criteria (Chi et al., 2013, p. 119). Currently, a growing number of AR apps are being used on mobile phones (Papagiannakis, George, Thalmann, & Nadia, 2007; Wagner, Reitmayr, Mulloni, Drummond, & Schmalstieg, 2010; Woodward et al., 2010) HMDs (Shin & Jang, 2009). This trend is supported by the microchips used in such devices getting smaller, cheaper and more performant. Because AR requires the user to be able to walk around and be present where the task is performed, AR systems must lay focus on portability and the ability to move around (Azuma, 1997). All AR systems and devices must be stable and able to withstand the elements (Azuma, 1997). Many new AR applications will be available once this capability is established.

The artifact of this paper is engineered to run on Android as well as iOS smartphones and tablets thanks to Unity's underlying ARFoundation Framework ("Unity's AR Foundation Framework," n.d.) which includes Apple's ARKit ("Augmented Reality," n.d.) as well as Google's ARCore ("ARCore," n.d.) platforms to support AR experiences.

3.2.1.3 Cloud servers

Cloud computing has the potential to expand the use of AR apps when used as a platform for obtaining information (Chi et al., 2013, p. 119). Cloud computing refers to internet-based services as well as the technology and software that runs on the data servers that deliver them. It is establishing itself as a cutting-edge delivery model for IT infrastructure, apps, and data management (Huang, Lin, & Lee, 2012). Because the internet operates in real time, IT systems with cloud-based functionality can make information more accessible to users (Huang et al., 2012). In a BIM setting, for example, files are often exported from one software and then imported into another (Chi et al., 2013, p. 120). However, because of this mechanism for exchanging data between apps, several copies of the data are created (Chi et al., 2013, p. 120). This difficulty is solved by the service-oriented architecture (SOA) (Moller & Schwartzbach, 2006), which allows data to stay in one application while being used or modified by other services. It then becomes a common platform for data that eliminates redundant information (Redmond, Hore, Alshawi, & West, 2012, p. 182).

Likewise, the artifact of this research is enhanced by virtual information provided by a web server that allows the user to modify or update content at any moment. Users may utilize AR as a front-end to explore virtual information in the field, similar to how they would with an internet browser, but with access to more relevant data (Cipresso et al., 2018). This method can help with jobs that need a lot of dynamic data, such as construction schedule monitoring (Golparvar-Fard, Peña-Mora, Arboleda, & Lee, 2009; Kamat et al., 2010), building/bridge inspection (Y. C. Chen, Kang, & Yang, 2011), and subsurface facility maintenance (S. Lee & Akin, 2011; Schall et al., 2008; Talmaki et al., 2010). The use of cloud computing can integrate virtual information into people's everyday lives, which is the purpose of augmented reality (Chi et al., 2013, p. 118).

3.2.1.4 User interfaces

Natural user interfaces (NUIs), for instance, are input systems that imitate human actions and movements (Ogiela & Hachaj, 2015, p. 207). Without the usage of indirect input devices, they can be utilized to communicate (Ogiela & Hachaj, 2015, p. 207). Furthermore, according to Chi et al. (2013, p. 118) they are highly suited for AR devices in the field because of their small size and weight.

A growing number of augmented reality apps use gesture (Chakraborty & Shah, 2018; White, Lister, & Feiner, 2007) and kinesthetic control (Juang, Hung, & Kang, 2013; Tonn, Petzold, & Donath, 2008). SixthSense (Mistry & Maes, 2009), for example, is a wearable kinaesthetic interface that adds virtual information to the tangible environment surrounding the user and allows users to interact with it using natural hand gestures (Chi et al., 2013, p. 118). It combines a camera and a projector-like device in a mobile wearable gadget (Mistry & Maes, 2009). Yeh et al. (2012) designed the iHelmet, a construction helmet with an iPod Touch and a tiny projector for accessing on-site information. Using the iPod's touch screen, iHelmet users may project subsurface information on wall structures in the field (Yeh et al., 2012).

ARCADE (Stein, 2012) is a program that creates real-time video-based presentations that give the impression that presenters may handle holographic 3D objects with their hands directly. Kintre (J. Chen, Izadi, & Fitzgibbon, 2012) is an application that allows users to scan any item and manipulate it by moving their bodies. The application uses the natural movement of human bodies to manipulate input media. An AR application's usability is determined not just by its reliability, but also by the quality of its control interface (Koreng & Kroemker, 2021, p. 10). In most cases, intuitive gestures and humanoid sensing control techniques are preferred over indirect controls when building an AR user interface (Chi et al., 2013, p. 118). As a result, greater effort should be put into developing control mechanisms for user interfaces that take natural human behaviors into account (Chi et al., 2013, p. 118).

3.2.2 Design and Architecture

As discussed in chapter 2.2.6 the purpose of construction spans is to draw attention to the fact that a construction project is open to the public and that the plans can be inspected by interested parties (Walker Späh, 2010, p. 5). In consideration of the answers of the experts interview during this research, the main stakeholders of this artifact will be the general public, such as residents who are affected by a new building, municipalities where this building is being built and developers, who are the ones to submit a building application.

This artifact is designed to offer residents the opportunity to inform themselves more accurately, independently, and transparently about new construction projects which will affect their quality of life. Municipalities should also be able to quickly and effortlessly visualize new construction projects which will affect their land- or cityscape. Lastly, developers as well as their architects, should be able to present their projects, design, and communicate their ideas in a meaningful and a comprehensible manner. The artifact was given the name “izanagiXR” as part of this thesis. Izanagi is one of the gods of creation in the Japanese Shinto religion (Cartwright, 2012). Figure 11 shows the architecture of the artifact of this research. The architecture is strongly oriented to the “Architecture of an AR application” from Chi et al. (2013, p. 118).

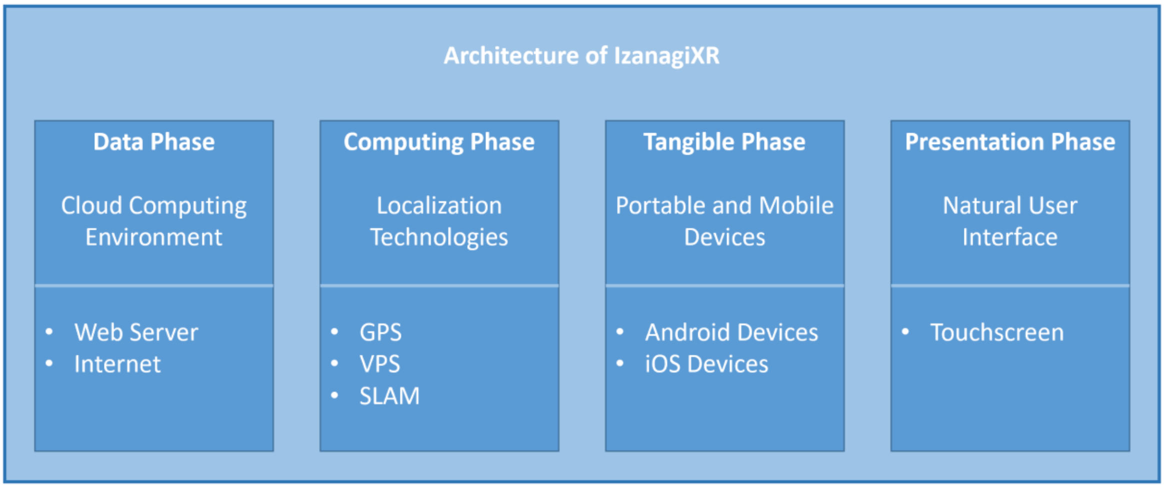

Figure 11: Architecture of izanagiXR

3.2.2.1 Data Phase

To be able to store and load 3D models this artifact utilizes a web server. More precisely, these models are converted into asset bundles within Unity and then uploaded to the domain www.coviello.tech hosted by the web hosting provider Hostinger through its FTP file manager. Users are also able to utilize other FTP clients such as SmartFTP or FileZilla. The application then needs an internet connection which enables the app to make a web request to the desired asset bundles located on a web server. The user will then be able to choose from a list of available models to load into the application.

3.2.2.2 Computing Phase

As already mentioned, for this research a VPS (Visual Positioning Service) provider is utilized to achieve the desired functionality. The VPS provider Immersal is chosen because they provide open and free software for their visual positioning service. They provide a seamless Unity integration which is crucial in developing the artifact. The Immersal software development kit (SDK) offers sample scenes with C#-Scripts making REST-API calls to the Immersal servers. The Immersal SDK therefore already allows the user to take images with their smartphone and submit them to the servers. These pictures get stitched together to a map which gets converted into a point cloud which includes all the visual features necessary to anchor models onto it. This point cloud can then be downloaded during runtime according to the user's GPS location. The user will get a list of available point cloud in their immediate environment. When the user has downloaded the point cloud, the 3D models can be downloaded from the web server and accurately placed in the environment by means of the visual features that have been extracted by the computer vision algorithm of the VPS cloud servers earlier. For this procedure, the user also needs a stable internet connection since the pictures and point clouds as well as the models are all uploaded and downloaded through web requests and the point clouds are loaded via Immersal APIs. GPS and vision-based techniques are commonly utilized for localization in outdoor AR applications (Dad, Arora, Parker, & Rachh, 2018). According to Treuillet and Royer (2010, p. 484), a vision-based technique delivers superior accuracy to GPS in urban environments.

As mentioned before, hybrid localization algorithms that combine data from various sensors to provide solid localization findings and, therefore, improve AR application performance (Akula et al., 2011, p. 641) are preferable. Especially in the application area of construction where the GPS signal could be blocked by buildings it is important to continue tracking the user's device with other sensors (Bailey & Durrant-Whyte, 2006; Chi et al., 2013, p. 119; Klein & Murray, 2007). The SLAM algorithm for this artifact is provided by the ARCore SDK from Google for Android and the ARKit from Apple for iOS, respectively. As the user moves through the world, ARCore or ARKit use SLAM to understand where the phone is relative to the world around it. This is especially important when the application tries to detect the floor to place the models correctly into the world.

3.2.2.3 Tangible Phase

The artifact of this paper is engineered to run on Android as well as iOS smartphones and tablets, as mentioned in chapter 3.2.1.2. Thanks to Unity's underlying ARFoundation Framework ("Unity's AR Foundation Framework," n.d.) which includes Apple's ARKit ("Augmented Reality," n.d.) as well as Google's ARCore ("ARCore," n.d.), projects that are created with this plugin can be easily compiled for either Android or iOS devices.

Mobile devices such as phones and tablets have been chosen instead of wearables such as smart glasses from Nreal Light/Air or even the Hololens 2 from Microsoft. Mobile phones and tablets are already widely used and cheap compared to smart glasses or mixed reality headsets. A further reason to choose mobile phones and tablets over smart glasses is the limited field of view (FoV) of current smart glasses. The Nreal Light glasses from Nreal and the Hololens 2 from Microsoft both have a field of view of just 52 degrees (Dayaram, 2021) while the Magic Leap 2 smart glasses have a field of view of just 70 degrees (Robertson, 2022). For comparison, the average human field of view is approximately 120 degrees (Younis, Al-Nuaimy, Alomari, & Rowe, 2019). Current smart glasses and mixed reality headsets therefore significantly restrict the view of the user and limit the area where augmented 3D content can be seen. Regular smartphones and tablet cameras offer a field of view of up to 120 degrees which is significantly higher than the field of view of current XR hardware (Simons, 2022).

The following table shows the sales numbers of each hardware category in comparison, its average prices, average FoVs as well as the average battery lifetime in casual use. The battery lifetime should also be considered in the development of the application because the use of visual computing, a stable internet connection as well as GPS localization will require a significant amount of energy.

Table 1: Hardware comparison for AR applications (Elgan, 2022; Harding, 2019; Lang, 2019; Lardinois, 2019; Michaels, 2022; Potuck, 2022; Winstead, 2022)

Device	FoV	Price	Estimated Sales Worldwide	Battery
Android Phone	70-120°	300$	1.5 bio. units (2021)	15-30 hours
Android Tablet	70-120°	350$	108.7 mio. units (2020)	5-10 hours
iOS Phone	70-120°	800$	242 mio. units (2021)	10-17 hours
iOS Tablet	70-120°	550$	57.8 mio. units (2021)	10 hours
Nreal Light	52°	599$	Few thousand units (Total)	3 hours
Hololens 2	52°	3’500$	520’000 units (Total)	2-3 hours
Magic Leap 2	70°	2’295$	10’000 units (Total)	3.5 hours

The BusinessWire states that the global market for smart AR glasses, which was anticipated to be 255.6 thousand units in 2020, is expected to expand to 8.8 million units by 2026, with a compound annual growth rate (CAGR) of 80.3 % throughout the analyzed period (Wood, 2021). In April 2022 it was estimated that worldwide there are around 6.6 bio. smartphone users, which translates to 83.72% of the world’s population owning a smartphone (Turner, 2022). A much wider coverage can therefore be achieved for the artifact of this research by choosing to deploy the application to smartphones and tablets instead of AR smart glasses.

3.2.2.4 Presentation Phase

The application will be operated through the touchscreen of the smartphone or tablet it is run on. This method of interface was selected because direct touchscreen interactions allow users to utilize their phones without having to memorize a number of rules and processes (Tanimura & Ueno, 2013). Tanimura & Ueno (2013, p. 228) describe how a natural-feeling UI must be provided to achieve intuitive operations. Therefore, the application will feature a touchscreen-based UI that feels familiar to users that already utilize smartphones or tablets frequently.

3.2.3 Requirements engineering

The requirements for the artifact result from the paper description and discussions with the supervisor, from the literature review and lastly from the expert interviews.

1. The software shall be able to run on a modern smartphone and tablet (Android/iOS) (Chi et al., 2013, p. 119).
2. The software shall provide a connection to the VPS of choice.
3. The software shall allow the user to create their own point clouds.
4. The 3D data shall utilize ubiquitous services to provide more versatile information (M. Chen et al., 2011, p. 569).
5. The software shall enable the user to manually align the 3D data to the point cloud.
6. The Software shall enable the user to visualize the 3D data in a previously saved position and rotation.
7. The software shall be able to instantly locate the user using GPS.
8. The software shall be able to call point clouds from the VPS according to the users GPS position (Talmaki et al., 2010, p. 8).
9. The software shall provide an easy and intuitive user interface (Ogiela & Hachaj, 2015, p. 207).
10. The different scenes of the software should exhibit a unified design for a more user-friendly operation (*E4*).
11. The software shall be operated through a touchscreen for a smooth use (Tanimura & Ueno, 2013).

The implementation of these requirements and the steps to achieve them is documented in chapter 4.

3.3 Estimation of the cost share of construction spans

To calculate the cost share of construction spans in the total construction project several statistics are needed. First the cost drivers of construction spans must be defined. For this, table two has been created which shows different cost drivers and how severely they affect the cost of construction spans.

Table 2: Cost drivers of construction spans

Cost driver	Description	Impact
Height	How tall is the construction span	Very High
Complexity	How complicated/uneven is the terrain	High
Space	How big is the construction area	Low
Time	How long does the construction span stand	Low
Provider	Which provider does one choose	Low

Secondly, the construction expenditure as well as the number of construction projects is needed. When the average cost of a construction project has been identified the average cost of a construction span can be applied to it to gather information about the cost share of that construction span in the whole construction expenditure.

The prices of construction spans depend on the height of the building, the complexity of the terrain where it will be placed, the space of the project, the period the construction spans stand on the space and lastly the supplier that is chosen for erecting the construction spans according to Joel Blutbacher (2022) from Keller+Steiner, a leading provider of construction spans in Switzerland. During construction, there are not only costs for land prices and the building costs, but also additional construction costs. As presented by the Federal Office for statistics (SFSO) the additional construction costs (ger. "Baunebenkosten") include insurance, special insurance, construction loan rates as well as bank fees which in total make up for about 5.9% of the total cost of constructing an apartment building in Switzerland (Bundesamt für Statistik, 2021).

This paper aims to deliver a cost estimation for construction spans for the average building. Since there are several distinct types of buildings, further specifications must be set. This paper follows a table of construction expenditure by client from the SFSO. The latest numbers are from 2016, so this paper continues with numbers according to 2016 statistics as well as comparing them to the latest numbers. Figure 23 shows the construction expenditure by client from 2016. This paper will differentiate between public-sector and private-sector clients. Furthermore, these clients lay the focus of their investments on different construction projects. For example, public-sector clients like municipalities and cantons invest mostly in infrastructure like streets or public buildings like schools or libraries while private-sector clients invest primarily into residential or commercial buildings (Bundesamt für Statistik, n.d.-b).

Construction expenditure by type of client and by type and category of construction works **T 9.4.1.7**
In millions of Swiss francs, at current prices

	Grand total	Expenditure by public-sector clients [1]					Investments of the private clients [3]				
		Total	Civil Engineering		Building construction		Total	Infrastructure [4]	Residence	Agriculture and forestry	Industry, trade, services
			Total	thereof streets	Total	thereof buildings with appartments [2]					
2012	61.780	20.197	12.191	5.571	8.005	632	41.584	4.229	28.609	639	8.107
2013	63.737	20.563	12.301	5.289	8.262	678	43.174	4.527	29.642	712	8.293
2014	65.638	21.632	12.788	5.667	8.845	741	44.005	4.721	30.129	749	8.406
2015	66.310	21.847	12.806	5.588	9.041	694	44.463	4.904	30.578	694	8.288
2016	66.433	22.224	12.527	5.203	9.696	883	44.210	5.047	30.711	668	7.784

1) Construction expenditures of the federal government, cantons, municipalities and corresponding public enterprises, including public maintenance work
2) Without public maintenance
3) Without private maintenance
4) Infrastructure: Utilities, waste disposal, road traffic, other transport and communications; Education, research; Health; Recreation, culture; Other infrastructure
Database status: 16.07.2018

Federal Statistical Office, Annual Construction and Housing Statistics
Contact: info.bau@bfs.admin.ch
© BFS - Swiss Statistical Encyclopedia

Figure 12: Construction expenditure by types of client (Bundesamt für Statistik, n.d.-b)

The estimation takes place in the results section. It only considers publicly available numbers from literature research and quotations from Keller+Steiner AG and does not consider other cost factors with occur due to objections or change requests, which according to *E1* could potentially relate to up to 20% of all construction spans. However, hereby the cost as well as the party who bears the cost of change request is not clearly regulated.

4 Results

4.1 Results of the expert interviews

The following tables show the frequency of the most mentioned topics during the expert interviews categorized and counted by the author.

Table 3: Questions regarding construction spans

Categories	Number of entries
Abstraction	7
Appearance	3
Accuracy	2

Table 4: Questions regarding the substitution of construction spans and AR

Categories	Number of entries
Engagement	7
Accessibility, Limitation	5
In research, Effort	3
Applicability, Early tests	2
Civil Engineering, Instruction, Price, Usability	1

Table 5: Questions regarding the proposed solution

Categories	Number of entries
Engagement	7
Effort	5
Abstraction, General Public, Developer, Municipality	3
Accessibility, Data, Price, Usability, Moderate, Detailed	2
Architect, Disruption, Instruction, Installation Company, Privacy, Simple, Sustainability	1

Table 6: All questions in total

Categories	Number of entries
Engagement	14
Abstraction	10
Effort	8
Accessibility	7

Limitation	5
Usability, General Public, Developer, Municipality, In research, Price	3
Accuracy, Data, Moderate, Detailed, Applicability, Early tests, Instruction	2
Architect, Civil Engineering, Disruption, Installation Company, Privacy, Simple, Sustainability	1

During the expert interviews the engagement of stakeholders as well as the additional engagement that AR can provide to the visualization of construction project was mentioned the most. The experts mention that AR cannot only be used as a communicative tool but also transform the period of the construction permit which can be seen as arguing space into a space of negotiation and collaboration as mentioned by *E4*. The experts agree that AR can enable the user to display more complex information in a more comprehensible way which can increase the engagement with stakeholders. Furthermore, *E5* adds that AR can lead to a better representation of a construction project and therefore build trust and reduce fears. The proposed solution was described by *E2* as well as *E4* as being able to increase Engagement by visualizing and recording a building to take it into a meeting and by presenting a building in a clearer way, respectively. At the same time *E4* raises the question of how the solution could be grown or more people could be engaged. Similarly, *E5* raises the question of who the target audience is and how much they would be willing to pay. To answer this question the research bases which assumptions on the answers of the experts from question 13 "Who could the proposed solution be most useful for?".

Three experts each are of the opinion that the solution would be most useful for the public, municipalities, or the developers of construction projects. It was mentioned that the public could benefit the most since this solution could enable them to imagine and visualize the construction project more easily and convey a better image overall. Municipalities could benefit the most since the proposed solution could simplify the approval process for building applications as mentioned by *E3*. *E4* thinks municipalities could save money because of less legal work and faster communication around building permits. Furthermore, they would have to develop less regulatory frameworks in the first place according to *E4*. "Municipalities could benefit the most from such a solution with a high degree of automation, where nobody must create new point clouds manually, otherwise they might not do it since it is connected with the risk of not creating a correct point cloud or making other mistakes", says *E5*. Installation companies, who erect the construction spans, are also named as a party who could benefit from the artifact of this research by *E1*. According to *E1*, installation workers could visualize the correct position before and after erecting construction spans to double check their work, which could lead to less mistakes and therefore cost savings for the company. Lastly, *E4* mentions how architects could use the proposed solution to their advantage by enabling them to better explain their decisions to other stakeholders.

From the coding process of the interview, abstraction was a crucial point. An answer related to abstraction has been given ten times by the five experts during the interview. Abstraction in this coding process means the ability to imagine a future building project. This keyword has been mentioned especially in answer to question 8 “What is your opinion on construction spans as a solution for visualization?”. The experts agreed on the abstract nature of current construction spans in Switzerland. The answers were balanced, meaning that the experts find construction spans to be a poor practice but appreciate that there is a way to transparently visualize construction projects in Switzerland. The experts mentioned how construction spans are not providing enough information for people to imagine what a future building would look like. This information includes shape, height as well as additional information such as shadows and reflections. *E5* brings up the point that in an increasingly digital world there should not be more than a simple physical reference on a property linking to the digital visualization needed. *E1* mentions that often the erection of construction spans is not done accurately. Combined with the fact that the accuracy of construction spans is not always correctly checked, a wrong construction span will convey the wrong image to all the stakeholders involved. Furthermore, the appearance of construction spans has been criticized. *E2* describes how construction spans are obstructing the view and are defacing the city- and landscape.

Resulting from the coding process of the interview, the category effort has been mentioned eight times in different contexts. Effort describes the effort and time that stands in connection with the use of the proposed solution. *E2* as well as *E4* see a hurdle in the need for a smartphone application. Also, users will need a stable internet connection and the knowledge how to use the app. So, users should be able to quickly get access and open up the experience. This goes in the direction of the argument of *E5* for having a single reference in the field and being able to link the digital experience from that. *E5* associates further effort with the proposed solution in that the users might not be willing to take pictures of the environment to create new point clouds. According to *E1* as well as *E5*, here a method has to be found to georeferenced and integrate existing point clouds into the proposed solution to increase the level of automation and make it more attractive to stakeholders. The category accessibility describes if the solution is transparent and if any stakeholder can use it. On one hand *E1* describes the solution as less accessible since people who are not tech-savvy are less likely to know how to use it, while on the other *E3* and *E5* find the solution more accessible since it can be easily used by people who cannot read plans which can dissolve inhibitions and allows them to engage and start discussing right away.

Another point the experts have mentioned during the interviews is the limitation of the AR-technology regarding the hardware as well as the software. According to *E5* it is not sufficient if users are simply able to visualize a model, they also need to be able to move around while the model stays at the same location as intended. Also, *E3* as well as *E4* describe the technology as not being ready and not working properly outdoors respectively. The stage in which the experts find themselves regarding the use of AR in their company based on their answers could be described as still in a researching (*E1, E2, E4*) or an early testing phase (*E3, E5*). More recommendations and opinions from the experts are mentioned in chapter 4.2 and will flow into the development of the artifact.

4.2 Results of the development of the artifact

The development of the artifact begins with the creation of a new Unity project. This is done via the Unity Hub, where unity versions can be installed and managed. This is also the place where modules for the different platforms can be added. In this project the modules for Android and iOS development are added. On the Unity Hub version the supported platforms are listed which can be extended with additional modules. The supported platforms in this case are Android, iOS, and Windows. Windows hereby is used for assessing the application on the laptop first before deploying it to a mobile platform. The new project can then be created. Firstly, AR Foundation from Unity must be installed to support Android as well as iOS devices. Additionally, the platform specific packages ARCore (Android) as well as ARKit (iOS) must be added from the Unity Package Manager window for registering their device specific inputs and sensors. In the following step the SDK of the VPS Immersal can be imported into the Unity project as well. The SDK can be found in the developer portal of Immersal. Immersal also already provides several sample scenes in their public GitHub repository. Among those are indoor navigation, content placement and mapping sample scenes. The whole application is split into four scenes which will be presented one by one subsequently.

4.2.1 MainMenu Scene

The main menu scene is the scene that is being displayed when starting the application and contains a brief description of the project on the user interface. Below the description there are three buttons for choosing one of the three different scenes mapping, visualizer, or planner. The buttons call the "LoadScene" method from the "SceneLoader" class and for this, take an integer as an input which represents the number of the scene in the build order. The build order is shown inside the brackets in figure 13.

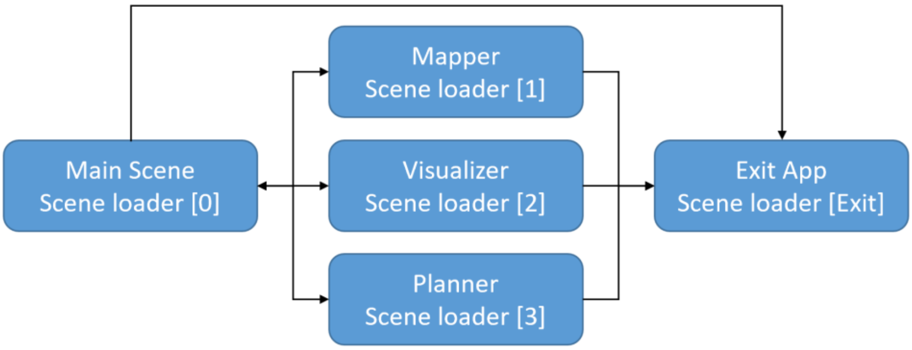

Figure 13: Scene build order

The "SceneLoader" class also contains a "Exit" method, which also can be called from a button on the user interface to quit the application. The exit method can be called from any scene at any time in case the user wants to quit the app. Also, scene 1-3 can always jump back to the main scene.

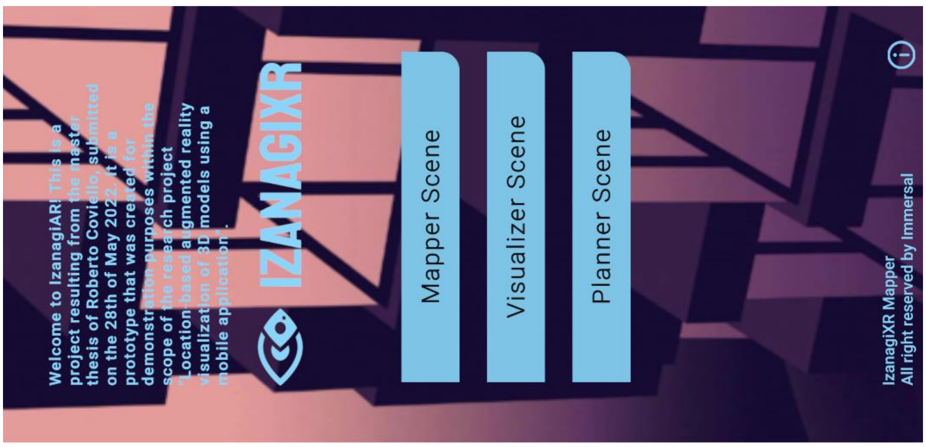

Figure 14: MainScene User Interface

Figure 14 shows the User Interface of the main scene. The description and the logo of the application are located on the upper part, the buttons for choosing the scenes are in the middle of the user interface with the button to quit the application on the bottom right.

4.2.2 Mapping scene

The mapping scene is built on basis of the mapper sample from the Immersal GitHub repository. The starting screen of the mapper scene contains a login panel. The user enters their e-mail address and password of their Immersal account. The URL to the Immersal server is being filled in automatically by Immersal using their own REST-API.

The "PlayerPrefs" in the Awake method of the LoginManager class saves the data to the user's device so the login data will automatically be filled in the next time the user wants to login. After these three fields are filled in the user can click on the login button to call the "OnLoginClick" method of the "LoginManager" class that allows the application to call the "Login" method after checking if the fields have been field in correctly. The "On-LoginClick" checks if the fields email and password are filled in, if so, it calls the "Login" method which logs into the Immersal account of the user, using Immersal's "Job-LoginAsync" API.

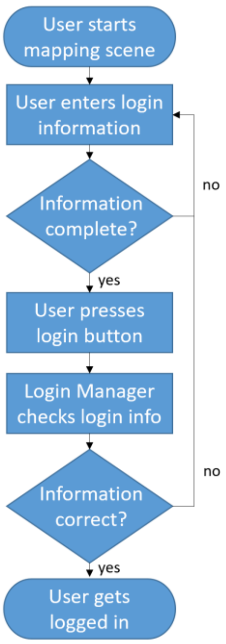

Figure 15: Login flowchart

After the user has logged in, the mapper UI is displayed. The user can switch between a workplace and a visualize mode which are the children GameObjects of the mapper UI which contains all the components that control the behavior of the UI. This can be achieved by simply adding Unity UI canvases to the scene and set the render mode to screen space overlay, which means the canvas will be overlayed and sits fixed on the screen. The visualize mode is deactivated when the workplace UI is enabled and vice-versa. As can be seen in figure 16, every reference to every UI element is saved on the "Mapper Settings" script component on the Mapper UI.

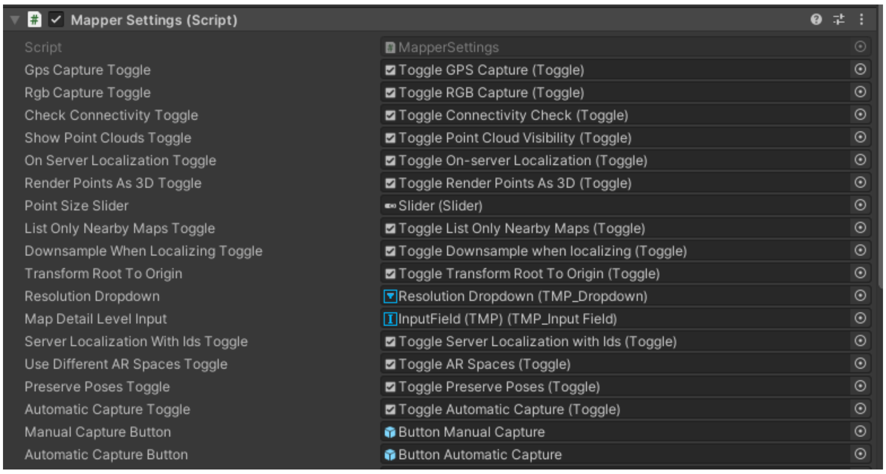

Figure 16: Mapper Settings component on the Mapper UI

All the Settings shown above are being saved in "PlayerPrefs". PlayerPrefs is a class that keeps track of the preferences of the player between game sessions. It can save string, float, and integer values in the platform register of the user. This means the application will remember the settings set by the user.

In the workplace mode the user has the option to collect new pictures through a method that calls REST-APIs from Immersal that get the position of where the picture has been captured from. Further settings in the workplace mode are if the user wants to additionally capture the GPS data of each image, capture the image in color or just black and white, check if the image is connected to the previously captured image or lastly delete or submit the capture images. Before submitting the images for map construction and anchor image must be set which is a normal image taken by the user but in the end will represent the zero-point of the constructed map in the end. The user can name the map and submit it for construction if all images have been taken. The images are then sent to the Immersal servers in a PNG format. Furthermore, the user can jump back to the menu or completely quit the application but as mentioned before, the other settings as well as the images taken will be saved locally on the user's device with the help of "PlayerPrefs". The captured images can be saved to the map with the help of a REST-API from Immersal called "SDKImageRequest" shown in figure 17.

```
[Serializable]
public class SDKImageRequest : SDKRequestBase
{
    public int bank;
    public int run;
    public int index;
    public bool anchor;
    public double px;    // camera x position
    public double py;    // camera y position
    public double pz;    // camera z position
    public double r00;   // rotation matrix row 0, col 0
    public double r01;   // rotation matrix row 0, col 1
    public double r02;   // rotation matrix row 0, col 2
    public double r10;   // rotation matrix row 1, col 0
    public double r11;   // rotation matrix row 1, col 1
    public double r12;   // rotation matrix row 1, col 2
    public double r20;   // rotation matrix row 2, col 0
    public double r21;   // rotation matrix row 2, col 1
    public double r22;   // rotation matrix row 2, col 2
    public double fx;    // camera intrinsics focal length x
    public double fy;    // camera intrinsics focal length y
    public double ox;    // camera intrinsics principal point x
    public double oy;    // camera intrinsics principal point y
    public double latitude;  // WGS84 latitude
    public double longitude; // WGS84 longitude
    public double altitude;  // GPS elevation
    public string b64;   // Base64-encoded PNG image, 8-bit grayscale or 24-bit RGB
}

[Serializable]
public class SDKImageResult
{
    public string path;
}
```

Figure 17: Save captured image to map

The visualize mode has the main purpose of enabling the user to download the map that has previously been created in workplace mode. The download map button calls a method that displays a list on the UI that shows all maps that have been geolocated in a predefined radius of the user. The list of maps can be obtained by calling a REST-API from the Immersal developer portal.

Figure 17 as well as figure 19 show several variables. The y-axis corresponds to the device's motion sensor hardware's detection of gravity which means the vector (0,-1,0) points downward (Apple Inc., n.d.-a). The rest of the coordinate system is determined by the device's location and orientation when the session setup is initially run. The application picks a basis vector (0,0,-1) perpendicular to the gravitational axis and pointing in the direction the device camera looks for the z-axis (Apple Inc., n.d.-a). The basis vector (1,0,0) is orthogonal to the other two axes and points to the right (Apple Inc., n.d.-a) as shown in figure 18.

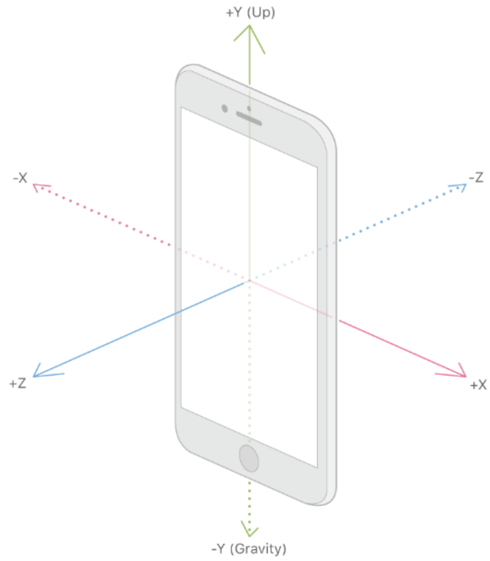

Figure 18: X and Z directions relative to the device's initial orientation (Apple Inc., n.d.-a)

The latitude and longitude are replaced by the actual GPS data from the user's device during runtime. The images can also be localized by using a Immersal REST-API. The result is a projection matrix in the AR Cloud space. It can be used to extract the position and rotation of the device, which then can be combined with the device's SLAM tracking.

```
[Serializable]
public class SDKLocalizeRequest : SDKRequestBase
{
    public double fx;    // camera intrinsics focal length x
    public double fy;    // camera intrinsics focal length y
    public double ox;    // camera intrinsics principal point x
    public double oy;    // camera intrinsics principal point y
    public string b64;   // Base64-encoded PNG image, 8-bit grayscale or 24-bit RGB
    public SDKMapId[] mapIds;  // list of maps to localize against
}

[Serializable]
public class SDKLocalizeResult : SDKResultBase
{
    public bool success;
    public int map;      // ID of the map if localization was successful
    public float px;     // x position within the map
    public float py;     // y position within the map
    public float pz;     // z position within the map
    public float r00;    // rotation matrix row 0, col 0
    public float r01;    // rotation matrix row 0, col 1
    public float r02;    // rotation matrix row 0, col 2
    public float r10;    // rotation matrix row 1, col 0
    public float r11;    // rotation matrix row 1, col 1
    public float r12;    // rotation matrix row 1, col 2
    public float r20;    // rotation matrix row 2, col 0
    public float r21;    // rotation matrix row 2, col 1
    public float r22;    // rotation matrix row 2, col 2
}
```

Figure 19: Localize images

Figure 19 shows the "SDKLocalizeRequest" API from Immersal to localize images inside the application.

To fully understand figure 17 and 19, one must also understand the remaining variables r00 to r22 which are of significant importance. Variables r00 to r22 describe the intrinsic matrix. The intrinsic matrix (abbreviated as K in equations as seen in figure 20) is based on the device camera's physical features and a pinhole camera model (X. Chen et al., 2021). On an image plane, you may utilize the matrix to convert 3D coordinates to 2D coordinates (X. Chen et al., 2021).

$$K = \begin{bmatrix} f_x & 0 & o_x \\ 0 & f_y & o_y \\ 0 & 0 & 1 \end{bmatrix}$$

Figure 20: Intrinsic matrix (Apple Inc., n.d.-b)

This means that r00 is the value from the first row of the first column, r01 is the value of the first row and second column, r22 is the value of the third and last row of the third and last column and so on. The pixel focal length is represented by the numbers fx and fy, which are the same for square pixels (Apple Inc., n.d.-b). The values ox and oy are the primary point's offsets from the picture frame's top-left corner. Pixels are used to express all values (Apple Inc., n.d.-b).

Furthermore, the visualize mode offers the options to show or hide the downloaded map, render the point of the map (point cloud) in 3D or 2D, a slider to adjust the size of the points, to list only nearby maps in a predefined radius or all maps from the user's account or to align the currently active or downloaded maps into one big map. As well as in the workplace mode, in the visualize mode there is also an option to return to the menu or quit the application. The map is being downloaded into the map in a BYTES format. Additionally, the Immersal server sends back a metadata file in the JSON format that contains all the necessary information such as longitude, latitude, and altitude.

The last feature of the mapper scene is the download and alignment of the 3D model that the user wants to place into the constructed map. For sending the asset bundles to the web server an FTP client is used. This paper uses FileZilla as the FTP client which allows the user to upload the asset bundles in binary mode. FTP binary mode is used to transport files without modifying or converting them (Bajo, 2013). Files are transported without being converted, thus the source and destination computers receive the same file (Waters, 2015). This step is crucial for the asset bundles to be correctly loaded into the application at runtime (Waters, 2015).

Figure 21 shows an overview of the procedure for the mapper scene from login to map creation, through the download of 3D models to their positioning and the storage of which position relative to which map (point-cloud).

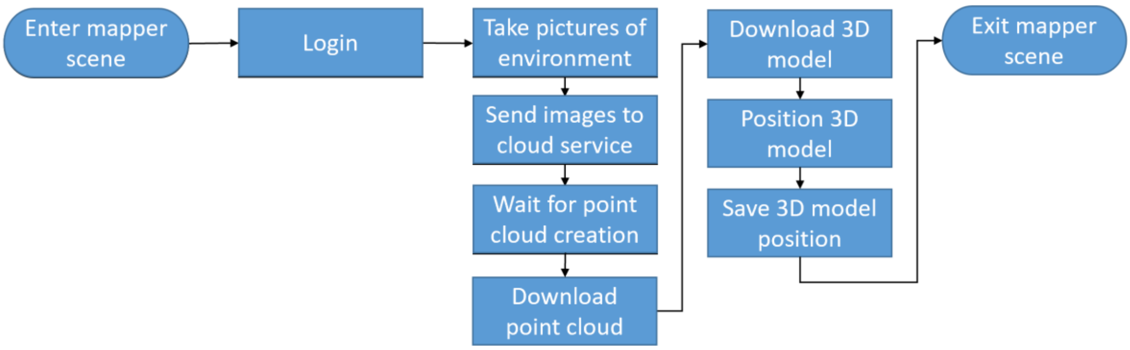

Figure 21: Mapper scene procedure

The map or point-cloud is accessible directly in the Immersal developer portal and looks like presented in figure 22. During the runtime of the application, it gets downloaded directly from the portal without manual setup in the BYTES format.

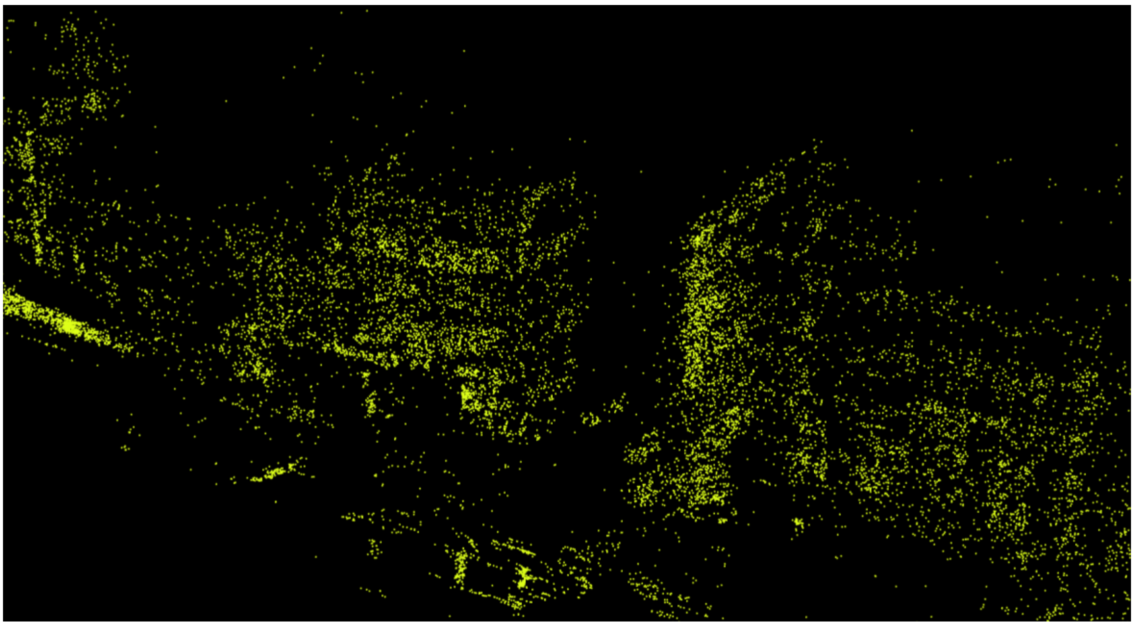

Figure 22: Sparse point-cloud example from a street with buildings

Also accessible in the developer portal is a denser point-cloud for visualizing the point-cloud or check which quality from the web-based portal. The dense point-cloud is shown below in figure 23. The dense point-cloud is helpful to the developer to visualize the sparser point-cloud in the BYTES format.

Figure 23: Dense point-cloud example from a street with buildings

4.2.3 Visualizer scene

The visualizer scene is a simplified version of the mapper scene. It also has the functionality of downloading a desired point-cloud after it has already been created and the model has been aligned in the mapper scene. Therefore, the visualizer scene is primarily designed for users who do not actively contribute to the application such as in taking images or uploading 3D models but exclusively use it to visualize a construction project quickly and simply. Therefore, it is the most used scene in the application by most stakeholders and at the same time the simplest one for easy access and use. Since the image localization as well as the download of the point-cloud work identical to the mapper scene, it is not further elaborated at this point. A particularity of the visualizer scene however is that the position and type of model gets loaded automatically into the scene, depending on the point-cloud from which construction project the user chooses to load. Depending on the point-cloud a reference between the point-cloud and the 3D model is loaded from a JSON file that keeps all references that are saved during the mapper scene.

4.2.3.1 Planner scene

The planner scene is completely decoupled from the VPS and acts as a quick demonstration tool which is especially aimed at project managers, architects or office personnel who quickly want to visualize the construction project onto any flat surface such as the floor or a table. To achieve this, the planner scene also takes some functionalities from the mapper scene. Namely, it uses the ability to download 3D models at runtime from the web server. Only in this scene nothing is being saved or manipulated, hence the user interface is kept simple and intuitive. 3D models can be downloaded, moved, and rotated, so that developers, architects, or other stakeholders are able to share the construction product with other interested parties wherever they are and if they have a flat surface around them. One peculiarity in this scene however is the possibility to also scale the 3D model since it will not be possible to visualize a project indoors in its full scale. With a scaling function however, stakeholders will still be able to scale the project to its full size and visualize it wherever there is enough space.

4.2.4 Analysis of similar solutions

This last section of the development chapter investigates alternative solutions to the proposed artifact. According to the experts, they are not familiar with any solution that is similar to the artifact or would be used for the same purpose. *E1, E3, E4* and *E5* have been researching about visualization solutions and even created a list of viable solutions. Concluding from the literature research, commercial or scientific AR applications or prototypes with a focus on location-based information are scarce. Xu & Moreu (2021) summarize the development of AR prototypes in the construction and civil infrastructure industry in their paper. However, these solutions are not relevant in this analysis since none of them is utilizing the capabilities of VPS. Nonetheless, there are prototypes which are used for checking the difference between on-site structures and design models (Xu & Moreu, 2021). GPS and orientation tracking technologies were applied in the development of the ARVISCOPE system to represent models dynamically (Xu & Moreu, 2021).

This paper, however, focuses on applications in the field of collaborative visualization of virtual information such as 3D models of buildings. Here, as mentioned before, the research is very scarce and primarily focuses on the development of indoor location-based augmented reality or outdoor navigation systems (Takeuchi et al., 2021; H. Zhang & Ye, 2020). As for visualization prototypes, ARVita was created by Dong et al. (2013) for the collaborative visualization of several users using HMDs. All users may interact with the dynamic images of real-time building processes with ARVita (Dong et al., 2013). Soman et al. (2017) created an app that allows designers and field workers to share augmented reality images. The localization of AR systems in an outdoor environment is one of the main challenges today (Pereira et al., 2020, p. 5666; Xu & Moreu, 2021, p. 8), which in the majority of cases is addressed by utilizing GPS nowadays (Kaddioui, Shahrour, & Oirrak, 2019; Ortega et al., 2019). These prototypes from the above-mentioned research papers are usually created to rapidly solve research problems, however they aren't very versatile since they are created for very specific purposes (Xu & Moreu, 2021). Using a robust commercial AR solution is typically recommended unless a researcher wishes to create a specific AR system for a specific study endeavor (Roitman, Shrager, & Winograd, 2017; Xiangyu Wang & Dunston, 2013). The most commonly mentioned commercial solution is Trimble, which is based on highly accurate GPS signal. Below is a table that presents similar solutions, what their underlying technology is, what their prices are and what their primary use case is.

Table 7: Analysis of solutions

Solution	Price	Operating System	Localization Technology	Primary use case
IzanagiXR	-	Android & iOS	GPS, VPS, SLAM	Visualizing location-based data
Trimble Sitevision	$3415 + 263/month	Android	GPS, GLONASS, Galileo, QZSS, SBAS	Visualization and measuring
ViewAR	$250/user/month	Android & iOS	Markers, 3rd party (Matterport, PTC, Placenote)	Indoor navigation, remote assistance
BIM Facility	-	Windows	Virtual Reality	BIM visualization
Arki	- (Beta)	iOS	LiDAR photogrammetry	Visualizing location-based data
ARloopa	$14.99/month	Android & iOS	Image-recognition, computer vision	Marketing, navigation

It can be concluded that currently there are no competing solutions to the one suggested in this research, especially considering the price class where it is presented in and the technology it is utilizing for its localization capabilities. Trimble provides fully accurate positioning while being used with a mobile phone, however due to its price point and the fact that it only supports special Android devices, this solution is not suitable for the broad public and therefore not appropriate for the area of application presented in this research.

4.3 Results of the estimation of the cost share of construction spans

Firstly, this paper aims to estimate the average cost of building a house or apartment building in Switzerland. According to Ofri (o. J.) the construction of an apartment building in Switzerland costs between CHF 2’385 and CHF 3’870 on average per square meter, therefore a price of CHF 3’128 per square meter is assumed. Ofri is an online marketplace that connects craftsmen or service providers with customers. Their numbers are based on prior offers submitted through their website. Since there have been around 28’000 offers and they had an offer volume of CHF 45 mio. in 2019 this section continues with these numbers from Ofri (Startupticker, o. J.).

The SFSO only offers data about how expensive the average Swiss apartment is. The number of square meters required to build an apartment building varies greatly and is not stated by the SFSO. It is therefore an average of 450 square meters assumed (Bundesamt für Statistik, n.d.-c). The average price for construction land in Switzerland is CHF 700 which amounts in this example to CHF 315’000 for the land. Calculating it together with the cost of building an apartment building per square meter, we get an estimated price for constructing an apartment building of CHF 1’722’600, which according to *E1* is on the lower side and less for cantons like Zurich and Geneva, where construction land can cost up to CHF 2’000 and even much more than that (“Wie viel kostet Bauland in der Schweiz?,” n.d.). Therefore, in this example additional construction costs, which are around 5.9% (“Was kostet es ein Haus zu bauen?,” 2020) of the whole construction cost, amount to about CHF 101’633.40.

Assuming an average price for construction spans for a single-family house for one year of 1’200 CHF to 1’500 CHF (*E1*) the costs of construction spans could amount to about 1.1% to 1.4% of all additional construction costs and around 0.06-0.1% of total construction costs. Also, there will be additional costs if there is an appeal proceeding for the construction span by a stakeholder (Walker Späh, 2010, S. 7) which is not considered in this paper. In 2018, CHF 67.3 bio. were incurred in construction expenditure in Switzerland (Wöhrmann, 2021). Of this, the costs for building construction (ger. Hochbau) amount to CHF 52.3 bio. and the costs for civil engineering (ger. Tiefbau) amount to CHF 15 bio. (Wöhrmann, 2021). Approximately 25% of this expenditure comes from public-sector commissioners (Wöhrmann, 2020) such as the federal government, the cantons, and the municipalities. 75% of the investment is therefore from private commissioners such as private individuals, institutional investors, or real estate companies.

Applying the previously calculated share of 0.1% of construction spans in the total costs of construction project to the amount spent on building constructions, we get an approximate yearly amount spent on construction spans in Switzerland of about CHF 53.8 mio. Therefore, the federal government of Switzerland and its cantons and their respective municipalities alone are spending CHF 13.45 mio. per year on construction spans. To put this into perspective, this amount corresponds to 0.21% of the total annual expenditure on education and research (CHF 6.427 bio.) which make up 10.9% of the total federal expenses in Switzerland for the year 2022 according to official numbers from the Swiss Federal Finance Administration (EFV) (2021). In Zurich alone, the public sector spent CHF 1.782 bio. in 2016 on building constructions (Statistisches Jahrbuch des Kantons Zürich 2020, 2020, S. 228). The share of costs of the construction span paid for by the public sector in this Zurich therefore amount to at least CHF 1.5 mio. in 2016. With a total amount of CHF 8.77 bio. spent on building constructions (public and private sector) in Zurich in 2016, the share of costs of all construction spans amount to roughly CHF 7 mio. It is important to note that these numbers are the very minimum and calculated on basis of conservative estimates and the least expensive construction spans on a perfectly even terrain. Furthermore, these construction span numbers are primarily for simple residential buildings. According to *E1*, other more complex and higher construction projects can incur a significantly higher cost for construction spans. A concrete example of how expensive construction spans can get is the construction of two high-rise buildings in Lucerne's Allmend, which required huge metal constructions. According to the construction company, the costs of the entire project amounted to around CHF 24 mio („Wohntürme Hochzwei“, o. J.). The costs of the construction spans alone amounted to CHF 150,000 (Martinu, 2008), which was 0.63% of the whole project costs.

As can be seen from this example, the cost of construction spans can vary greatly according to the project's height and complexity and of course by far not all construction projects are simple apartment buildings. In fact, as of 2020 there are in total 1'765'551 residential buildings in Switzerland, 1'003'710 of which are single-family homes and 481'382 are apartment buildings (Bundesamt für Statistik, 2021b). Additionally, as can be seen in figure 23, there are many more construction projects that are not residential and are vastly different in their size and complexity as well. The paper focuses solely on residential buildings such as single-family homes and apartment buildings since other categories such as infrastructure, education, transportation, agriculture, and forestry as well as industry and commercial projects vary greatly and cannot simply be estimated.

Since the SFSO provides the investment amounts of each category already, the cost estimation of the construction spans and the number of projects in each category is needed to calculate the cost share of construction spans in the total construction project. To get a cost estimation from Keller+Steiner AG, the most impactful cost driver, namely the height of the average building in each category must be defined. The building size is defined by the number of floors or apartments in the building. In Switzerland, more than half of the buildings with residential use are single-family houses (Bundesamt für Statistik, 2021a). This situation is clearly reflected in the building structure according to the number of floors, which can be seen in figure 24. 88% of single-family houses and 77% of all buildings with residential use have two or three floors (Bundesamt für Statistik, 2021a). In the case of apartment buildings and buildings with secondary use, more than two thirds (71%) have at least three floors (Bundesamt für Statistik, 2021a).

Buildings by building category as well as construction period and number of stories **T 09.02.02.02**
2020

	Building with residential use					
	Total	With ... floor(s)				
		1	2	3	4	5+
Total	**1 765 551**	**123 497**	**820 918**	**543 607**	**162 667**	**114 862**
Single-family houses	**1 003 710**	**102 019**	**614 099**	**266 836**	**18 685**	**2 071**
Apartment buildings	**481 382**	**4 351**	**110 057**	**191 534**	**104 969**	**70 471**

Status at December 31, 2020
Source: BFS – GWS
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Office (FSO), POP Section, info.gws@bfs.admin.ch, Tel. 058 467 25 25

Figure 24: Buildings by number of floors (Bundesamt für Statistik, 2021b)

For single-family houses, an average amount of floors of 2.4 is assumed, for apartment buildings as well as commercial buildings 3.2 floors on average is assumed. Furthermore, for residential buildings an average floor height (not room height) of 2.8 m is assumed (Kanton Luzern, n.d.), for commercial buildings an average floor height of 3.5 m is assumed (Architektvergleich.ch, n.d.). The categories together with details about height that can be found through literature research are then combined into a table that can be presented to Keller+Steiner AG.

Table 8: Average height of each category

Categories	Average height per floor	Total average height
Road construction	Vastly different	Vastly different
Residential building	2.8 (Kanton Luzern, n.d.)	6.72m / 8.96m
Infrastructure	Vastly different	Vastly different
Agriculture and for-	Vastly different	Vastly different
Commercial build-	3.5 (Architektvergleich.ch, n.d.)	11.2m

The SFSO states that in 2019 11'126 new residential buildings have been constructed (Bundesamt für Statistik, n.d.-a). Since only the investment amounts from 2016 are known, as can be seen in figure 25, assumptions must be made about the development of the construction expenditure in 2019. According to numbers from the SFSO we can see that at least until 2018 the construction expenditure has decreased slightly by approximately 2-3% since 2016 (Bundesamt für Statistik, n.d.-a). Adding up all investments for residential buildings from public and private clients CHF 31.594 bio. have been spent in 2016. Considering a decrease in construction expenditure of 3% this means there would be investments of CHF 30.646 bio. in 2019. Dividing the total construction costs through the 11'125 equals an estimated average investment per project of CHF 2'754'697.

Now, according to *E1* the simplest and least costly case for construction spans would be a simple single-family home or apartment building without extensions or complicated architecture or terrain that requires six metal poles which are up to 12 m high. The price for such a construction span on a perfectly flat terrain would amount to CHF 1'247. Are there slightly higher poles needed up to 15 m, the price for construction spans would amount to CHF 1'380.90. According to *E1* and his database at Keller+Steiner AG it is not unusual for projects to be built on more complex terrain or in need of higher poles. "These prices are highly individual and hard to estimate", clarifies *E1*. The information from *E1* and Keller+Steiner AG allows rather a calculation with the most frequent data, therefore the median and less with average values. However, this paper aims to deliver a rough estimate to the reader of the cost share of construction spans in the whole construction project. Assuming that the median lies between the previously calculated conservative cost of building a house in Switzerland of CHF 1'722'600 and the average investment per project for a residential building of CHF 2'754'697 in 2016, the cost estimation continues with a value of roughly CHF 2.2 mio, including single-family houses as well as apartment buildings. For a building that may have four floors instead of three and is located on an uneven slope, the cost of a construction span increases sharply and can be ten times the price of a simple construction team very quickly. Considering the numbers from Keller+Steiner AG, it is estimated that the cost share of construction spans in the whole construction project is in the range of 0.06 to 0.7% for most construction projects. This could mean that the Swiss federal government, its cantons, and municipalities, which had a construction expenditure of CHF 16.825 bio. in 2018, spends between CHF 10.1 mio. and CHF 117.8 mio. on construction spans per year. Considering the total expenditure for construction projects for public and private clients the cost could amount to between CHF 40.38 mio. to CHF 471.1 mio. per year, which is highly dependent on the complexity and height of the average project in that period. For contrast figure 25 illustrates the Swiss government spending of 2021.

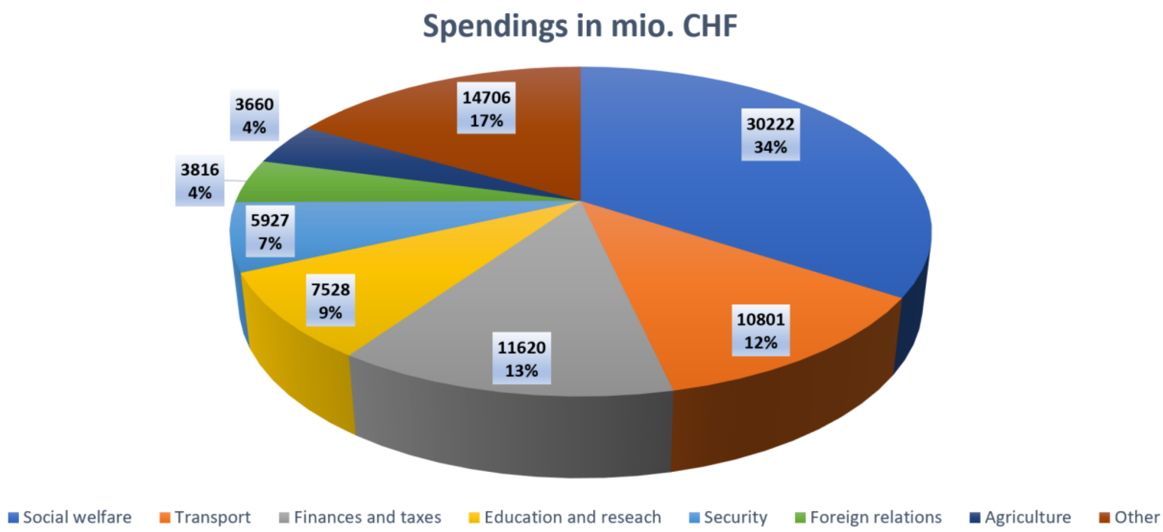

Figure 25: Swiss federal government spending (EFV, 2021)

To conclude the Swiss federal government had a spending of CHF 88.334 bio. in 2021. This means at least 0.012% up to 0.13% of the whole federal budget or potentially even more have been spent on construction spans alone in 2021 which could be used for social welfare, transport, education, and research or any other of the above-mentioned sectors. Important to note is, it is recommended to use the lower end of this estimate as it represents the normal case according to *E1*, who himself estimates the whole construction span market to around CHF 80 mio., which is right at the lower end of the estimation of this research paper. Furthermore, according to *E1*, a trend can be observed that the height of buildings and the complexity of where they are being build is steadily increasing.

5 Discussion

The discussion chapter is going to briefly reiterate the research problems and questions. Afterwards, the key findings from the results chapter are going to be summarized. Subsequently, these findings are interpreted and set into the appropriate context.

This research work is dedicated to the Swiss peculiarity of construction spans, the metal poles that must be physically erected before any construction project begins. Their purpose is to draw attention to the fact that a construction project is open to the public and that the plans can be inspected by interested parties (Walker Späh, 2010, S. 5). This should make it clear to all those affected on site whether and to what extent the new construction project will affect the surrounding area. Although in most cases it is sufficient to express the building cube with its horizontal and vertical extension in a simplified way (Walker Späh, 2010, S. 6), the erection of metal poles leads to a disfigurement of the landscape. Furthermore, a building structure must be erected prior to the submission of the building application and must remain in place until the building permit and any appeal proceedings have been legally resolved (Bösch, 1993, S. 481ff.).

This paper has sought to determine whether and in what way it is possible to replace the physical set-up of metal poles with augmented reality visualization. in the case of augmented reality, information is immediately integrated into a person's real-world view of the activity allowing for more efficient retrieval and visualization of data (Xiangyu Wang et al., 2014, S. 97). Technically, augmented reality (AR) may place digital information in the physical setting of a workstation, in this case inside the predetermined construction area, in real time (Xiangyu Wang et al., 2014, S. 97). AR therefore has the potential to replace construction spans while offering interested parties the opportunity to visualize the construction project easily and accurately.

The aim is to find out what the benefits are and what requirements should be implemented to make the artifact useful. Furthermore, this paper aims to find out for which stakeholders this application would be the most useful. An important aspect is also the potential cost savings in using AR which was investigated in the estimation of the cost share of construction spans. The question which technical components are necessary for the realization of the artifact was explored in the development part of the artifact. Lastly, the paper seeks to find out which conditions are attached to the usability of the artifact. The paper aimed to answer this question in the interview part of this research with the help of the opinion of experts.

5.1 Findings of the expert interviews

They key findings from the expert interviews are presented in this part. According to the experts, engagement is an important reason one would want to use augmented reality as opposed to traditional ways of visualization. This statement goes in line with the research from Jessen et al. (2020) which elaborates on the captivating and enjoyable nature of AR use which in turn supports certain types of customer creativity. Their findings support a systematic process of innovative consumer engagement in which positive AR experiences drives customer creativity, which enhances expected satisfaction with the user's purchase decision (Jessen et al., 2020). Furthermore, the emerging marketing literature on AR (Heller, Chylinski, de Ruyter, Mahr, & Keeling, 2019; Hilken, de Ruyter, Chylinski, Mahr, & Keeling, 2017; Rauschnabel, Felix, & Hinsch, 2019) proposes that AR represents an enabling technology for customer engagement. It can be reasoned that by offering the visualization of construction projects, AR has the ability to lower the mental effort needed to participate in innovative actions (Chi et al., 2013, p. 118). Furthermore, in their study, Scholz and Smith (2016, p. 149) claim that building immersive experiences promotes customer involvement, which validates the experts' perspective.

The aspect of increased engagement is of such high importance for this research since the visualization of construction projects using AR would be predominantly used by the public or private individuals that are interested in new projects or projects that impact their immediate surrounding and therefore their life. Therefore, an artifact must be effective to the community or the public as a whole. Katika et al. (2022), for instance, suggest that AR, acting as an engagement tool, can increase end-users' perceived interest and engagement in circular economy concepts. It can also assist to close the gap between government and citizens, which has been shown to influence circular economy adoption in this particular case (Huijts, Molin, & Steg, 2012; Perlaviciute & Steg, 2014). The experts further believe that AR is capable of displaying complex information in a more understandable manner. Other researchers have suggested that AR can assist people to adjust their perspective or frame of reference, helping them to better grasp complicated events like new economic models and concepts (Dede, 2009). This is also backed by study results which state that ICT technologies have a good influence on citizen involvement (Mukhtarov, Dieperink, & Driessen, 2018; Stern, Gudes, & Svoray, 2009). Lastly, the findings of Jessen et al. (2020) show greater social involvement and community cohesiveness, rapid technology dissemination, and relevance, all of which address fundamental shortcomings of existing ICT engagement techniques (Peoria, 2020; Porra & Hirschheim, 2007; Stern et al., 2009). This is a relevant finding for this research because the experts also suggested that the broader public might be the stakeholder that benefits the most from the artifact developed in the context of this research. This is on one the hand because of the mentioned increased stakeholder engagement but also because the experts agree that AR can create a more collaborative atmosphere. Important to note is that, because of the increased engagement and comprehension, the experts believe that the use of AR could lead to an increase of trust and a reduction of fear by the people to whom the information is presented.

E1 raises the point that such an artifact as presented in this research could be used complimentary to erecting construction spans and function as a tool for quality check and employee training. This statement is supported by the research of Sorko and Brunnhofer (2019) which states that the use of AR solutions offers a multitude of potentials in training such as reducing set-up and assembly times and that employees can be trained individually and error rates can be reduced (Sorko & Brunnhofer, 2019, p. 90). Webel at al. (2013) conclude in their study that because people receive the majority of information through their eyes and vision dominates perception in the majority of circumstances, information visualization is critical for building effective training methods and skill building (Webel et al., 2013, p. 401). In their 2013 study they also already mention the value AR trainings obtain from being able to link location-dependent information to physical objects (Webel et al., 2013, p. 402).

From the evaluation of the expert interviews, abstraction is a keyword that has been mentioned multiple times by the experts. In this instance abstraction describes the ability of AR to visualize the construction project in an understandable way and how it compares to construction spans. The experts mentioned how construction spans are not providing enough information for people to imagine what a future building would look like. This information includes shape, height as well as additional information such as shadows and reflections. The experts describe how on the one hand the construction spans do not deliver enough information and *E1* elaborates how also the mere accuracy of construction spans is a problem. The experts agree that AR could not only deliver a higher amount and better quality of information but also increase the accuracy and correctness of visualization. As mentioned earlier, according to Dede (2009) AR can assist people to adjust their perspective or frame of reference, helping them to better grasp complicated events. Porter and Heppelmann (2017) describe in their Harvard Business Review from 2017 why every organization needs an AR strategy. One of the main reasons is that AR improves people's ability to rapidly and accurately absorb information, make decisions, and execute tasks quickly and efficiently. This is due to AR's ability to overlay digital information directly onto physical surroundings, allowing users to process the physical and digital at the same time without the mental work of linking the two, according to Porter and Heppelmann (2017). Rezende et al. (2017) looked at AR-supported education and concluded that while conventional books requires students to use their imaginations to fully comprehend what is being discussed, augmented environments can lessen this abstraction by substituting two-dimensional graphics with three-dimensional objects that can be interacted with. Tang et al. (2003) have provided evidence already in 2003 that AR systems improve task performance and can relieve mental strain on construction and installation jobs. Therefore, it is established that numerous studies comment on the mental relief and therefore more efficient information reception that AR can offer users.

Another crucial point addressed by the experts is the accessibility of AR applications, which is also addressed in the development of the artifact of this study. The opinions of the experts are divided in this regard. While *E1* is describing the artifact as less accessible due to the technology illiteracy of general users, *E3* as well as *E5* find the proposed solution more accessible since it can be easily used by people who cannot read construction plans which can dissolve inhibitions and allow them to engage and start a discussion right away. Accessibility hereby not only describes the ability to use but also the possibility to use the app for people with impairments or barriers to entry. Elmqaddem (2019) describes how AR apps have become accessible through the spread of smartphones and tablets. Furthermore, learning becomes more pleasurable and effective as a result of the opportunities for visualization and realization of concepts made available to the learner through AR (Klopfer & Squire, 2008; Sumadio & Rambli, 2010). This piece of study is relevant for this paper since enjoyment while learning has a favorable benefit for individuals and organizations (Tews, Michel, & Noe, 2017, p. 52).

However, according to studies based on the diffusion of innovations theory, young, highly educated people, and males are more inclined to accept new technologies, which might impact the adoption of AR apps (Atkin, Hunt, & Lin, 2015; Rice & Pearce, 2015). This implies that female and older people are less likely to use AR apps which in turn supports *E1*'s claims. Also, according to Arifin et al. (2018) because of the simplicity with which non-professionals may design AR applications today, user experience (UX) is frequently overlooked in the development, and there are currently no standard UX measures for AR apps. However, as Dutta et al. (2022) point out and as have been mentioned before, having fun and being excited to try something out, which AR tends to create an ideal environment for, can increase the chances of the user to learn a piece of information or technology more efficiently. To conclude, there are currently no studies which suggest that AR apps are easier or more difficult to use than regular mobile applications. However, the nature of AR being exciting and intuitive can increase the chances of users learning faster.

Lastly, concerns were raised by the experts regarding the readiness of AR hard- and software. According to *E3*, *E4* as well as *E5* existing AR hardware and software-solutions are not ready yet to be deployed outdoors. Of course, this statement strongly depends on what one wants to achieve with AR. If the statements of the experts are related to the artifact presented in the paper, indeed some difficulties can be identified, which will be discussed in the following findings of the development of the artifact.

5.2 Findings and improvements of the artifact

When developing AR solutions for outdoor scene there are indeed still many challenges. All the way back to 1999, Azuma et al. (1999) concluded in their study about how to make AR work outdoors that none of the available tracking methods at the time provides a complete solution on its own. Localizations methods such as VPS have emerged and improved significantly since then and are able to provide tracking for AR application on their own. However, the claim from Azuma et al. (1999) still holds true when talking about one single solution that provides very precise tracking on its own in an outdoor context (Dad et al., 2018).

For example GPS can only be used outdoors and also only provides an accuracy of a few meters within the actual range of the user under good conditions (Dad et al., 2018). While VPS provide superior accuracy compared to GPS (Treuillet & Royer, 2010, p. 484), VPS are usually used indoors, since factors like light, reflection and the change of scenery of an area for example due to the change of seasons can affect the accuracy significantly (Anup et al., 2017; Ruizhi & Liang, 2017; Yadav et al., 2018). It was therefore projected by Azuma et al. (1999) that hybrid tracking is the only feasible approach for providing satisfying accuracy, which is still widely accepted nowadays (Akula et al., 2011, p. 641; Chi et al., 2013, p. 117). A disadvantage when using hybrid localization methods, as described by Azuma et al. (1999), could be that the system complexity and at the same time the cost increases. However, the weaknesses of individual sensors or tracking methods are compensated for by another sensor, resulting in a more robust overall system than if each sensor were used separately (Akula et al., 2011; Azuma, 1999; Bailey & Durrant-Whyte, 2006; Klein & Murray, 2007; Talmaki et al., 2010). A user operating outdoors, unlike in an indoor setting, has an infinite number of potential locations and orientations (Behzadan et al., 2008, p. 91). This implies that most indoor location systems that rely on pre-installed infrastructure like trackers and markers may not be stable or scalable enough to handle all conceivable user scenarios (Behzadan et al., 2008, p. 91).

Looking at AR hardware, while smartphones are more affordable and accessible than smart-glasses (Shapira, 2020), smartphone's sensors are still limited especially in terms of camera capabilities (Zheng, Li, & Jiang, 2013, p. 26). However, as shown in the results chapter, smartphones have and will continue to have a significantly higher market share than smart glasses. Since the artifact of this research aims to be used by the public, this is an important consideration to make. Furthermore, smartphone capabilities are constantly improving. According to Rotsidis et al. (2019) AR has increasingly gotten more accessible and inexpensive as mobile computer capability has improved, which is a trend this research made use of. Since the development of the artifact did not produce concrete findings but more of an artifact that can be used for further studies or testing, this section continues to offer improvement recommendations for the further development of the artifact. There are numerous improvements recommended to add to the artifact.

Firstly, the artifact laid little focus on the UX as described by Arifin et al. (2018). For tests with subjects the UX of the artifact should certainly be improved and simplified. Namely, the current artifact offers many settings that may be irrelevant or confusing to users. Secondly, the artifact is tied to a Immersal developer account. This means that a user that wants to use the application needs to login to their Immersal developer account. This issue could be solved by creating a middle layer where the users register and login to the application itself and use an Immersal account provided to them by the developer, or an effortless way to setup an Immersal account within the application. Thirdly, to create a point-cloud the user must take images with their smartphone manually. As proposed by *E5*, implementing a way of reusing already existing and highly accurate point-clouds from companies could be a significant value driver for the proposed solution. It would also eliminate an error source, since in this case professionally created point-clouds could be used instead of manually created ones using smartphones. Fourthly, the digital 3D models that the user wants to visualize in the physical world must be uploaded to a database as Unity AssetBundle. This means the 3D model must be prepared and converted inside Unity to be uploaded and then be downloaded again during runtime. Optimally, the user could upload their 3D models to an online database where the software converts them and stores them correctly to be used inside the application. This could potentially be achieved through a pipeline that takes the user's 3D models as input.

5.3 Findings of the estimation of the cost share of construction spans

This section discusses the findings of the estimation of the cost share of construction spans measured on the whole investment of a building project.

Due to the lack of literature on this topic, calculations and assumptions were based on statements made by expert *E1* from Keller+Steiner AG, which is one of the largest and best-known companies for construction spans in Switzerland and official numbers from the SFSO. Combining estimations from *E1* with statistics from the SFSO allows for a quite accurate estimation of the market volume of construction spans and in turn an estimation of their share in construction projects. For a more accurate estimation two calculations which are based on slightly different assumptions on house prices especially were combined. The first estimation results in a cost share of between 0.06-0.1% and the other one of 0.06-0.7%. The first estimation was simply made with a low-end construction investment and a minimum price for quite simple construction spans. This of course is not the usual case, especially when moving to more expensive areas such as Zurich, Zug or Geneva ("Wie viel kostet Bauland in der Schweiz?," n.d.). This range depends on the period and how many tall buildings have been constructed in this time. According to *E1*, he is observing more orders for higher buildings and buildings in more condensed areas which in turn makes the measuring, staking out and erecting more expensive as well. Multiple Swiss studies also support this claim and observe a trend of more condensed building, a reduction of the average living area per person and a significant increase of high buildings being built since 2010 (Beutler, 2018; Kälin, 2022; Schmid, 2020).

When presenting the calculated market volume of between CHF 40.38 mio. to CHF 471.1 mio. per year to *E1*, the higher end of the estimation was found to be too high, while the lower end was rather unrealistic due to the mentioned conditions on which it was based. Because Keller+Steiner AG tried to calculate the market volume themselves during this research project, this paper is oriented to their calculations as well. *E1* estimates a market volume of roughly CHF 80 mio. which sits right at the lower end of the estimated range of this research. From the results section it is known that CHF 67.3 bio. were incurred in construction expenditure in Switzerland in 2018, roughly 25% of those costs are from the public sector while 75% are from private investors.

Now, looking at the amount spent on construction spans, the question is raised, why is it spent, could not it be saved for more meaningful investments and how could construction spans be replaced to save those costs. This raises the question if not municipalities are the real benefiters of a solution such as the proposed artifact of this paper simply alone for financial reasons and not the public like elaborated before like suggested by *E4*. The amount of CHF 80 mio. could be seen as market potential for a software solution to replace construction spans as proposed in this research. From this information a discussion could be held to answer the question of *E5* as to how much would users be willing to pay for such a solution. As mentioned before, by bridging the gap between imagination and reality, AR helps businesses to enhance brand recognition, establish a loyal customer base, and engage with their audience (Huijts et al., 2012; Katika et al., 2022; Mukhtarov et al., 2018; Perlaviciute & Steg, 2014). Taking this information into account, the use of a solution that allows users to visualize construction projects with the help of AR is not just beneficial if companies or municipalities can replace construction spans with it and save costs, but it also has many more benefits. Therefore, taking full advantage of this technology can be a significant value driver for construction companies, developers, municipalities but also the public alike.

The estimation of the cost share of construction spans in this paper only shows the cost of erecting construction spans for simple buildings or projects without considering any other aspects or cost drivers. However, this cost share could potentially be much higher considering the environmental impact of using construction spans or the opportunity loss of not digitizing this industry. For comparison, similar assumptions have been made and investigated by Fleisch and von Wangenheim (2021) from ETH which claim that Switzerland could save 8.2 bio. francs by digitizing the healthcare sector which would amount to roughly 11.8 % of total 2019 healthcare expenditures. Investing such opportunities for construction spans could potentially present a higher cost share and therefore emphasize a bigger reason for companies and public parties to find a solution for cutting cost and increasing efficiency or stakeholder engagement.

6 Conclusion

This paper investigated the current state of AR specifically in the construction industry and proposed a solution as to how to visualize construction projects. By conducting five expert interviews, challenges and opportunities for the artifact have been identified and general assumptions about the current state and the future of construction spans in Switzerland have been made. Through a calculation of the cost share of construction spans measured on the whole investment into a construction project, it can be stated how impactful the costs of construction spans are and thus the discussion for digitization and the search for an alternative or addition to current methods should be initiated. This research has elaborated on benefits and challenges when creating an application to visualize 3D building models using AR for replacing construction spans in Switzerland. The main benefits are increased understanding and engagement that an AR visualization can achieve, while main challenges are the accuracy of current tracking methods for outdoor use cases and the accessibility for less tech-savvy users.

This research has shown that because modern building projects suffer information gaps between the planning and execution stages (Salman, Khalfan, & Maqsood, 2012, S. 16), communication tools are critically needed (Chi et al., 2013, S. 119). Furthermore, it can be concluded that for AR applications hybrid localization methods produce the most accurate results (Akula et al., 2011, p. 641). With the increased development and use of augmented reality apps, there are several opportunities for implementing AR and improving traditional approaches utilized in the construction industry (Chi et al., 2013, p. 120). Four enabling technologies that according to Chi et al. (2013) may be merged into AR applications are localization, natural user interface, cloud computing environment, and portable as well as mobile devices. Based on these four technologies, the analysis suggested the following trends for future AR development efforts: hybrid tracking methods, gesture control of AR interfaces for operation with both hands, the provision of 3D assets using ubiquitous services such as databases or web servers, as well as light and portable AR devices for field operation.

This research has looked at the different stakeholders for the proposed solution and with the help of experts explored for whom such a solution could be most beneficial for. Expert opinions differ to some extent, but it can be stated that a solution such as the one presented in this paper can offer the municipalities, construction companies and the population numerous benefits. From a cost perspective, the commissioners of construction projects would naturally benefit the most. However, it is still necessary to find out what price these parties would be willing to pay for such a solution. Municipalities could also save a lot of costs and effort, and the population would be given a tool with which they can independently evaluate in detail a construction project that potentially affects their quality of life. This research project has established a cost estimate for the cost share of construction spans measured on the total project investment of about 0.1% which can be considered a significant share considering the otherwise little usability or benefit construction spans provide to the stakeholders.

Current AR engagement is often confined to input and gestures through a two-dimensional touch screen (Hürst & van Wezel, 2013, p. 254). This can lead to several issues. For example, users are forced to face their device towards a virtual asset in the real world, which may not be a favorable posture for interacting with the artifact (Hürst & van Wezel, 2013, p. 254). Furthermore, moving fingers across the screen obscures big portions of the content (Hürst & van Wezel, 2013, p. 254). Also, VPS still do not provide the desired accuracy and do not perfectly work outdoors by themselves (Treuillet & Royer, 2010). VPS are usually used indoors, since factors like light, reflection, and the change of scenery of an area can affect the accuracy significantly (Anup et al., 2017; Ruizhi & Liang, 2017; Yadav et al., 2018). Hybrid tracking methods should be used for creating accurate AR application which can increase their complexity but also their robustness (Akula et al., 2011, S. 641; Chi et al., 2013, S. 117).

This paper suggests that considering the high impact as well as cost share of construction spans businesses and public bodies should invest in digitalization or an addition to current methods for the creation of added value for all stakeholders involved. This research has shown that AR applications are capable of visualizing realistic models, engage stakeholders and create significant value for their users. Future work could focus on the full cost of construction spans since this paper only looked at the pure cost of construction. However, there are more cost drivers to construction spans such as the environmental impact or the bureaucratic effort that goes into managing them. Also, there is a societal impact that should not be neglected. Lastly, this paper tries to offer a solution to create a place of discussion rather than dispute. Research on how many objections occur and if they could be reduced with the use the proposed solution could really proof its value to stakeholders.

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Appendix

A Guiding questions for expert interviews

Expert Interviews(English)

1. Do you agree to the interview being recorded?
2. Do you agree to your company and you being mentioned by name in the paper?
3. Do you want an electronic copy of the final master thesis sent to you?

Presentation of the master thesis

- Background of the master thesis

Sounding questions

4. In which function/role do you work?
5. How long have you been involved in the Swiss construction industry for?
6. What is your experience with construction spans?
7. What do current approaches look like for visualizing construction projects in Switzerland?

Questions guide

Questions regarding the substitution of construction spans and AR

8. What is your opinion on construction spans as a solution for visualization?
9. What do you know about projects where AR was already used in construction?
10. What projects are you working on or planning that use or will use AR in construction?
11. What benefits and challenges do you see in the use of AR for the visualization of construction spans?

TECHNICAL SOLUTION WILL BE PRESENTED HERE

Questions regarding the proposed solution

12. What do you think are benefits and challenges (practically/legally) of implementing and using the proposed solution?
13. Who could the proposed solution be most useful for?
14. What is your opinion to the proposed solution regarding completeness and applicability?
15. In which form could the proposed solution be useful for your company?
16. Which existing similar solutions do you know?
17. What would be your preferred way of gathering data for the proposed solution?
18. What level of detail for the data would in your opinion be sufficient?

Follow-up questions

19. Are there any further questions or things that are relevant to the research?

Figure 26: Guiding questions for expert interviews (English)

Expert Interviews (German)

1. Sind Sie damit einverstanden, dass das Interview aufgezeichnet wird?
2. Sind Sie damit einverstanden, dass Ihr Unternehmen und Sie selbst in der Arbeit namentlich erwähnt werden?
3. Möchten Sie ein elektronisches Exemplar der Abschlussarbeit zugeschickt bekommen?

Präsentation der Masterarbeit

- Hintergrund der Masterarbeit

Sondierungsfragen

4. In welcher Funktion/Rolle arbeiten Sie?
5. Wie lange sind Sie schon in der Schweizer Baubranche tätig?
6. Welche Erfahrungen haben Sie mit Baugespannen gemacht?
7. Wie sehen die aktuellen Vorgehensweisen zur Visualisierung von Bauprojekten in der Schweiz aus?

Frageleitfaden

Fragen zur Substitution von Baugespannen und zu Augmented Reality

8. Was ist Ihre Meinung zu Baugespannen als Lösung für die Visualisierung?
9. Was wissen Sie über Projekte, bei denen AR bereits in der Baubranche eingesetzt wurde?
10. An welchen Projekten arbeiten Sie, bei denen AR im Bauwesen eingesetzt wird?
11. Welche Vorteile und Herausforderungen sehen Sie in der Nutzung von AR für die Visualisierung von Baugespannen?
12. Was heisst ready?

DIE TECHNISCHE LÖSUNG WIRD HIER VORGESTELLT

Fragen zum Lösungsvorschlag

13. Was sind Ihrer Meinung nach die Vorteile und Herausforderungen (praktisch/rechtlich) bei der Umsetzung und Nutzung der vorgeschlagenen Lösung?
14. Für wen könnte die vorgeschlagene Lösung am nützlichsten sein?
15. Wie beurteilen Sie die vorgeschlagene Lösung hinsichtlich Vollständigkeit und Anwendbarkeit?
16. In welcher Form könnte die vorgeschlagene Lösung für Ihr Unternehmen nützlich sein?
17. Wie lauten ähnliche Produkte, die Sie bereits kennen?
18. Was wäre Ihr Vorschlag für die Beschaffung von Daten für die vorgeschlagene Lösung?
19. Welcher Detaillierungsgrad der Daten wäre Ihrer Meinung nach ausreichend?

Folgefragen

20. Gibt es weitere Fragen oder Dinge, die für die Forschung relevant sind?

Figure 27: Guiding questions for expert interviews (German)

B Interviewer presentation

Figure 28: Interviewer presentation p. 1

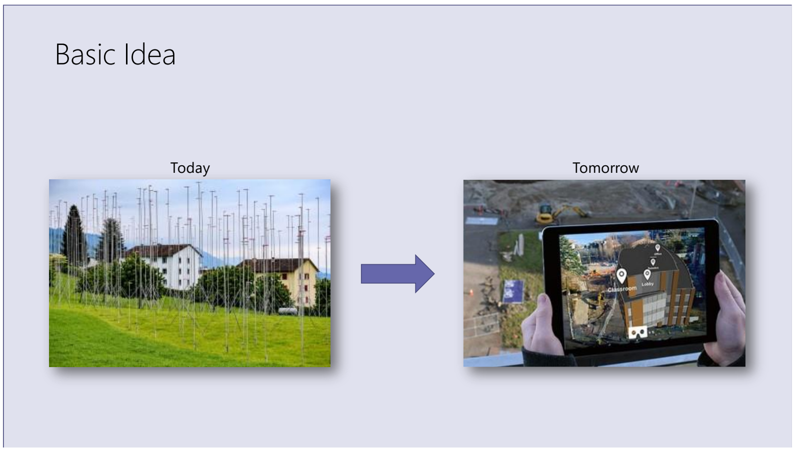

Figure 29: Interviewer presentation p. 2

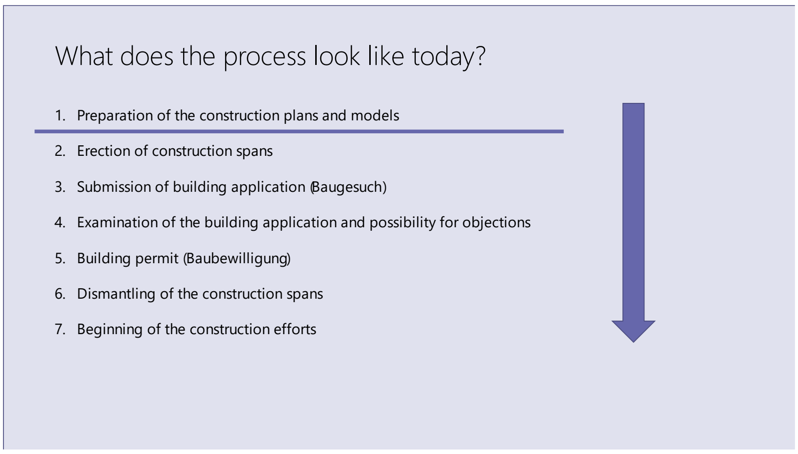

Figure 30: Interviewer presentation p. 3

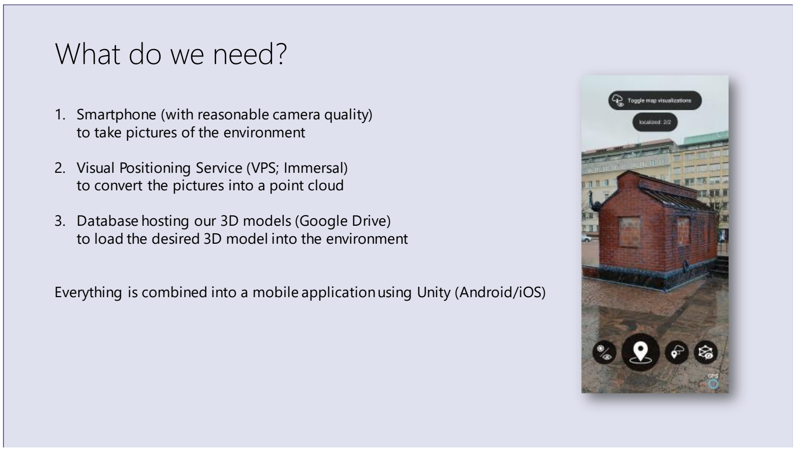

Figure 31: Interviewer presentation p. 4

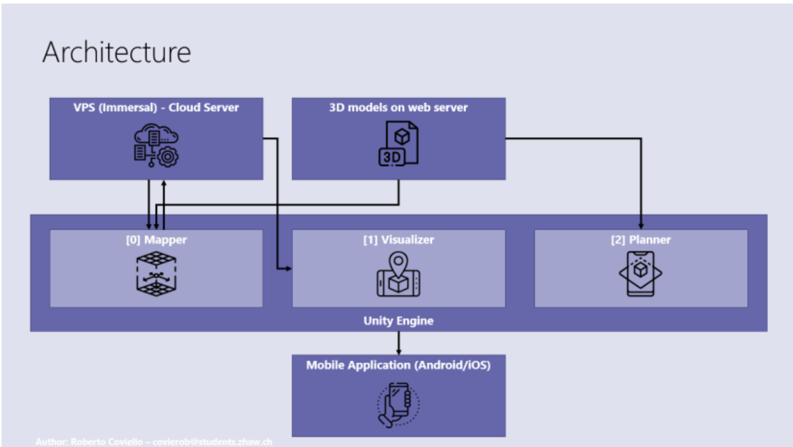

Figure 32: Interviewer presentation p. 5

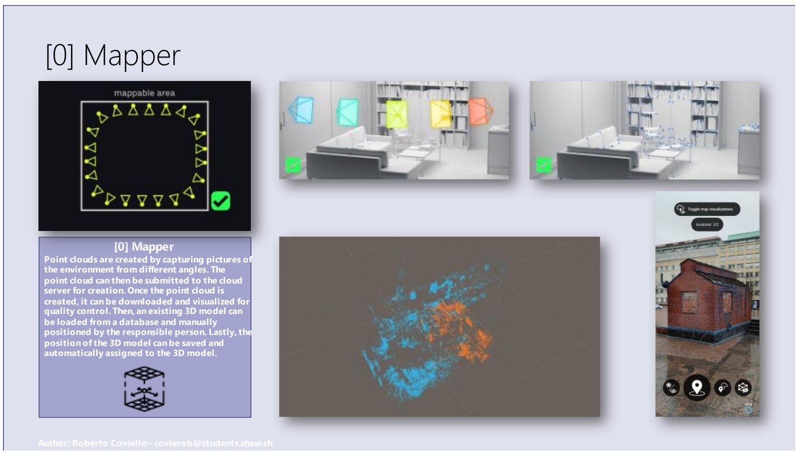

Figure 33: Interviewer presentation p. 6

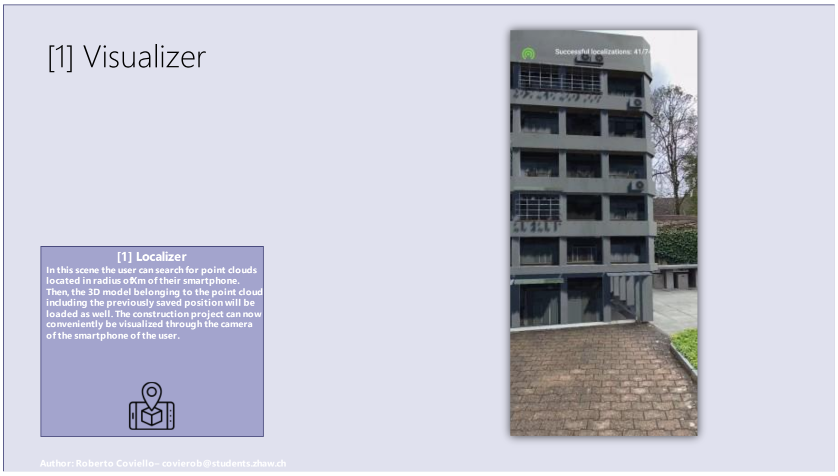

Figure 34: Interviewer presentation p. 7

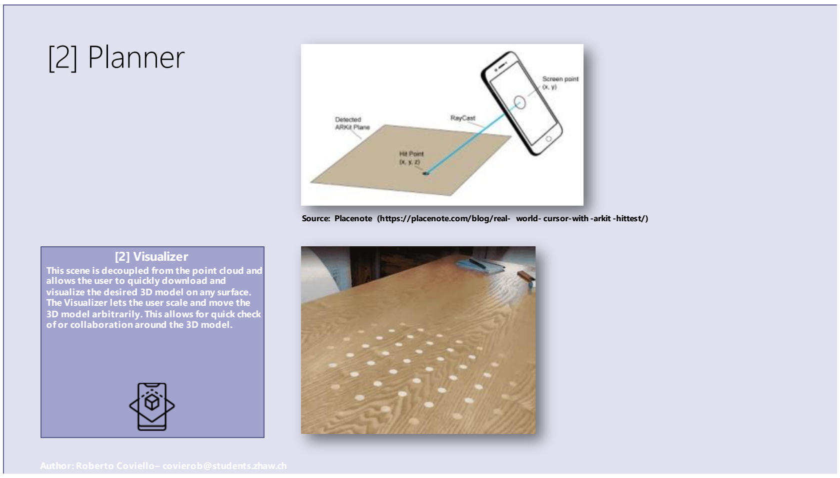

Figure 35: Interviewer presentation p. 8

C Interview coding guide

Expert	Statement	Encoding	Category	
Question 8: What is your opinion on construction spans as a solution for visualization?				**Questions regarding construction spans**
1	Only partly suitable for visualization, depends on size and shape.	Inaccurate representation	**Reference**	
1	Certain positions of construction spans like forests are not of much use, because you can't imagine much there	Too high level of abstarction	**Abstraction**	
1	Good reference to height so you can estimate how tall the building will be	Good reference for height	**Reference**	
1	Work is not done accurately, many mistakes, construction spans are several meters wrong in some cases	Inaccurate representation	**Accuracy**	
1	It's actually harming the neighbor, because certain mistakes no one notices and so they get a false image	Depict the wrong image	**Accuracy**	
2	Not beautiful, defaces surroundings	Defacing surrounding	**Appearance**	
2	Can give insight into how buildings will look, but only very abstractly	High level of abstraction	**Abstraction**	
3	Hard for borrowers to imagine what exactly is being built now	High level of abstraction	**Abstraction**	
4	It is a poor manner but important for visualising	Manner of visualization	**Appearance**	
4	Not enough information like with 3D models	Not enough information	**Abstraction**	
5	Good if you did not have the digital world	Manner of visualization	**Appearance**	
5	Optimally in the physical world only one reference and the rest digitally	Reference for digital visualization	**Reference**	

Figure 36: Questions regarding construction spans

Question 9: What do you know about projects where AR was already used in construction?			
1	More often used in civil engineering or road construction	Civil Engineering, Road Construction	**Civil Engineering**
2	In planning, project presentation, sales, marketing	Planning, Presenting	**Engagement**
2	Instructions on site, safety relevance	Instructing, Training	**Instruction**
3	First Pilotprojects, nothing concrete	First Pilotprojects	**Early tests**
5	You always have to stand in the same place, still relatively limited	Technology limitation	**Limitation**
Question 10: What projects are you working on or planning that use or will use AR in construction?			
1	Initial research conducted but nothing concrete yet	Initial Research, not in use yet	**In research**
3	Trying out AR, VR and see where they could use it	Initial Research, not in use yet	**In research**
4	Considered a product with AR but decided to tackle another area, since AR is not really ready	Limited capabilities	**Limitation**
5	Pilot project in Lucerne for spatial planning	First Pilotprojects	**Early tests**
5	Technology not ready; Not developed in house	Technology limitation	**Limitation**
Question 11: What benefits and challenges do you see in the use of AR for the visualization of construction spans?			
1	Business case is lacking for meaningful application of this technology	Lacking business case	**Applicability**
1	A lot of people who are not tech-savvy enough to use it or don't have appropriate devices	Lack of knowledge	**Accessibility**
1	AR is much more accurate and detailed	Accuracy, Detail	**Accuracy**
1	Existing solutions are very expensive	Expensive existing solutions	**Price**
1	Is it then actually used by the individuals?	Lacking application area	**Usefulness**
2	Makes the project less abstract, it can represent how it will look later incl. environment	Reduce abstraction	**Abstraction**
2	Range, you need at least smartphone, install app, you need to know and operate it	Operating efforts	**Effort**
3	Communicative tool to the outside	Planning, Presenting	**Engagement**
3	Good for people who cannot read plans; dissolves inhibitions	Less knowledge required	**Accessibility**
3	Smartphone app can be easily handled	Easy handling	**Usability**
3	The hardware is not really ready yet	Technology limitation	**Limitation**
4	Users are lazy; maybe they don't have the app, phone or internet	Operating efforts	**Effort**
4	AR is not working perfectly in open spaces	Limited capabilities	**Limitation**
4	People with less knowledge in technology who get to decide	Lack of knowledge	**Accessibility**
4	More than one design/proposal at a place	Multifunctional technology	**Versatility**
4	Make it a negotiation space instead of a place of complaining	Stakeholder engagement	**Engagement**
4	Building company can engage with residents	Stakeholder engagement	**Engagement**
4	Maybe the models are already too detailed and the developers/architects lose negotiating space	Stakeholder engagement	**Engagement**
5	Display complex information in an easy and comprehensible way for everyone	Planning, Presenting	**Engagement**
5	Increases transparency if it moves from an online platform into the real world	Increasing Transparency	**Accessibility**
5	You don't have to interpret plans or construction spans but can start discussing right away	Less knowledge required	**Accessibility**
5	Better representation can build trust and reduce fears	Stakeholder engagement	**Engagement**

Questions regarding the substitution of construction spans and AR

Figure 37: Questions regarding the substitution of construction spans and AR

Questions regarding the proposed solution

Question 12: What do you think are benefits and challenges (practically/legally) of implementing and using the proposed solution?			
1	Useful application if you can get the data	Getting data	**Data**
1	Data from building applications are mostly not consistent	Inconsistent data	**Data**
2	Significantly cheaper than construction spans	Cheap replacement	**Price**
2	No material consumption; More sustainable	Material consumption	**Sustainability**
2	Can visualize and record buildings and then take them to meeting	Planning, Presenting	**Engagement**
2	Coverage is a problem; Must be usable by all	Insufficient coverage	**Accessibility**
2	Requires good network coverage	Requires connection	**Accessibility**
2	When selling the property additional info can be provided	Additional info	**Abstraction**
3	Privacy policy; What do you see at the neighbors?	Privacy concerns	**Privacy**
4	Save money; Practical sense, run it by yourself	Cheap usage	**Price**
4	Present a building in a more clear way	Stakeholder engagement	**Engagement**
4	Legally, improve the speed at which these proposals can get done	Accelerate building proposals	**Time**
4	How to make it user friendly by providing uniform user interface across scenes	Uniform user interface	**Usability**
4	How to grow the product; How to get engagement of the people	Stakeholder engagement	**Engagement**
4	Will cease or decrease the activity of certain companies and therefore some municipalities will be more resistant to this change	Disrupt companies' activities	**Disruption**
5	Architects are not going out to take pictures and measure the environment again	Operating efforts	**Effort**
5	Also municipalities will not go an take pictures because it could be a source of errors which they don't want to take responsibility for	Risky activity	**Risk**
Question 13: Who could the proposed solution be most useful for?			
1	Assignees at the installation company would probably benefit the most in terms of avoiding mistakes	Avoiding mistakes	**Installation Company**
1	Overall population would benefit most from the software itself	Overall population	**General public**
2	People who do construction development; construction companies	Construction company	**Developer**
2	The general public might benefit the most	Overall population	**General public**
3	Developer; Planning	Construction company	**Developer**
3	General public; market is relatively large	Overall population	**General public**
3	For authorities; approval process	Authorities	**Municipality**
4	Municipalities; save time and money because of less legal work and you can communicate faster; less regulatory frameworks they have to dev	Less regulatory work	**Municipality**
4	Real Estate Developers save money, can communicate projects more easily and clear to municipalities and residents	Developers save money	**Developer**
4	Architect, to explain their decision on designs and ideas	Architect	**Architect**
5	With a high degree of automation, municipalities would be interested in	Municipalities	**Municipality**
Question 14: What is your opinion to the proposed solution regarding completeness and applicability?			
1	Data processing would have to happen automatically without picking up a point cloud first	No extra work	**Effort**
2	Could more additional information be displayed? Energy consumption, shadowing, etc.	Additional info	**Abstraction**
3	Maintenance planning; photovoltaics; shadow casting	Additional info	**Abstraction**
4	Easier to explain and provided with a uniform design	Uniform user interface	**Usability**
5	Customer Jouney is not fully thought out; who needs it when for what? How much willing to pay for it?	Customer Journey	**Engagement**
Question 15: In which form could the proposed solution be useful for your company?			
1	For visualising a construction span before finishing the job for controlling	Instructing, Training	**Instruction**
1	Project manager can visualize object at any time and everywhere	Stakeholder engagement	**Engagement**
3	For the communication of building projects	Stakeholder engagement	**Engagement**
4	Bringing together partners in the planning and financing phase; complementing the existing Praedia platform; testing new projects	Stakeholder engagement	**Engagement**
5	If you could georeference and reuse existing models	Use existing assets	**Versatility**
Question 16: Which existing similar solutions do you know?			
1	Trimble, which is based on GPS and costs around 30k per device		
2	Rather solutions to create Digital Twins, e.g. Matterport		
3	Trimble		
4	Matterport AR tools		
4	BIM Facility		
4	Realcube		
4	BUT		
5	Trimble already heard but no other supplier with an equivalent product known		
Question 17: What would be your preferred way of gathering data for the proposed solution?			
1	Difficult, might go through communalities		
2	Architects, building developers		
2	SIA would have to provide a structure that is the same for all architects		
3	Swisstopo		
3	In PFD format		
3	Architects; modern architectures always do it in 3D		
4	Architects		
5	Data from municipalities in the form of PDF; building applications with height and the floor plan		
Question 18: What level of detail for the data would in your opinion be sufficient?			
1	For the replacement of a construction span, the representation of a block would be sufficient	Simple representation	**Simple**
2	Shadow cast with sun movement; reflection	Additional info	**Detailed**
3	Models must be sufficiently detailed to represent interests	Represent interests	**Moderate**
4	Accurate 3D model in FBX format	Accuracy, Detail	**Detailed**
5	1:200 level of detail	Moderately detailed	**Moderate**

Figure 38: Questions regarding the proposed solution

D Various quotations for construction spans

VERMESSUNG

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Projektleiter	Joel Blutbacher

Keller & Steiner AG Fahrwangen
Herr Joel Blutbacher
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5615 Fahrwangen

Offerte 27273

Fahrwangen, 03.05.2022

Bezeichnung	Menge	Einheit	Preis	Total CHF
Montage, Demontage und Transport Alu-Baugespann Höhe = ca. bis 12m	6.00	Pauschal	707.85	707.85
Einmessen und Nivellieren mit GPS **Inkl. Lieferung Absteckungsprotokoll**	1.00	Pauschal	450.00	450.00
Vermietung Preis pro Woche CHF: 8.47 Preis pro Monat CHF: 36.30	1.00	Tag	1.21	
Zwischentotal				**1'157.85**
7.7 % MWST-pflicht. Betrag von			1'157.85	89.15
Rechnungsbetrag, zahlbar innert Vorauszahlung				**1'247.00**

Figure 39: Construction span quotation single-family home (*E1*)

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Bezeichnung	Menge	Einheit	Preis	Total CHF
Montage, Demontage und Transport Alu-Baugespann Höhe = ca. bis 15m	6.00	Pauschal	832.15	832.15
Einmessen und Nivellieren mit GPS **Inkl. Lieferung Absteckungsprotokoll**	1.00	Pauschal	450.00	450.00
Vermietung Preis pro Woche CHF: 17.71 Preis pro Monat CHF: 75.90	1.00	Tag	2.53	
Zwischentotal				**1'282.15**
7.7 % MWST-pflicht. Betrag von			1'282.15	98.75
Rechnungsbetrag, zahlbar innert Vorauszahlung				**1'380.90**

Figure 40: Construction span quotation apartment building (*E1*)

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Bezeichnung	Menge	Einheit	Preis	Total CHF
Montage, Demontage und Transport Alu-Baugespann Höhe = ca. bis 30m	4.00	Pauschal	2'850.87	2'850.90
Einmessen und Nivellieren mit GPS **Inkl. Lieferung Absteckungsprotokoll**	1.00	Pauschal	450.00	450.00
Vermietung Preis pro Woche CHF: 52.36 Preis pro Monat CHF: 224.40	1.00	Tag	7.48	
Zwischentotal				**3'300.90**
7.7 % MWST-pflicht. Betrag von			3'300.90	254.15
Rechnungsbetrag, zahlbar innert Vorauszahlung				**3'555.05**

Figure 41: Construction span quotation for a high building up to 30m (*E1*)

E GitHub repository and video of the application izanagiXR

- This is the link to the **private** GitHub repository of izanagiXR, created by Roberto Coviello over the course of this research for answering the research questions of this paper. Only individuals who are invited to the repository get access to the source code to protect the intellectual property of its creator and the university it was created for.
- This is the link to the public YouTube video of izanagiXR, created by Roberto Coviello over the course of this research for presenting the results of the development of the artifact and its functionalities.

Declaration of originality

I confirm that the submitted thesis is original work and was written by me without further assistance. Appropriate credit has been given where reference has been made to the work of others. The thesis was not examined before, nor has it been published. The submitted electronic version of the thesis matches the printed version.

Name and signature of the student

Roberto Gabriele Coviello

[redacted]