



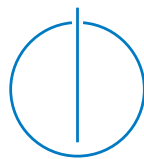
DEPARTMENT OF INFORMATICS

TECHNISCHE UNIVERSITÄT MÜNCHEN

Bachelor's Thesis in Informatics

**Development of a User Friendly Content
Creation System for the Stolperstein
Memorial Augmented Reality Application**

Alexander Partsch





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**Entwicklung eines Nutzerfreundlichen
Systems zur Erstellung von Inhalten für die
Stolperstein-Denkmal Augmented Reality
Anwendung**

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Submission Date: 15.03.2022



I confirm that this bachelor's thesis in informatics is my own work and I have documented all sources and material used.

Garching, 15.03.2022

Alexander Partsch

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Abstract

The *Stolpersteine* project is the world's largest decentralized memorial in commemoration of the victims of the Holocaust. It was founded by the German artist Gunter Demnig and up to this day over 75,000 stones were placed in over 1600 cities in 26 different countries. A *Stolperstein* is a small cobble-stone like object that is integrated into the pavement. On each stone the name of a Holocaust victim is written together with varying short information snippets. The stones are placed at the last place a victim freely chose to live. The *Stolpersteine* AR project is a prototype of an augmented reality mobile application that aims at detecting these stones in the pavement and displaying additional information in 3D about the person the stone is dedicated to. The basic idea of the application is that by visualizing the life of the victims and providing additional information the original intention of commemoration is enhanced. However due to the huge amount of stones and different locations an easy system to upload information for new stones and to maintain the information about existing stones is needed. A key concern for such a system is ease of use since people with the necessary knowledge about the commemorated victims typically don't have a computer science background. Therefore the initial approach of a web-interface is revisited and improved by the implementation of a new separate web-application. A short evaluation on the acceptance of the new web-interface and some smaller additions to the AR application that were implemented has been conducted in the form of expert surveys. The qualitative feedback from these surveys is evaluated and taken into account for the outlook of future work for the *Stolpersteine* AR project.

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1 Introduction

“A person is only forgotten if their name is forgotten”

- Talmud, Jewish Writing [DH22]

1.1 The Stolpersteine Memorial

The Stolpersteine memorial is the world’s largest project in commemoration of Holocaust victims. Until this day more than 75,000 Stolpersteine have been placed in 1600 cities distributed over 26 countries. Each stone is a commemorative plaque giving short information about a person who became a victim of the Nazi regime. Figure 1.1 shows a location in Munich where multiple such stones are integrated into the pavement. Most of these people were deported and murdered. The victims have been persecuted for various reasons like being Jewish, Sinti or Roma descendants. Others were persecuted for being homosexual, their religious or political views or a disability. The latter has been euphemized under the term “euthanasia” by the Nazis [JEW22].

The Stolpersteine project was brought to life by the German artist Gunter Demnig. His main goal is to keep the memory of the victims of the Holocaust alive. Each stone is representative for a person and their last freely chosen place of residence before deportation by the Nazis. Artist Gunter Demnig does not exactly remember why he choose to call the installation “Stolpersteine” but it is said by himself that he liked the ambiguity of having stones which could lead to people physically stumble and at the same time make them aware of victims of the Holocaust. This sudden awareness is described by him as a “stumbling” of heart and mind [DH22].

However this decentralized art installation is impressive, modern technology can give means of improving the experience created by the Stolpersteine. In 2021 the foundation of an augmented reality application was laid down by Nicolas Lenßen with the aim to provide and visualize additional information about the people commemorated by the Stolpersteine [Len21]. The work of our thesis is to improve the augmented reality (AR) prototype and address the issue of collecting and maintaining the information needed for the application (app).



Figure 1.1: Example of an installation of multiple Stolpersteine that can be found in Seestraße 8, Munich [Len21].

1.2 Augmented Reality

Although it can be argued about when the field of augmented reality emerged, its roots can be traced back to the work of Ivan Sutherland. In 1968 he constructed the first virtual reality (VR) system in the form of a heavy head-mounted display (HMD). Advances in computing power made it possible to create the first AR system. In 1992 Boeing introduced a system to assist workers of an airplane factory in assembling wiring by displaying schematics via a HMD directly into the real world. Today augmented reality is used in a wide field of application, from navigation systems, medical applications, maintenance and training programs to games and more [SH16].

1.2.1 Brief Introduction to Augmented Reality

A popular definition of augmented reality comes from Ronald T. Azuma. He distinguishes virtual reality (or a virtual environment) from augmented reality by the fact that in VR a user is completely immersed and the real world is entirely replaced by a virtual one. In contrast to that users of augmented reality applications can still see the real world while also getting presented with virtual objects superimposed or composited with reality. Azuma states that unlike other researchers his definition gives no limitation on the used technology like requiring a HMD. His definition of AR consists of three characteristics [Azu97].

- Combination of real and virtual [objects]¹
- Real time interaction

¹content in brackets added by the author

- Registration [of real and virtual objects]¹ in three dimensions

Figure 1.2 shows a qualitative scale how AR is situated between the real and virtual world. This taxonomy dates back to an article by Milgram et al. [MK94] which was published in 1994. A huge motivation for using augmented reality is that it enhances the user's perception by providing additional information in the form of virtual objects. More importantly information can be shown that the user cannot perceive in real world [Azu97]. This is also the main motivation of the augmented reality mobile application developed for the Stolpersteine memorial. Since information from the plaques is limited, the user receives additional information in augmented reality while not losing the connection to the real world art installation.

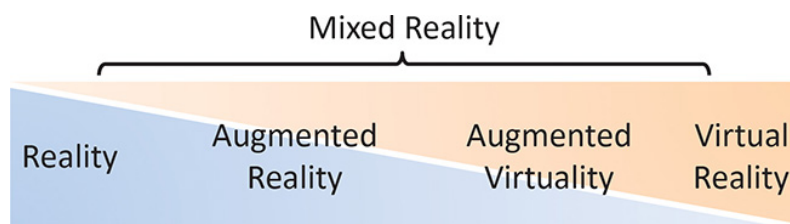


Figure 1.2: The continuum between real and virtual world. Augmented Reality is a form of Mixed Reality and therefore a combination of both. Taken from [SH16].

1.2.2 Technical Basics of Augmented Reality

The development process of modern AR applications is convenient in the sense of that programmers do not have to deal with the concrete implementation of important features such as device tracking, plane detection or feature point detection. For the Stolpersteine AR application these requirements are fulfilled by the software packages AR Core [ARC22] and AR Foundation [ARF22] which are available for the popular game engine *Unity*². Nevertheless it is worthwhile to give a brief overview of the main concepts which are addressed by AR applications, leading to a better understanding in how AR applications are able to combine virtual and real environments.

An AR application addresses three main concepts which partially overlap and are interlinked. These are **Tracking**, **Calibration** and **Registration**. However terminology and their interpretation might differ slightly in different literature. Each of these tasks is necessary to correctly place virtual objects into an image of the real world.

Tracking or in augmented reality usually 3D-tracking is vital because it sets position and orientation of the display and real world objects into relation with each other. This is known as a pose measurement and has to be done continuously. AR applications are real time and therefore the user, i.e. position and orientation of the display, can move dynamically and objects can move as well. Poses therefore have to be updated on a regular basis.

²<https://unity.com/> (accessed: 2022-03-07)

The next task is **calibration** which in contrast to tracking is a task which is usually only done once, e.g. on the first launch of the application. Calibration can also be done automatically by the application and means determining parameters that relate the measurement device, i.e. usually the tracking device like a camera, to a known reference. This is important so that the tracking components of the system deliver the right values for pose measurements.

Finally **registration** means the task of finding a common coordinate system between real and virtual objects. This information is provided by tracking and guarantees that real and virtual objects align to each other. A simple example could be a virtual flower pot standing on a real table. One can see that all these three tasks are interlinked

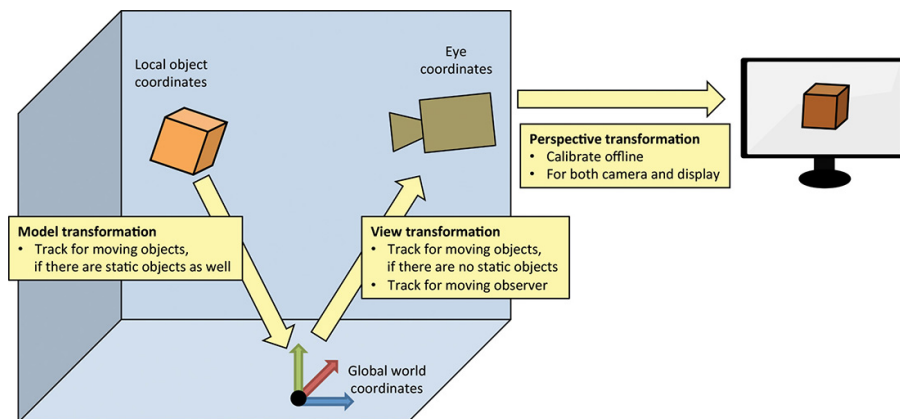


Figure 1.3: Coordinate transformations for an object from its local coordinate system to eye/camera coordinates and ultimately to (2D) screen coordinates [SH16].

and necessary to get the required transformations which can be seen in figure 1.3. Model transformations determine the position of objects in the real world (global world coordinates). This is relevant for virtual objects to determine their position and orientation in relation to the world. For virtual objects this task can be done by the application itself. More interesting is the view transformation since it conveys the relation between camera coordinates and world coordinates. Consequently tracking is needed to determine this transformation to measure poses of real world objects to place virtual objects in relation to them. For simplicity and because of our scenario of a mobile phone application it can be assumed here that no additional calibration between camera and display is necessary. The last step is a projective transformation which essentially means the projection of 3D camera coordinates to 2D device coordinates. This step depends upon camera and display and can be determined by offline calibration since this is a static relation [SH16].

1.2.3 Software Applications using Augmented Reality

Augmented reality applications can be found in a variety of different topics and fields. According to [Jul11] for research the most prominent application fields are **advertising**

and commercial, entertainment and education, medical applications and mobile (phone) applications. Additionally it should be noted that other huge application sectors are **construction and industry, maintenance and training, personal information displays or navigation** [SH16]. The field of mobile phone applications nowadays significantly overlaps with many other application fields. A lot of personal information applications run on mobile phones like *Google Translate* [SH16] and also entertainment and education purpose AR programs like museum guides use mobile phones [Jul11]. Our Stolpersteine AR application is situated in the field of educational applications which run on mobile devices. Specifically the Stolpersteine AR app falls into the context of cultural heritage applications.

1.3 An Augmented Reality Application for the Stolpersteine Memorial

A huge motivation for the development of an AR application for the Stolpersteine memorial is the received criticism about the Stolpersteine project. While receiving a lot of positive reception also criticism can be heard even from Jewish societies. It is often stated that the victims remembered by the Stolpersteine are once again and now literally “trampled under foot” since the Stolpersteine are part of the pavement. Another concern of critics is that the Stolpersteine do not convey enough information about Holocaust victims and therefore are not able to awaken empathy for them [Wet20]. The first criticism is a matter of opinion and not shared by everyone. Especially artist Gunter Demnig has rejected such and similar criticism [Sto11]. Also it is a fact which can hardly be addressed by an AR application. However the second issue can be improved by an augmented reality application. The initial prototype developed by Nicolas Lenßen addresses this concern by providing textual background information about the person, a Stolperstein is dedicated to, an image and 3D markers which are displayed on a map [Len21].

Lenßen has provided a working prototype which was developed in the scope of his thesis. However due to the early development stage the project has still a lot of shortcomings and issues. Specifically the upload of Stolperstein information shall be improved by developing a new web-interface. Also additions to the mobile app prototype are made in accordance with user feedback and issues mentioned in [Len21].

2 Related Work

In this chapter the Stolpersteine augmented reality project is classified in comparison to similar projects. Similarities between these projects are highlighted but also potential differences are pointed out. For this evaluation we consider especially technical and content-related aspects.

2.1 Mobile AR Applications in Cultural Heritage Sites

The Stolpersteine augmented reality application can be classified as a mobile application for a cultural heritage site. Cultural heritage is an application context that is often combined with augmented reality. In this section a number of related projects are listed which are similar to the Stolpersteine application but also differ in other aspects. The following projects shall give an overview of how the Stolpersteine AR application lines up in the field of cultural heritage applications which use augmented reality.

2.1.1 Streetmuseum - An Augmented Reality App by the Museum of London

The *Streetmuseum* application is a mobile phone app which was developed by the "Museum of London" in cooperation with the "Brothers and Sisters" agency. The app is location based and shows historical images from different time periods of London's streets overlaid onto the smartphones camera image which can be seen in figure 2.1. The AR app was developed in a short time period and relies on GPS data and *Google Street View* while the content in form of historical photographs was provided by the "Museum of London". Each photo has longitude and latitude information associated with it to be able to show the users the images at the exact place it was taken. Additionally to the visual component users can also access information about the image and its historical significance. Aim of the app is to reach out to new potential visitors of the "Museum of London", create awareness for the history of London and ultimately encourage users of the app to actually visit the museum. The app received positive reception and created over 300,000 downloads towards the end of 2011. It was able to attract an audience of young adults which are normally not part of the traditional museum audience. The "Museum of London" continued the successful app with the *Streetmuseum Londinium* application which focuses on the Roman past of the city of London. It has the same features as the *Streetmuseum* app but extends them with video content and interactive parts like "digging up" and "collecting" Roman artifacts [Jea12]. *Streetmuseum* relates to our work as it is also location based application and uses GPS data as a basis for determining the content which is shown to the user. It focuses



Figure 2.1: A street in London enhanced by the *Streetmuseum* AR app. Historical images from the database of the Museum of London can be shown as an overlay over the present day street scene viewed through the camera of the user’s mobile phone. Taken from [PMR18].

also on historical content but is different in terms of the supposed intention because the application has a significant marketing aspect while our app aims to be purely educational. The type of content shown is quite similar between *Streetmuseum* and the *Stolpersteine* AR app because both show photos and give additional information in text form. The feature of overlaying historical photographs on the real world scene like in *Streetmuseum* could also be interesting for the *Stolpersteine* AR app and may be investigated in future work.

2.1.2 Augmented Reality at the U.S. Holocaust Memorial Museum

In 2018 the United States Holocaust Memorial Museum tested an augmented reality app to improve the experience in one of their exhibition rooms. The so called “Tower of Faces” shows the lives of Lithuanian villagers who became victims of the Holocaust. The augmented reality application was tested as a pilot project with 80 students [Tak18]. A group of teenage aged visitors from this group described their experience with the app as very valuable. They generally felt more connected to the people shown in the pictures and reported to get a lot more information out of the exhibition than they normally would by simply looking at the images without additional AR information [USH18]. This project is similar to the *Stolpersteine* App in a number of ways. It is also a mobile phone application which recognizes objects in the real world and then augments them with additional information. This information is textual which is also one of the ways



Figure 2.2: Visitors using a mobile phone based augmented reality application to receive additional information about Lithuanian villagers who became victims of the Holocaust [Tak18].

the Stolpersteine App conveys information. The motivation of both apps is very similar since both aim at providing information about victims of the Holocaust.

2.1.3 Bergen-Belsen Augmented Reality Guide

The Bergen-Belsen memorial site is a historical place in northern Germany which commemorates the concentration camp located here during WWII. The camp was burned down in April 1945 shortly after its liberation so that today almost no physical remains of the original structures can be found [Pac+14]. Since this memorial is associated with the Holocaust, a thematic overlap between the Bergen-Belsen AR project and the Stolpersteine application is obvious. A team of the University Pompeu Fabra from Barcelona, Spain and members of the Bergen-Belsen Memorial developed a hand-held augmented reality application which uses historical archive data from 1944 and 1945 to bring the historical structures of the camp site back to life. Information about the site is saved in a database, associating historical documents in the form of digitized multimedia files with geo-location coordinates. The database itself is maintained through a web application by experts of the memorial foundation and changes to the database affect the displayed content in the AR app directly [Pac+14]. As can be seen this general structure is almost identical to the Stolpersteine project. Especially the need for experts to maintain the data shown by the application is the same in our app and the Bergen-Belsen project. The Bergen-Belsen AR app offers historical information in the form of images, texts and abstract 3D reconstructions of the destroyed buildings. This information can be accessed on various points of interest determined by geographical coordinates [Pac+15] which can be seen in figure 2.3. Also our Stolpersteine AR app uses GPS based location data to determine the appropriate content that is shown to the user. Additionally in

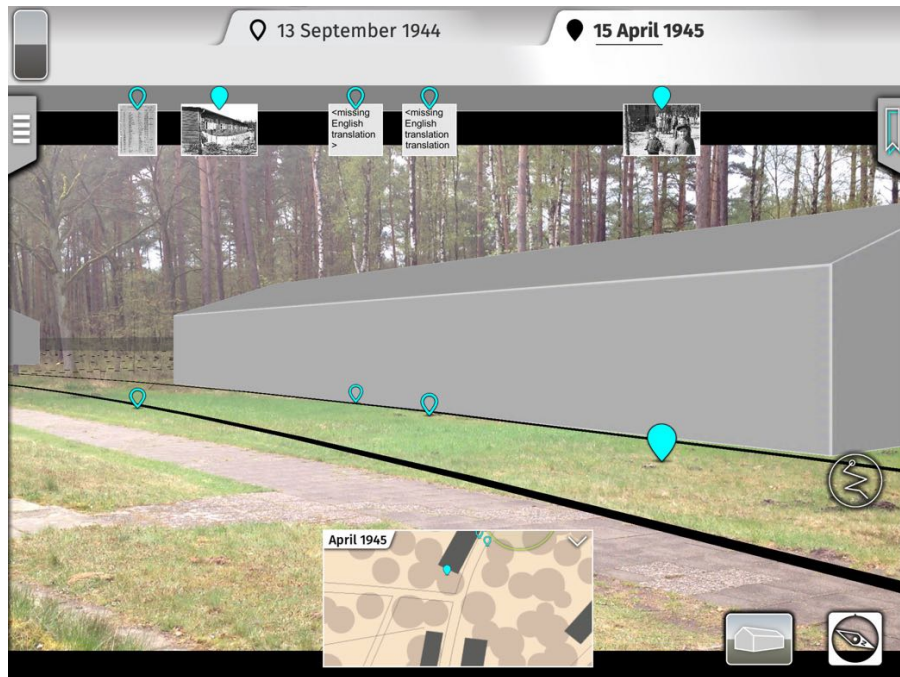


Figure 2.3: User interface and content available for augmenting the real world scene at the Bergen-Belsen memorial site. The top bar shows available content in the viewing direction. Also the indicators show the place in the real world the content associates with and show the distance to the location by their display size [Pac+15].

our application the Stolpersteine itself are used as points of interest and anchors for content displayed on the screen of the mobile device. This is a technical difference to the Bergen-Belsen app which in turn therefore uses compass and gyroscope data together with GPS data to determine the viewing direction of the user. With this the application can determine where the user is looking at on the historical site and show the associated information for the current point of interest [Pac+15].

2.1.4 Augmented Reality for Exploring Underwater Historical Sites

A multinational team of researchers developed an augmented reality application for augmenting a cultural heritage site that is submerged under water. In their evaluation of the potential of augmented reality for exploring underwater historical sites they presented a project with two different applications using two tracking methods to augment the underwater site of an ancient Roman villa [Čej+21]. Both application solutions rely on inertial measurements with the integrated inertial measurement unit (IMU) of smart phones and tablets respectively. The phone solution utilizes markers placed on the ground to determine the absolute position of divers while the tablet application uses an acoustic system to determine the divers position in the underwater

area. The latter suffers from a low update rate which makes it necessary to use a sensor fusion approach and also integrate visual and inertial data into the position calculation to fill in the gap between two acoustic localization steps. In these underwater AR applications users can switch between different presentation modes. A top view is available which gives access to an overview of the whole site and a first person view where users can view a 3D reconstruction of certain points of interest, cf. figure 2.4, or show the present view of the site [Čej+21]. This work relates to the Stolpersteine project



Figure 2.4: Augmented reality view of the underwater scene from the tablet based AR application. The application shows a potential reconstruction of the historical Roman villa and also provides additional data for divers like the current depth [Čej+21].

through its context of cultural heritage. Similar to our work, the underwater project also aims at improving the users experience and impression of a cultural heritage site with a historical context. It also depicts a very recent example of augmented reality in cultural heritage sites and one could draw a connection between the marker based detection approach in this project and the detection of Stolpersteine in our application. Both are used to determine an absolute position within a site and are used to determine the position of virtual content displayed by the applications. However it should be noted that marker detection is an established method while our app uses a machine learning approach to determine the position of Stolpersteine via object detection. The similarity to marker based detection lies in the fact that each Stolperstein functions as an anchor for the Stolperstein augmentation scene.

2.2 User Generated Content for an Augmented Reality Application

Previously a number of projects and applications have been presented which deal with the topic of cultural heritage by providing an AR experience. With the development of a user friendly web interface the Stolpersteine application now also stretches out to a different type of application: applications with user generated content. In 2010 researchers of the “Nokia Research Center” presented a system that gathers information from possibly multiple web services and provides this data to a mobile augmented reality application. The core feature is a “Content Aggregation Service” that collects data from different web application programming interfaces (APIs) and serves as a data source for a mobile AR application, cf. figure 2.5. The main challenge this research

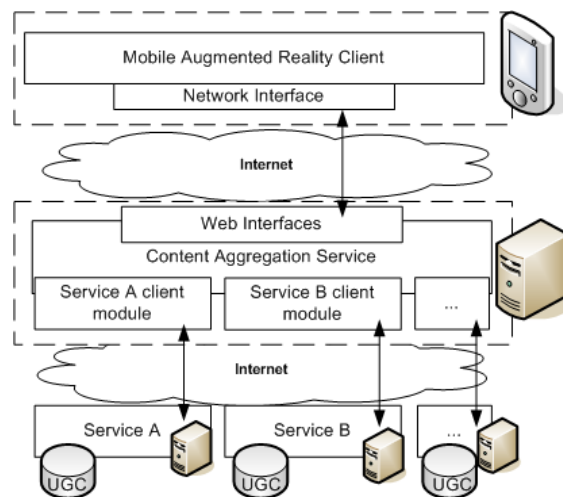


Figure 2.5: Generic system architecture of a prototype system developed by Nokia. A content aggregation service serves as a data provider for a mobile AR application and gathers its data from different other web services through publicly accessible APIs [BSY10].

prototype tries to solve is providing an easily extensible solution to include multiple data sources for an augmented reality application without the need of updating the mobile client itself. This is a fundamentally different approach compared to our Stolpersteine project. In the Stolpersteine app the data is directly supplied by users who are most likely experts in the field of Holocaust research but not in handling complex IT systems. Data therefore is not automatically collected in our project and is already entered in a way the AR application can use it. The “Content Aggregation Service” itself however is very similar to the Stolpersteine AR backend because both implement the representational state transfer (REST) architectural style and provide data for a mobile application in a way the mobile application can directly use to augment a scene in the real world [BSY10]. A major difference between the projects also is that compared to

photos uploaded on “flickr”, the Stolpersteine data is very sensitive content since it deals with the Holocaust. It can be seen from this example that AR projects which use user generated data exist but supplying data for our application is much more similar to the way it is done in the Bergen-Belsen project, discussed in section 2.1.3. This research prototype might not be very similar to our frontend web-application but therefore the so called “Content Aggregation System” is more closely connected to our backend. Our backend works similarly when receiving data from the web-interface and providing data for the augmented reality application.

3 Goals and Requirements

The main goal of this thesis can be divided into two aspects. First the continuation of the Stolpersteine augmented reality project in the form of an augmented reality mobile application and second the development of a user friendly web-interface for saving data for this AR application. The second step also focuses on user feedback and a small qualitative evaluation of the new web-application.

3.1 Importance of Usability

Usability expert Steve Krug states in his book “Don’t make me think! - Web & Mobile Usability” [Kru14] that the most important thing about usability is the principle of “Don’t make me think” which already appears in the title of his book. He explains that he found this to be the most important principle in web design since users quickly get frustrated if the website is misleading or unclear in any way and users don’t get what they expect from the website’s appearance. This means that good design is straight forward and users can at first glance find the functionality they were looking for. The *Stolpersteine Manager* is not a commercial project which means that users don’t turn to a competitors site but nevertheless it is important that the potential expert users like the handling of our web-application. This statement is also consistent with the findings of Hu et al. in their study from 1999 [HMC99]. In their investigation of the impact of different user interfaces on task completion effectiveness and user satisfaction, they found out that the lower the perceived cognitive load the higher the user satisfaction with the system. Once the Stolpersteine AR project matures, it will become more and more important that users with the required expert knowledge not only are in principle able to, but also *want* to supply information for the augmented reality application. Therefore it has to be avoided that users get frustrated by a clunky web-interface.

On the other hand, usability itself is more than the quality of a user interface. The ISO norm 9241-11 defines usability as a context specific property to achieve certain goals effective, efficiently and to the users satisfaction [RF13]. Therefore usability always has to be seen in the context of the application’s usage. For our web application, for example, this means that it is not necessary to explain what a “Stolperstein” is because every potential user will learn about this in advance but it is certainly necessary that the procedure to create and enter Stolpersteine data is clear and does not require trial and error. Relying on user feedback it is therefore beneficial to develop a good web application to maintain the data. Even if things are non satisfactory in the first iteration of this development process, future work can profit from the insights gained in this

thesis.

3.2 Advantages and Acceptance of Augmented Reality

A main motivation of using augmented reality is the intention to improve the user's experience. Studies show that by using augmented reality in software applications, enjoyment can be achieved by users which leads to an increased incentive in using these applications repeatedly and additionally a beneficial effect in learning can be observed. A study about acceptance of an AR application in a cultural heritage scenario found out that users want to use augmented reality applications because of these two aspects [HK12]. Another study with high school students showed that augmented reality applications can be used to increase the effectiveness of learning [Ibá+14]. Furthermore an advantage for using augmented reality in cultural heritage scenarios is summarized in [AE12]. In this article it is pointed out that augmented reality is scalable and not limited to real world possibilities which means that information texts, images, audios and other information can be presented as needed. Additionally historical sites do not need to be disturbed by e.g. physical information displays which is also an advantage for AR.

These are all aspects which shall be achieved by the Stolpersteine AR project. The goal is that users are more likely to engage with the stories concerning Holocaust victims and to invoke empathy in the user when they receive more information about the people commemorated by the plaques. This would be the ideal achievement since it closely connects to the intention of the Stolpersteine project [DH22].

3.3 Implementation of a User Friendly Web-interface

Originally the Stolperstein data could only be maintained through a web-interface supplied by the backend. In [Len21] the web-interface was described as very rudimentary and not suitable for non trained users. Although this interface is not intended for a broad public, it should be more visually appealing and more intuitive to use for the experts which shall use it. Furthermore some functionality is not implemented in the existing web-interface which should be realized by the new web-application. A number of goals have been identified which are listed here in decreasing priority.

1. The existing functionality that the web-interface for the backend already features needs to be recreated. One of the most important tasks is to also integrate a map which displays existing Stolpersteine locations and allows the modification of them from the map view.
2. Missing functionality should be implemented. This especially refers to the editing of existing Stolpersteine. Currently the editing functionality is missing completely. Since Stolpersteine also possess additional information like life stations and relations, an editing functionality for those information also needs to be implemented.

3. The overall interface needs to be structured in a clear manner and functionality should be implemented with common behavior in mind. For example the mouse cursor should change according to the actions the user can take. For example clickable elements should change the cursor to a pointer. Also the navigation within the web-application should be intuitive by providing a navigation menu which utilizes common symbols for the respective functionalities.
4. The authentication process needs to be handled more explicitly in the form of a login procedure since the integrated functionality of the Django framework for a user login can no longer be used. Regular users furthermore should not need any knowledge about the used backend.
5. Additional functionality and improvements to existing features should be implemented in regard to user feedback.
6. After the essential features and change requests by users have been completed, further improvements can be made to the web-interface. As suggested by [Len21] a search functionality for Stolpersteine locations or even for specific Stolpersteine could be useful once the amount of data grows. Other options include internationalization and making the web-interface more accessible on mobile devices, e.g. by converting the web application into a progressive web app (PWA).

Furthermore, as already hinted in these goals, the implementation of the interface shall be evaluated with a small set of test users which have a background on the historical matter but not in computer science. The web-interface is developed together with them through informal feedback and with the shortcomings of the original web-interface in mind. Later on, the resulting web-application is evaluated by a qualitative review by these test users.

3.4 Intended Improvements to the Stolpersteine AR Application

As mentioned in the “Future Work” section of Nicolas Lenßen’s thesis [Len21], there are multiple improvements that could be implemented for the mobile augmented reality application. Since the implementation of a more user friendly and feature complete web-interface as discussed in the previous section 3.3 is already a huge task, some smaller issues shall be addressed and improved in the AR application.

- An indicator for the next Stolperstein location since at the moment users get little feedback where the next Stolperstein location is and how far away they are from it. Although a display of near Stolpersteine directly projected into the world space would create more immersion, this is a more complex task which should be revisited in future work. The decision therefore has been made to include a textual information with the distance to the next Stolperstein location.

- Audio content will be included into the AR app. Therefore a new scene has to be made which allows the play-back of audio files. In this entirely new implementation, for now, one audio file per Stolperstein shall be supported.
- Additional information shall be made available that is more fine grained than the current possibilities to display text about the person the Stolperstein is dedicated to. This requires a new scene and a procedurally created selection of the individual text snippets.

While this is not the main task of this thesis it is intended to improve the user experience on the basis of the existing application. The test users for the web-application also had the possibility to test the augmented reality application, however this was optional for them.

4 Technical Realization

The technical realization of the continuation of the development mentioned in chapter 3 can be divided into four main tasks. Those are the implementation of the new web-interface, changes to the existing backend application, improvements to the AR application and the crucial part of publicly hosting new web-interface and the backend application to make those available for test users.

4.1 Architecture Overview of the Stolpersteine AR Project

The architecture of the Stolpersteine AR project is based on the original implementation of Nicolas Lenßen [Len21]. In our work this foundation has been expanded and adjusted to the new requirements. The Stolpersteine AR project consists of three separate

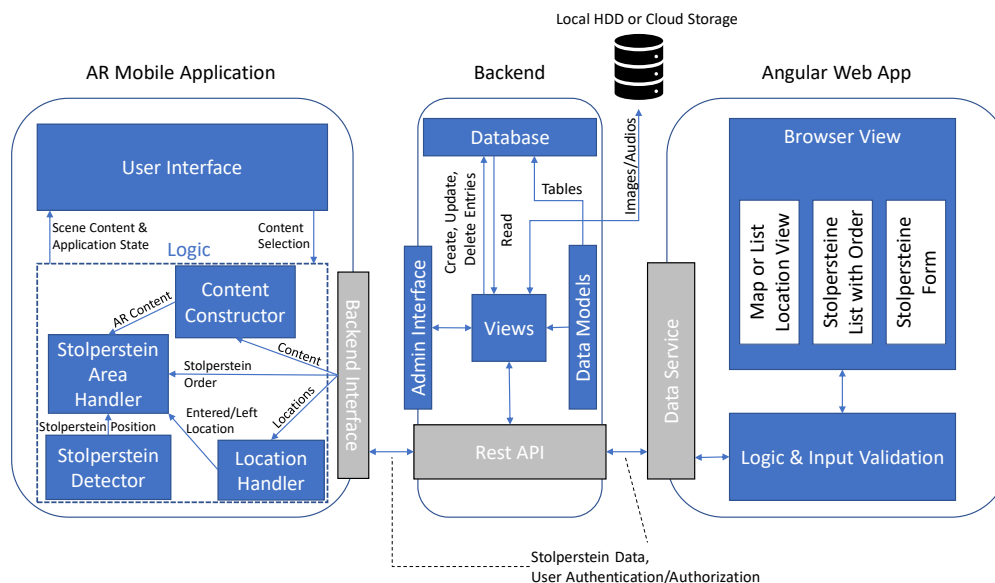


Figure 4.1: The Stolpersteine AR project consists of three major parts. A backend application based on the *Django* framework which manages the database interaction and allows for retrieving and saving of Stolpersteine data. A web-interface to enter new Stolpersteine data which is then saved by the backend and the AR mobile application which displays the Stolpersteine data at the appropriate locations.

programs which can be seen in the overview given in figure 4.1. A backend application manages the storage of Stolpersteine data and associated media data. It is the central component because web-interface and mobile AR application rely on it. The backend implements a REST API which enables retrieving and storage of data via HTTP web requests. Additionally it handles the authorization process for the web-interface so that only authorized personal can access the Stolpersteine data and edit it. The third program is the actual AR mobile application which is developed using the *Unity* game engine. Its backend interface communicates with the *Django*¹ backend application and retrieves data from it which is necessary to augment the Stolpersteine. Other core components of the AR app are the Stolperstein Detector, Location Handler, Stolperstein Area Handler and Content Constructor. The detection of Stolpersteine and the localization of the user via GPS and therefore the display of the correct Stolpersteine data is covered in Nicolas Lenßen’s Bachelor thesis [Len21] in detail. Also information about the different scenes available from a Stolperstein is described here.

The following sections cover the newly developed *Angular* web-application and the backend application based on the *Django* framework. At last the improvements to the AR application are presented but the previously done work in the form of existing scenes and Stolpersteine detection is omitted.

4.2 An Angular based Web-interface

The existing *Django* backend which was developed together with the first iteration of the Stolpersteine AR app already has a web interface to create new data entries for Stolpersteine. However these data forms where implemented in a “quick and dirty way” as pointed out by the original author of the application, Nicolas Lenßen [Len21]. The new web-interface therefore aims at improving different shortcomings of the original interface which have been identified in chapter 3. The *Angular* web-application has been named *Stolpersteine Manager* to differentiate it from the mobile application and to make clear for users that it is used to maintain Stolpersteine data.

4.2.1 The Angular Framework

The new web interface for managing data for the AR application is developed using the *Angular* framework. *Angular* provides an easy way to implement a modern web application. Its core concept is dividing a web-application into different components which are structured in a hierarchical manner, starting from a root component. Dependency injection and data bindings enable the possibility to share and exchange data between components as well as functionality [Ang22].

Together with modules like *Angular Material* [Anm22] a high quality user interface can be built very fast. Additionally other dependencies can also be integrated directly within the *Angular* application.

¹<https://www.djangoproject.com/> (accessed: 2022-03-07)

4.2.2 Technical Requirements

A number of technical requirements need to be addressed so that the web-application can be used as a data management tool for the existing backend.

Due to the prototype nature and sensitive data concerning the Holocaust, an authentication procedure is necessary for users to ensure that not anybody who happens to know the URL of the web-application but is not authorized can access and modify Stolpersteine data. Simply speaking a login procedure is needed.

The original web-interface already features a map which shows existing Stolpersteine locations and enables the possibility to create new ones. The new web-interface should therefore also feature a street map to display Stolpersteine locations. Additionally such a map can be used to infer geo-location data in the form of longitude and latitude since users should not be bothered with using third party sources to determine the geographical coordinates of a Stolpersteine location.

At last a form is needed to enter Stolpersteine data. This form should also check if the entered data is valid and will be accepted by the backend so that users get an immediate feedback if they need to change their data entries. Additionally the Stolpersteine need to be sortable per location so that the AR application uses the correct data for each stone if a location has more than one Stolperstein.

4.2.3 User Authentication and Authorization

First we must ensure that only authorized users can access the *Stolpersteine Manager*. Therefore the backend application is used to authenticate users. The *Django* backend has its own web-interface and most importantly an admin section where user profiles can be set up. Additionally a REST endpoint has been implemented that provides an access token if the correct username-password combination is entered by the user, cf. figure 4.2. This access token then in turn can be used to set the authorization header in the user's web requests. Through this access token the backend knows which user tries to access it which can also be used to enforce a role based access control (RBAC). To access the *Stolpersteine Manager* users first need to click the "Login" button and type in their username and password. This information is sent to the backend and if the supplied combination is correct, an access token is delivered with the backend's answer. This access token is then saved to the browsers local storage from where it can be accessed easily without the need of sending authentication requests to the backend constantly. Finally the token needs to be sent in the authorization entry of the header of every request. To achieve this, *Angular* itself provides a mechanism called "HTTP Interceptor" which automatically intercepts outgoing HTTP requests and modifies them.

4.2.4 Integration of a Dynamic Map with OpenLayers

The at first obvious solution for integrating a map service into the *Stolpersteine Manager* is using *Google Maps* since *Angular* is a Google product and *Google Maps* would integrate

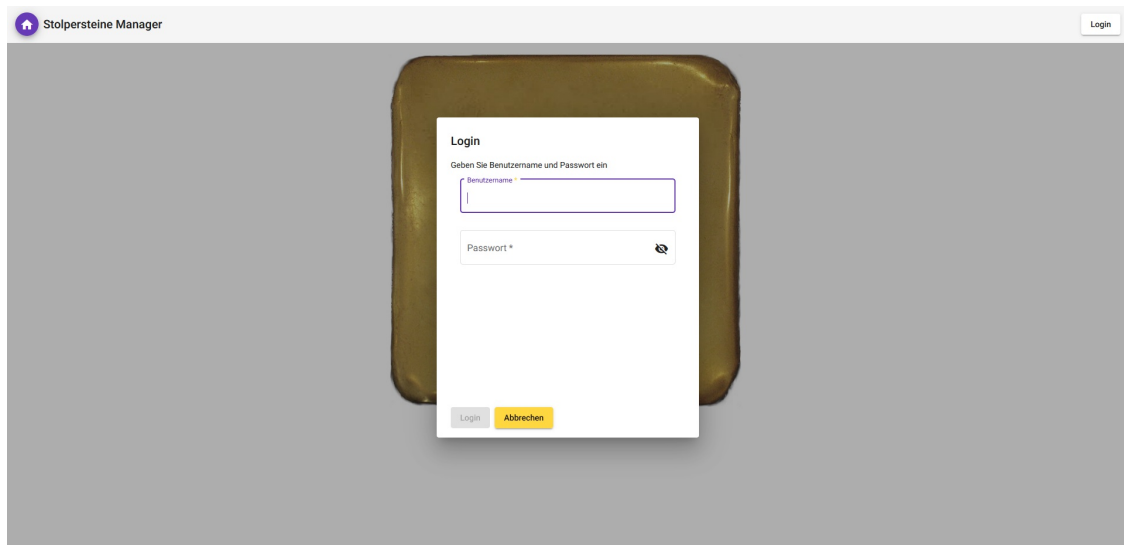


Figure 4.2: Login dialog for the Stolpersteine Manager where users need to enter a username and password in a classical manner. The password can be obscured (standard) or displayed in plaintext.

well. However to use *Google Maps* a billing account has to be supplied to receive an API access key which is necessary to use *Google Maps* within our own application². An alternative was found with the *OpenLayers*³ library which provides an interactive and customizable map. The main advantage to *Google Maps* is that it uses open source mapping services. In our particular case we use *OpenStreetMap* as a map source. The *OpenLayers* map is implemented in the *Stolpersteine Manager* as an *Angular* component which enables the integration into the app and makes it possible to draw and remove markers of Stolpersteine locations, make them clickable and open a dialog directly on the map with the possibility to select a location for editing. Additionally the map is also used for retrieving longitude and latitude values when creating locations and Stolperstein life-stations. The map component and its usage can be seen in figure 4.3.

4.2.5 Adding and Reviewing Stolperstein Locations

The first step for adding and editing Stolperstein data is to implement the concept of locations. These locations correspond to a place in the real world with geographical coordinates. Each location has one or more Stolpersteine and is used by the AR mobile application to determine if the user is near such a location and which is the correct data that correspond to the Stolpersteine in the real world. Adding a new location should be as easy as possible, especially without the need of researching its geo-coordinates

²<https://developers.google.com/maps/documentation/javascript/get-api-key>
(accessed: 2022-03-07)

³<https://openlayers.org/> (accessed: 2022-03-07)

from an external source. Therefore when opening the add dialog a simple click (or touch on mobile devices) is sufficient to fill out the longitude and latitude field of the dialog. For human users also an optional name can be specified per location. Usually the address where Stolpersteine are located should be chosen as a location name. The existing Stolpersteine locations can be found on the map itself, symbolized by clickable location markers. Also a list view of all locations is available from the menu bar on the top of the page which can be seen in figure 4.3.

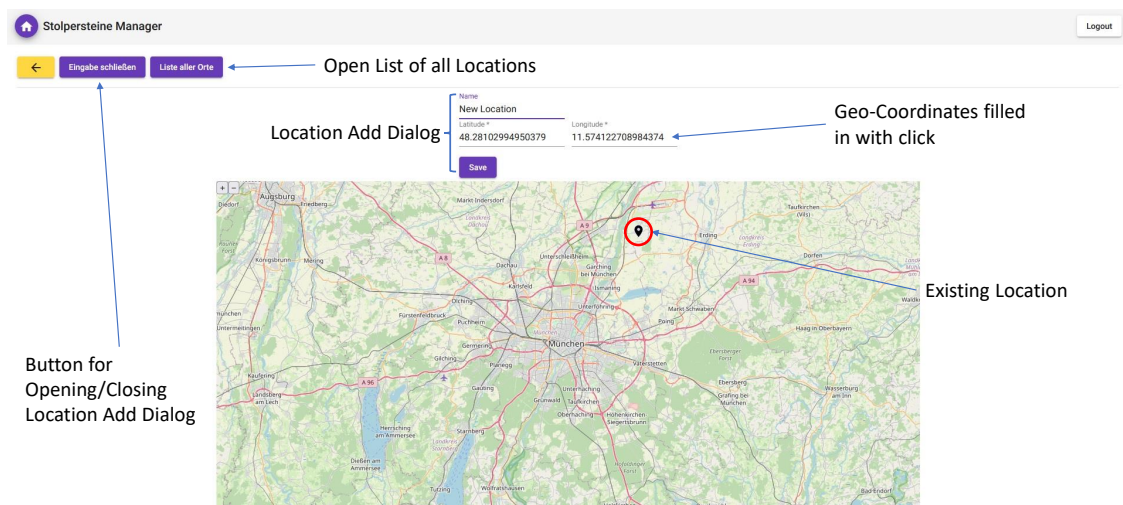


Figure 4.3: A button opens and closes the dialog to add a new location. The location itself can simply be created by clicking on the map to fill out latitude and longitude information. Existing locations are represented by a marker on the map. A click on such a marker opens a dialog with a link to the editing page of the location.

4.2.6 Stolpersteine Management per Location

Each location has one or more Stolpersteine as described in section 4.2.5. From this page existing Stolpersteine can be accessed and edited and new ones can be created. Also the location can be deleted entirely including all Stolpersteine associated with it. For the AR mobile application also the ordering of the Stolpersteine is very important since this is a crucial information to decide which is the correct data for a Stolperstein in the real world. The Stolpersteine detected by the AR application are ordered internally from top left to bottom right which means that the order of the Stolpersteine created with the web-interface need to reflect this scheme. Ordering in the *Stolpersteine Manager* can be performed by dragging and dropping the individual Stolpersteine cards, cf. figure 4.4.

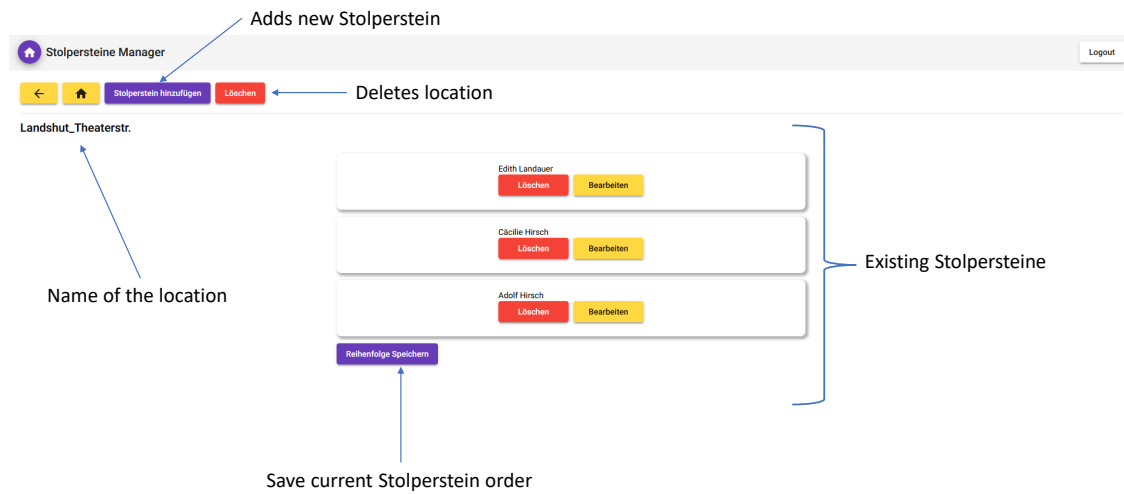


Figure 4.4: The existing Stolpersteine belonging to the selected location are presented as a list. The order of the list can be changed per drag and drop. The ordering on this page from top to bottom corresponds to ordering of top left to bottom right in the real world.

4.2.7 The Stolpersteine Form

The core component of the *Stolpersteine Manager* is the Stolpersteine form. It provides the user with the interface to upload data which can be used by the augmented reality mobile app to augment the real world scene with additional information. Consequently the form is designed to match the data, the AR app expects. To make the form clear and avoid confusion, it is grouped into five logical steps. Additionally the form checks if all necessary fields have been filled in so that the backend accepts and saves the Stolperstein. This is enforced by disabling the “Save” button as long as these requirements are not fulfilled.

Basic Information

In the first step users are prompted with multiple input lines for different basic information about the person the Stolperstein is dedicated to, cf. figure 4.5. These include the name of the person, the Stolperstein location which is filled in automatically, birth and deathdate, birth and death place and the reason for persecution. The dates can be conveniently filled in with a calendar so that users do not need to worry about the correct date format. Also the reason of persecution is by design limited to certain options which match those expected by the AR application. The options can be selected from a drop down menu.

The screenshot shows the 'Stolpersteine Manager' web interface. The main content area is titled 'Grundlegende Informationen' and contains a form with the following fields:

- Name: Cécille Hirsch
- Ort des Stolpersteins: Landshut_Theaterstr.
- Geburtsdatum: 17.01.1876
- Todesdatum: 30.09.1941
- Geburtsort: Koblenz
- Stolperort: Krankenhaus Landshut
- Grund der Verfolgung: Jüdische Abstammung

On the left side of the form, there is a vertical navigation menu with four items, each with a checkmark icon:

- ✓ Dateien Hochladen
- ✓ Zusätzliche Information
- ✓ Beziehungen
- ✓ Lebensstationen

Figure 4.5: Basic personal information about the Stolperstein like name of the victim, birth date and death date.

Media Upload

In the next step the user has the possibility to upload media files. These are important to provide audio-visual information about the victim. A photo and an audio file can be uploaded here which are both optional, cf. figure 4.6. If a photo has already been uploaded for the current Stolperstein, the existing image can be seen as a preview directly in the form itself. A new image can be uploaded by clicking on the respective button where the preview shows the selected image in this case. Similarly this can be done for the audio file. However if the user wishes to hear an existing audio, the audio file first must be downloaded here and then can be played back by the user on their local device.

Additional Information

The third step of the form consists of two text boxes and a “Plus” button which allows to add more custom texts. The first two boxes allow to set the family and general information text which have a dedicated sub-scene in the AR application. The button is a new addition, suggested by user feedback, to add information more customizable. Different information about the life of the person can be entered here and divided into as many texts as needed, cf. figure 4.7.

Relations

In the fourth step of the Stolperstein form optional relationships to other people with Stolpersteine can be added. Users can select another Stolperstein from a drop-down list and specify the type of relationship with the person from the current Stolperstein. This type is also selected from a drop-down list, offering multiple options like “family member” or “work colleague”. Additionally a description about the relation can be given. Existing relationships are displayed as an editable preview which can be seen in

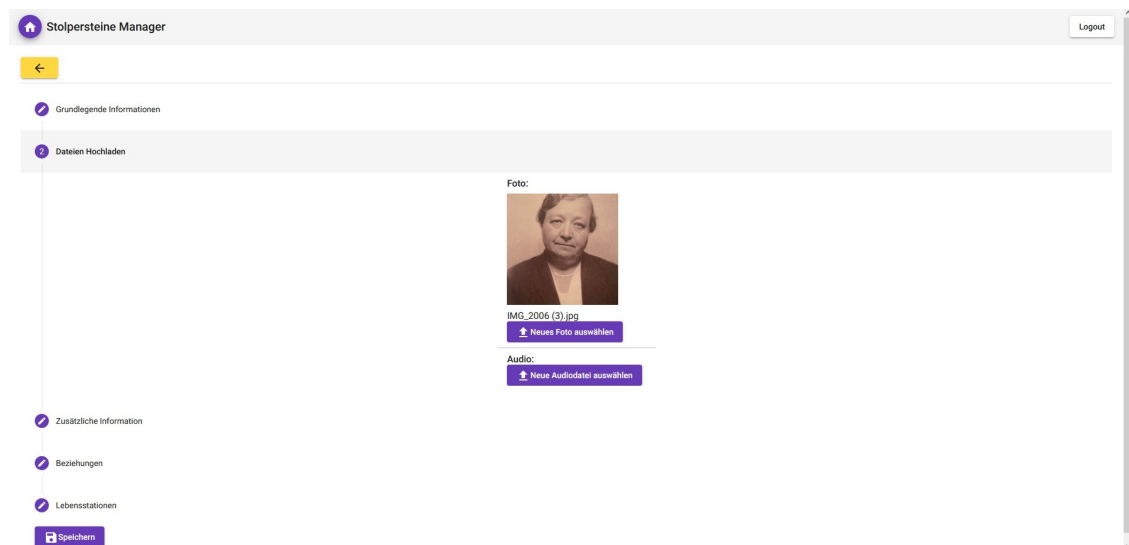


Figure 4.6: Upload buttons for uploading an image of the displayed person and an audio file. For the here shown Stolperstein a photo of the person the Stolperstein is dedicated to has already been uploaded and is shown as a preview in the form.

figure 4.8.

Life Stations

Finally the last piece of information that can be declared for a Stolperstein are life stations. Life stations have a title and a description and are linked to geographical coordinates. As the name suggests these entries are used to depict important parts of the respective person's life. The selection of the geographical coordinates is realized by the integrated map feature described in section 4.2.4 and functions analogous to selecting coordinates for a Stolperstein location. These coordinates are then used by the AR application to display the life stations on an interactive map. Alike the other steps, already existing life stations are shown as a preview with the possibility to delete or edit them, cf. figure 4.9.

4.3 Backend

The backend application that manages the database for Stolpersteine and location entries already exists from the previous work done by Nicolas Lenßen. It uses the *Django*⁴ and *Django REST*⁵ framework to build a web API which is used by the *Stolpersteine Manager* and the AR application. This API uses the paradigm of representational state transfer which was first described by Roy Fielding in 2000 in his dissertation [Fie00]. The main characteristic why this is useful for us is that resources, e.g. Stolpersteine or

⁴<https://www.djangoproject.com/> (accessed: 2022-03-07)

⁵<https://www.django-rest-framework.org/> (accessed: 2022-03-07)

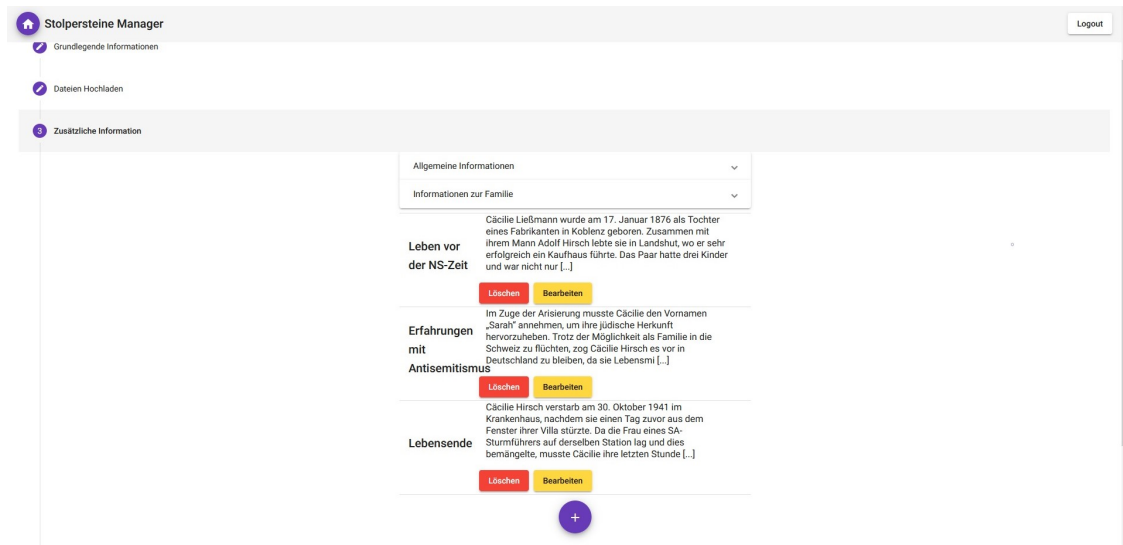


Figure 4.7: In the additional information step three custom text boxes have been added here. The user used the custom text boxes to denote different life stages of the person with separate texts.

locations, are made available by resource identifiers which is simply an URL in our case. Data can be retrieved and modified through these identifiers with HTTP requests which is what we need for our application and which is also common practice for modern web-applications. Since the foundation for handling Stolpersteine data has already been implemented in the existing *Django* application the choice was made to keep the backend and extend it for the new needs introduced by the *Stolpersteine Manager*.

4.3.1 New Data Models

For the database management, *Django* relies on data models. It uses the data models defined in a Python file to create the necessary tables in a relational database and maintain them. Two changes have been made compared to the original project. First the possibility to upload an audio file has been added. Since the photo is now not the only media file, a new data model has been added which contains all the media files associated with a Stolperstein. In the current implementation only one image and one audio file can be saved per Stolperstein which is also reflected by the data model.

The second change is the addition of text boxes. Each text box relates to a Stolperstein where every Stolperstein can have multiple text boxes.

The incoming data from web requests and outgoing data from the database are then serialized by so called “model serializers” which are for example responsible for collecting the text boxes associated with a Stolperstein.

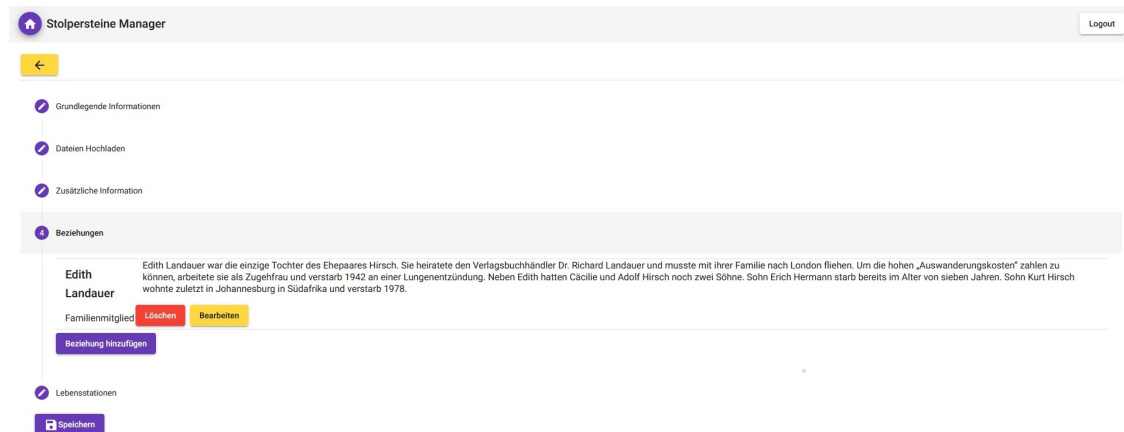


Figure 4.8: Relationships specified for the current Stolperstein. In this example one Stolperstein has been selected and denoted as a family member.

4.3.2 API Changes

Previously the addition of new Stolpersteine data was handled directly within the web-interface provided by the *Django* applications' data forms. With the *Stolpersteine Manager* this is now done by an external application. Therefore new REST endpoints are needed to retrieve data for the *Stolpersteine Manager* and to enable the modification of it.

GET requests

For retrieving data from the backend HTTP GET requests are used. For these requests endpoints are implemented that supply all locations, all Stolpersteine, all Stolpersteine from a specific location and a specific Stolperstein which is referenced by its ID. The possibility to retrieve only specific Stolpersteine is useful since the amount of data transferred can be limited to only the data that is needed by the frontend application.

POST requests

POST requests modify or add new data. There are dedicated endpoints to add or update Stolpersteine, add locations, update the order of the Stolpersteine of a specific location and to upload media files for existing Stolpersteine. The upload of media files has been decoupled from saving Stolpersteine since media files are always connected to an existing Stolperstein but changing the contents of a Stolperstein does not necessarily mean that media files have changed and need to be uploaded.

DELETE requests

Finally Stolpersteine data should also be deletable. Users might find themselves in a situation where they think that some information is no longer relevant or incorrect and

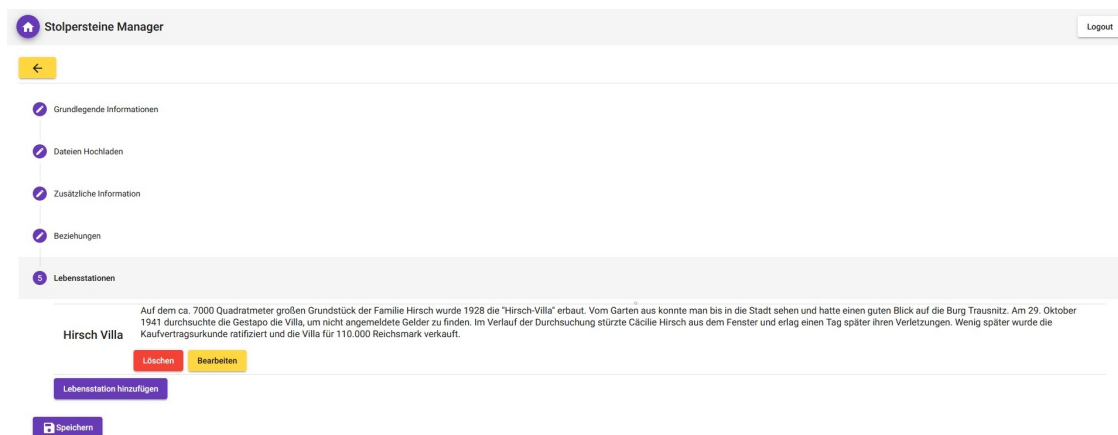


Figure 4.9: View of existing life stations for a Stolperstein. The form here is analogous to the relation form presented in figure 4.8.

they don't want or can modify it. Therefore endpoints have been implemented to delete a location or an entire Stolperstein, but also relations, life stations and text boxes can be deleted separately since they are not an integral part of the Stolperstein model but rather just associated with a Stolperstein through its ID.

The API changes have been designed in a way that every functionality needed by the *Stolpersteine Manager* is present. However in future work some refactoring could be made. For example modifying data normally should not be performed by a POST request but rather a PUT request. Also deleting existing assets is currently not possible and conventions regarding resource identifiers should be enforced in future versions. At the moment every functionality is represented by an individual request mapping but for good practice this should be done by distinguishing between request methods.

4.4 Public Hosting

To make the *Stolpersteine Manager* testable, the web-application as well as the backend have to be hosted publicly so that test users can access the web-interface. The scale on which the test has been performed does not demand a high scalability or availability. The hosting providers for frontend and backend application were chosen by two principles. Deployment should be **easy** and require as few configuration as possible. Therefore for the *Angular* web-application and the *Django* backend two recommended providers have been chosen. Additionally both chosen providers are **free-to-use** if the necessary scale is small which means that the applications are not too large in terms of required disk space and low site traffic. This is fulfilled by our applications.

4.4.1 Deployment of the Angular Web-interface

For the deployment of the *Angular* web-application the Google service *Firebase*⁶ has been used. *Firebase* is one of the recommended deployment possibilities for *Angular* web-applications⁷ and is free when using its so called “Spark Plan”. Even in the free version it offers sufficient resources for a hand full of test users. Particularly interesting is the possibility to choose a custom domain without extra charge which enabled us to use the expressive URL `https://stolperstein-manager.web.app`⁸. Deployment to *Firebase* can be done directly within the *Angular* command line interface (CLI) which is convenient for fast and easy deployment of new versions of the website.

4.4.2 Deployment of the Backend Application

Crucial for the functionality of the *Angular* frontend is a working backend that supplies the necessary information and interaction possibilities. Therefore also our *Django* based backend application has to be hosted publicly which has the beneficial side effect that it also enables us to use the Stolpersteine AR application from anywhere and not just in a local test environment. For the deployment of the backend *Heroku*⁹ was chosen because it is a recommended hosting provider for *Django* applications. A detailed tutorial¹⁰ exists for setting up the deployment and it is also free of charge. Configuration of the hosting environment is also very easy from the online dashboard *Heroku* offers. However saving media files can not be done directly on *Heroku* because the containers *Heroku* uses to run applications have an ephemeral file system which means that static files are deleted regularly. Therefore an additional step has been made to enable saving of media files like images and audio. The solution for this is the cloud storage provider *Cloudinary*¹¹. There are two reasons why this provider was chosen. First, it does not require any credit card information to use the free version of this cloud storage and second, it integrates well with the *Django* framework and does only require a minimal setup to change the storage of media files from local disc to this cloud storage.

4.5 Improvements to the AR Application

The AR application itself is still in an early prototype stage and almost all aspects still need improvements as well as new functionality that enhances the user experience. Since the number of improvements and new features that can be realized within the scope of this thesis is limited a selection of those has been made. Inspired by user feedback two

⁶<https://firebase.google.com/docs/hosting> (accessed: 2022-03-07)

⁷<https://angular.io/guide/deployment> (accessed: 2022-03-07)

⁸This URL will likely change in the future/become unavailable

⁹<https://www.heroku.com> (accessed: 2022-03-07)

¹⁰<https://developer.mozilla.org/en-US/docs/Learn/Server-side/Django/Deployment> (accessed: 2022-03-07)

¹¹<https://cloudinary.com/> (accessed: 2022-03-07)

new features have been implemented which are an audio player to play-back audio files and a selection scene that enables users to display additional text information. On top of that also some minor improvements have been made to the AR application. All shown figures in this section are recorded with a dummy Stolperstein that has been created for test purposes. This means that any data shown in figures 4.10, 4.11 and 4.12 does not correspond to an actual Stolperstein and therefore is of exemplary nature.

4.5.1 Audio Player

The implementation of the audio player consists of three steps. First the audio file needs to be downloaded and temporarily saved by the application similar to the photo that can also be displayed by the AR application. The logic for that is analogous to the download of an image. The audio player needs an own scene similar to the other information scenes which are available for a Stolperstein. This scene includes an audio player with play and pause functionality where also users have the possibility to skip to a certain point of the audio file by using the play-back progress slider. For this feature an existing cost free prefab from the *Unity* asset store¹² has been used and adapted. This audio player component also supports the play-back of multiple audio files that can be selected from a list and a selective download of these files. This could be interesting for future improvements of the audio player. The last step is making the audio player scene accessible. Therefore a 3D icon has been created that resembles a speaker. Tapping on this 3D icon on the screen of the mobile device opens the audio player scene, cf. figure 4.10.

4.5.2 Variable Text Information

According to user feedback the existing text boxes were not sufficient. The overall opinion was that just providing the possibility to put in information about the family of a victim or some general information didn't allow to enter information fine grained enough. It was thought that a very long text about the life of such a person is not fitting for the AR application. As a solution the option of creating a variable amount of text boxes was implemented. In the web-interface the "Additional Information" form was expanded with a "Plus" button as explained in section 4.2.7. The "Plus" button can be seen in figure 4.7. The major question for integration of the text boxes into the augmented reality app was how these text boxes can be accessed properly without cluttering up the interface and allowing a variable number of texts. Providing a 3D icon for every text box in the general selection scene of the AR app would have crammed the interface unnecessarily. Instead only one icon is added to the selection scene which opens a list of buttons. This button list is created dynamically depending on the number of text boxes available for the current Stolperstein. Each button opens the respective text box so that users can read the information, cf. figure 4.11.

¹²<https://assetstore.unity.com/> (accessed: 2022-03-07)



Figure 4.10: New 3D icons have been added to select the newly implemented scenes (left). The 3D speaker icon opens the audio player scene (right) which opens a player to play-back the audio file that can be uploaded in the Stolperstein form.

4.5.3 Minor Improvements

Several minor improvements have been implemented as discussed in section 3.4. The result of these minor improvements can be seen in figure 4.12. The first improvement is the disabling of the device's camera in order to not disturb the user with a shaking background during text scenes. Several such text scenes exist which present the user with textual information during which the camera image is now frozen. The camera is reactivated once the user returns to a 3D scene where 3D objects are present to augment the real world scene.

In the original prototype the possibility to detect Stolpersteine by a simple touch on the display had already been implemented. Therefore the option to switch between this touch detection and the camera detection has been added to the user interface of the AR application. On the one hand this feature is useful for debugging purposes and on the other hand it is also helpful for regular users of the app since the stones can now

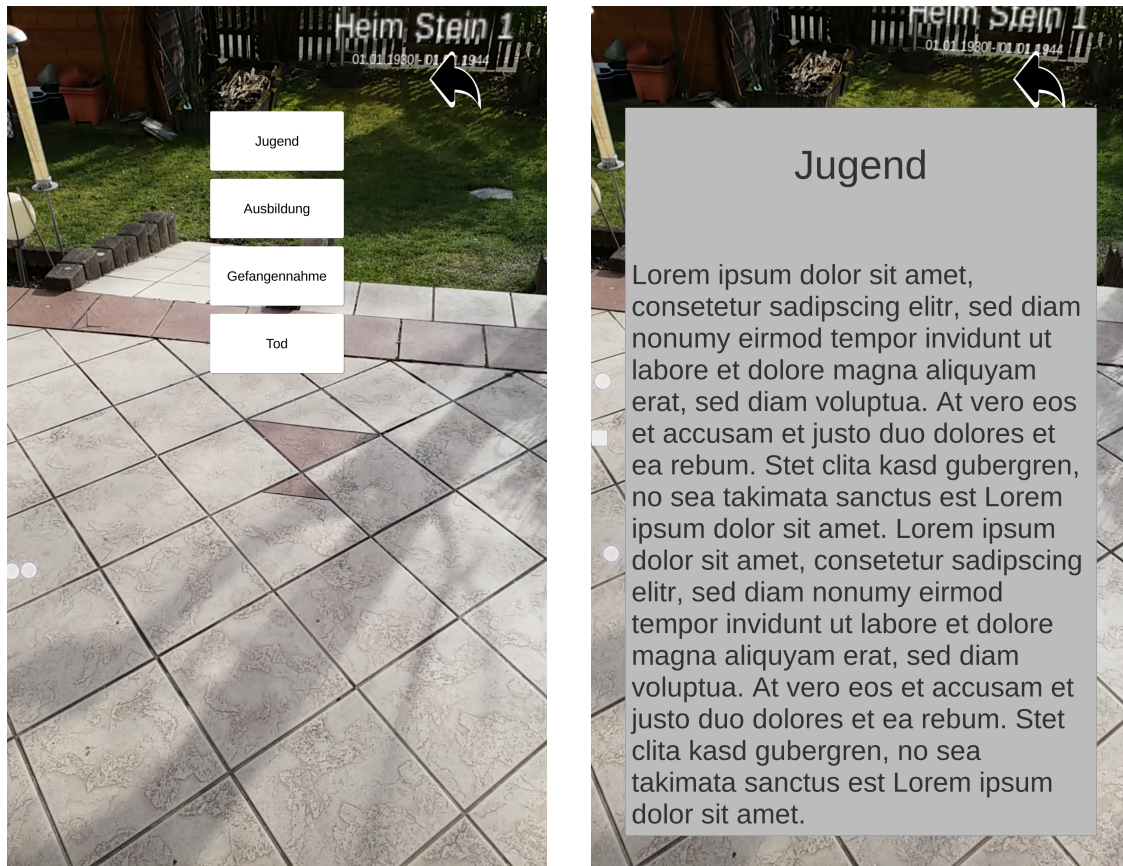


Figure 4.11: Selection scene for the variable amount of text boxes (left) and exemplary view of one of the text boxes here filled with a placeholder text for test purposes (right).

also be detected if the detection via camera image fails. This potentially improves the operation of the app under bad lighting conditions.

The last minor improvement is inspired by user feedback. It was reported that the Stolpersteine detection pops up unexpectedly when entering a Stolperstein location and no real feedback is given when the user is not close enough to a location. As a result a text has been added to the user interface which displays the name and the distance to the next Stolperstein location. Once the user enters the location, which is now defined by them being no more than 20 meters away from the locations geo-coordinates, the text switches to "Inside location <location name>".

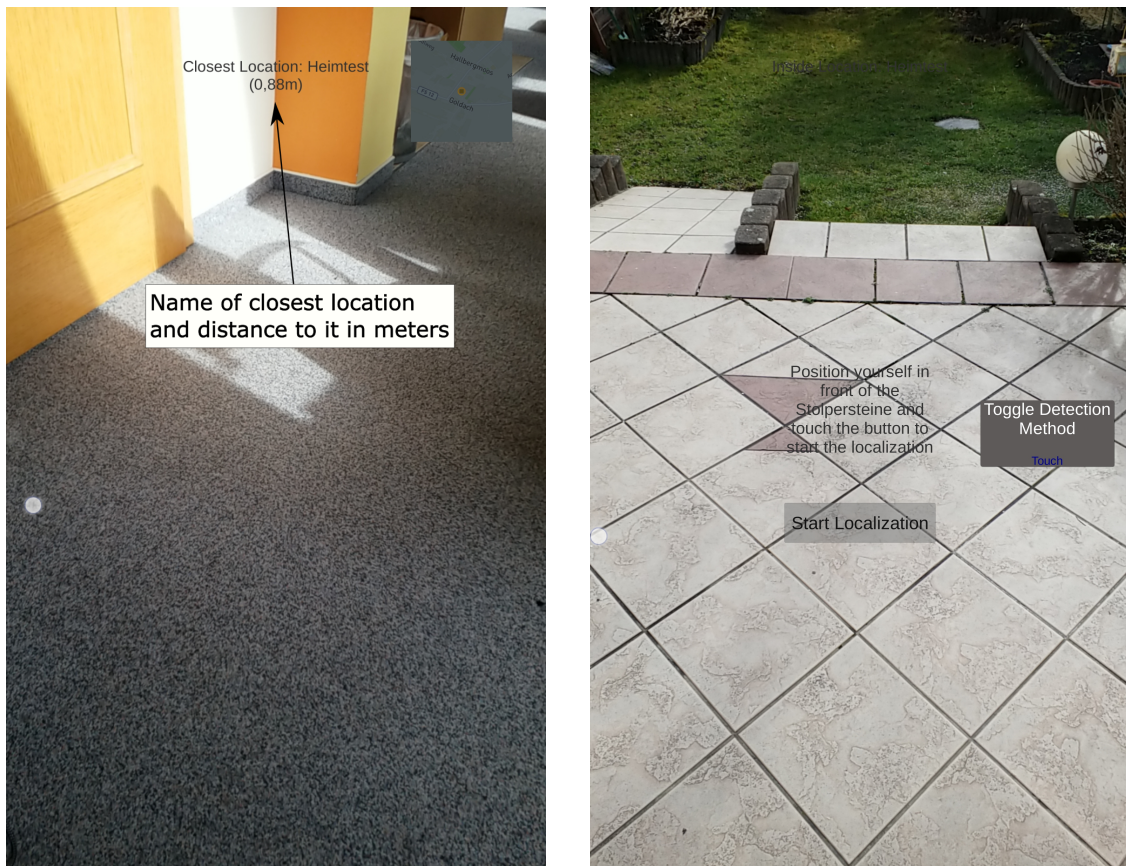


Figure 4.12: When outside a location a text is displayed at the top of the screen showing name and distance to the next location (left). Here the text has been made visible for demonstration purpose as if the user is not inside the location although this is actually the case here. When inside a location a button on the right edge of the screen now appears which allows to change the detection method between "Touch" and "Camera Detection".

5 Evaluation and Discussion

Web-interface and augmented reality application have been tested by a small set of test users. This qualitative test is presented in this chapter, evaluated and finally discussed. The insight gained from the conducted survey is then used to reflect on future improvements for the *Stolpersteine AR* project.

5.1 Methodology

The methodology used in the evaluation of the web-interface usability and augmented reality app acceptance can be divided into three evaluation concepts. First, for the web-interface a system usability scale test was conducted which was mandatory for every participant taking the survey. Second, several questions were presented to the participants targeting at their general experience and perception of both web-interface and augmented reality application. These questions were optional and were intended as a guidance for the survey participants to structure their opinion about the used systems. And third, also informal communication mostly based on email exchange was taken into account. The feedback created from this communication channel was primarily used to immediately improve web-interface or AR application.

The system usability scale (SUS) test is a short linear scale based test with ten questions. The questions presented are intended to produce the most extreme reactions by participants and cover different aspects of system usability. The linear scale for each question ranges from one to five where one means “strongly disagree” and five means “strongly agree”. Five of the statements have a positive formulation while the other five have a negative one in order to avoid participants of going blindly over the questions without thinking. For the final score of the SUS test this means that the points of the negative questions are inverse to the actual scale because “strongly disagree” here means a good usability. The SUS test is a robust and reliable tool to quickly assess the usability of a system [Bro96] and therefore is a good measure to see how well the developed piece of software was received. The test here was adapted from [Bro96] to the context of a web-application and translated to German with the help of two German translations^{1 2} of the English original.

Three specific questions about the *Stolpersteine Manager* were presented to the participants in the next section of the survey. Those questions were not mandatory and

¹<https://blogs.sap.com/2016/02/01/system-usability-scale-jetzt-auch-auf-deutsch/>
(accessed: 2022-03-07)

²<https://blog.seibert-media.net/blog/2011/04/11/usability-analysen-system-usability-scale-sus/>
(accessed: 2022-03-07)

targeted three different aspects of the system. The first one asked if the user experienced any technical problems, specifically regarding to the handling of the web-application. The users should give an impression about the user friendliness and usability they experienced, excluding topics that are object to content specific issues. These content specific issues were the substance of the next questions which asked for the intelligibility of the Stolperstein form. The last question targeted the actual content users could supply for a Stolperstein. They were asked if any information was missing or even obsolete and also which form fields were thought to be useful.

The last block considered the **user experience with the AR mobile application**. These two questions could potentially not been answered by every participant since it required manually installing the prototype AR application to their personal mobile phone. The two questions were if the user is satisfied with the display of the information in the AR app, he or she entered with the *Stolpersteine Manager* and if the user thought that the app enhances the experience of visiting Stolpersteine in the real world. Part of the last question also was if the original intent of the Stolpersteine of invoking empathy was improved.

Finally the participants also had the opportunity to give custom feedback without underlying questions. Answers from this section will also be included in the evaluation.

5.2 Qualitative Feedback

The type of feedback used to evaluate the Stolpersteine AR project is qualitative because the number of participants in the conducted survey were limited to three people. This limitation was desirable since the Stolpersteine AR app and the web-interface are still in an early prototype stage. This means that the distribution of the AR app is limited since users have to manually install the application and cannot use the *Google Play Store* or *Apple App Store*. The Stolpersteine also deal with the very sensitive topic of the Holocaust. That means that a large scale test should only be conducted with proper moderation of the user content created with the *Stolpersteine Manager*. Researching data for Stolpersteine additionally requires expert knowledge which implies that only a small group of people can adequately handle the web-application. Due to the fact that the project is still in an early stage it can profit from further refinement and additions to the AR app and in consequence also to the web-interface. Therefore collecting qualitative feedback at the moment is more suitable than quantitative feedback since users often have valuable suggestions on how to improve the software. This can be explicitly in the form of feature requests or implicitly by their positive or negative experience with certain aspects of the applications.

However the SUS test is a form of quantitative feedback it should be noted that the results from this test are not statistically significant. We believe that a SUS test is nonetheless valuable in the current development stage because the results give a hint if the implemented web-interface receives the intended acceptance.

5.3 Expert Surveys

Out of the three participants in the test of the *Stolpersteine Manager* and the optional test of the AR app, two of them answered the SUS test and interview questions. Demographic data of those two participants can be found in table 5.1. Both of them visited the seminar³ “Geschichtsvermittlung digital: neue Zugänge zu historischen Orten”⁴ at the “Ludwig-Maximilians-Universität München” (LMU) where they were initially made familiar with the *Stolpersteine* AR project.

Name	Elena Sagerer	Stefan Schöffmann
Age	24	24
Gender	Female	Male
University Course	Teacher for “Realschule” (Subjects: German, History, Educational Psychology)	Teacher for “Mittelschule” (Subjects: Religious Education, German, History, Social Studies)

Table 5.1: Demographic information of the two testers for the newly implemented *Stolpersteine Manager*. Both participants study for becoming a teacher and have no computer science background.

5.3.1 Results of the System Usability Scale Test

For all participants in the conducted survey it was mandatory to fill out a system usability scale test. The asked questions can be found in table 5.3 in two languages - German and English. The German version was asked because all the participants were German speaking and the seminar in which the test was performed was also held in German.

The system usability scale test was evaluated according to [Bro96]. The odd numbered questions have a positive formulation and contribute to the score according to the answer minus one. The even numbered questions however have a negative formulation and their contribution to the score is inverse to the odd numbered ones. Here their contribution is five minus the given answer. The scores of each question are then summed up and multiplied by a factor of 2.5 which results in a final SUS score between 0 and 100. Bangor et al. conducted a large scale evaluation how interviewees would adjectively rate the system they used after performing a standard SUS test [BKM09]. As a result they came up with the results presented in figure 5.1. According to Bangor et al. their results are highly significant and the correlation between adjective rating and SUS score is very high. Although we are not interested in using a single item questionnaire, this study gives a good impression on how the testers subjectively received the usability

³conducted by: A. Pleyer, D. A. Plecher, M. Pöllath

⁴Eng: teaching history digitally: new approaches to historical sites

of the website. Brooke gives no suggestion in [Bro96] what is the minimum SUS score so that a system can be viewed as having a “good” usability. However Bangor et al. [BKM09] claim that any rating below 70 indicates that the system has usability issues. This would mean in accordance to the results presented in figure 5.1 that “Good” is the minimum adjective rating for a system without relevant usability issues. The results

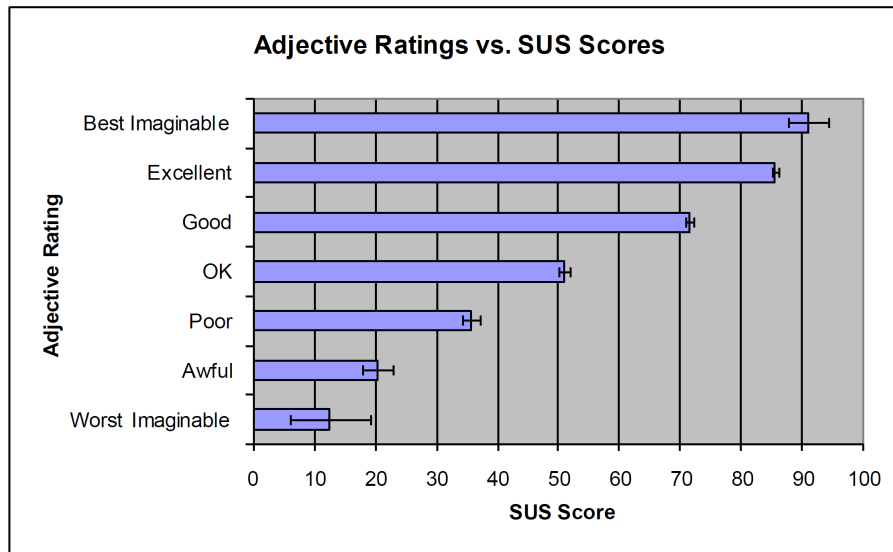


Figure 5.1: Results of the comparison between SUS score and adjective rating performed by Bangor et al. SUS scores and given adjective rating correlate very well and give a good impression what a SUS score means “in words”. Taken from [BKM09].

of the SUS tests of both participants can be found in table 5.2. Both SUS scores are in the acceptable range, however they differ by 20 points. The tendency of answers is very similar for most questions. The most notable difference can be found in question 4 where Elena Sagerer strongly disagreed that she would need a technical person to assist her, while Stefan Schöffmann strongly agreed on this matter. This could also explain why Stefan Schöffmann was undecided on question 10 if he had a lot to learn before he could use the website correctly. As a result this might indicate that getting started with the web-application is not straight forward for every user, although the general reception of the website is acceptable according to both scores. The results from the test can be labeled as *Best Imaginable* (Score = 95) and *Good* (Score = 75) according to figure 5.1 where the adjective with the closest mean score was taken respectively. Since this is a qualitative evaluation, no definitive conclusion should be drawn from the SUS test and the results rather should be interpreted as a guidance for future development.

Tester	Elena Sagerer	Stefan Schöffmann
Question 1	5	4
Question 2	2	1
Question 3	4	4
Question 4	1	5
Question 5	5	4
Question 6	1	1
Question 7	5	5
Question 8	1	1
Question 9	5	4
Question 10	1	3
SUS Score	95	75

Table 5.2: Each question of the SUS test can be rated from 1 (strongly disagree) to 5 (strongly agree). Elena Sagerer assessed the site with one of the highest possible scores, while Stefan Schöffmann did not rate every aspect as positive. The most notable difference lies in question 4 which covers the aspect if the tester had the impression that they needed a technical person to assist them.

5.3.2 Original German Interviews

Additionally to the SUS test, the testers could also fill out some optional questions. As explained already in the previous section, all questions were asked in German. The results of these asynchronous interviews are presented in this section, were first a question is listed, followed by the answers of each participant.

Part A: Questions about the *Stolpersteine Manager*

(Technik): Gab es Dinge, die dich bei der Verwendung (wiederholt) geärgert haben? Das können Dinge sein, die bei der Bedienung umständlich oder frustrierend waren, aber auch technische Probleme.

Elena Sagerer Anfangs trat bei mir häufiger das Problem auf, dass die eingetragenen Inhalte nicht gespeichert wurden bzw. nicht als gespeichert sichtbar waren (Lebensstationen, Bilder). Dieser Umstand wurde dann aber bald behoben. Es wäre toll, wenn das nachträgliche Ändern/ Anpassen des genauen Standorts ermöglicht wird.

Stefan Schöffmann Im Großen und Ganzen gab es keinen besonderen Schwierigkeiten bei der Verwendung der Webseite und App *Stolpersteine Manager*. Allerdings fand ich es etwas kompliziert Orte außerhalb Deutschlands als Erscheinungsorte (Lebensstationen) geographisch einzutragen. Hier wäre es schöner den Namen, die Straße oder den

	German Original Version	English Translation
Question 1	Ich kann mir vorstellen die Webseite häufig zu verwenden	I think I would like to use the website frequently
Question 2	Ich finde die Webseite unnötig komplex	I found the website unnecessarily complex
Question 3	Die Webseite war einfach zu benutzen	The website was easy to use
Question 4	Ich hatte das Gefühl, dass ich Unterstützung von einer technisch versierten Person bräuchte, um die Webseite korrekt zu verwenden	I think that I would need the support of a technical person to be able to use the website correctly
Question 5	Ich finde, dass die verschiedenen Funktionen der Webseite gut integriert sind	I found the various functions on the website were well integrated
Question 6	Es gab zu viele Inkonsistenzen bei der Webseite	I thought there was too much inconsistency on the website
Question 7	Ich kann mir vorstellen, dass die meisten Menschen den Umgang mit der Seite schnell erlernen würden	I would imagine that most people would learn to use the website very quickly
Question 8	Die Bedienung der Webseite war sehr umständlich	I found the website very cumbersome to use
Question 9	Ich habe mich bei der Verwendung der Seite sehr sicher gefühlt	I felt very confident using the website
Question 10	Ich musste zunächst eine Menge Dinge lernen, bevor ich die Webseite verwenden konnte	I needed to learn a lot of things before I could get going with the website

Table 5.3: Questions for the system usability scale test that were presented to the participants. The German version is the one that was asked and a translation of each question is provided for the English reader.

Ort eintragen zu können anstatt diesen auf der großen Karte zu suchen. Automatisches Erkennen nach Ortsnamen-Eingabe. Zudem ist es nicht ganz einfach die richtige Reihenfolge der Erinnerungsorte einzuhalten, denn die eingetragenen Informationsboxen haben sich bei mir nicht korrekt verschieben lassen. Was nicht ist, kann ja noch werden. Trotzdem eine sehr gute und tolle Webseite.

(Nutzerfreundlichkeit): Waren die Formfelder zum Anlegen von Stolpersteinen leicht verständlich? Wenn ja, was hat dir gut gefallen? Wenn nein, womit hattest du Probleme?

Elena Sagerer Das Eintragen innerhalb des Managers stellte (abgesehen von oben genannten Dingen) keine Probleme dar. Besonders toll fand ich, dass auf meinen Wunsch hin mehr Textboxen ermöglicht wurden und auch das Einfügen einer Audiodatei als neue Funktion ergänzt wurde.

Stefan Schöffmann Mir gefiel die Einfachheit und verständnisvolle Sprache zum Eintragen der Informationen über Personen, welche Stolpersteine erhielten. Es war alles übersichtlich gestaltet und gut sichtbar.

(Inhalt): Was fehlt deiner Meinung nach noch? Aus Sicht eines Historikers/historisch versierten Person, welche Informationsangaben waren nützlich, welche ggf. überflüssig und welche haben gefehlt?

Elena Sagerer Ergänzungswünsche:

- mehrere Bilder einfügen, auch zu den entsprechenden Textboxen, die man bei "zusätzliche Infos" hinzufügen kann, sodass in der App dann der Text und darüber oder darunter ein Bild erscheint.
- Beziehungen auch zu Personen herstellen, die (noch) keinen Stolperstein besitzen (bspw. über ein zusätzliches Symbol, das dann in der App erscheint)
- die Möglichkeit eines Textfelds für die Literatur- und Quellenangaben, das man dann auch separat in der App aufrufen kann
- die Möglichkeit Links einzufügen, die auf andere Websites führen, um ggf. mehr Informationen zu erhalten
- ein bisschen schwierig finde ich das Feld "Allgemeine Informationen". Ich denke, es wäre gut, dort zu ergänzen, was in diesem Feld eingetragen werden soll (bspw. "Geben Sie in wenigen Sätzen einen Kurzüberblick zur Person" o.Ä.).

Alle anderen Felder und Funktionen finde ich super und sehr nützlich!!!

Stefan Schöffmann Vielleicht wären verschiedene Symbole (Lebensabschnitten z.B. Eheringe - Heirat) eine Überlegung wert, denn mit Gegenständen prägte sich das historische Lernen leichter ein.

Part B: Questions about the AR application

Wurden die Informationen, die du auf der Webseite eingetragen hast zufriedenstellend in der App angezeigt? Hättest du erwartet, dass manche Dinge anders dargestellt werden?

Elena Sagerer Das Bild mit Lebensdaten und den Symbolen darunter wird super dargestellt. Es ist sehr anschaulich und macht sofort Lust, sich durch die einzelnen Symbole zu klicken.

Auch die hinzugefügte Funktion, durch die angezeigt wird, wie weit man vom nächsten Stein entfernt ist, finde ich sehr hilfreich. Leider wird diese Anzeige bei meinem Smartphone von der Innenkamera verdeckt (Vielleicht könnte man diese also noch etwas weiter nach unten setzen).

Nicht ausgefüllte Kästen werden als leere Kästen angezeigt (bspw. "allgemeine Infos"). Ggf. kann man das so ändern, dass diese Kästen dann gar nicht erscheinen.

Es wäre schön, wenn man die Schrift- und Kästenfarbe sowie die Schriftart noch anpasst, sodass alles ansprechender auf den Rezipienten wirkt.

Stefan Schöffmann Das kann ich leider noch nicht beurteilen. Bislang sind meine Installationsversuche der APK-Datei trotz APK-Installer und ausreichenden Speicherplatz auf dem Handy misslungen. Ich suche nach einer Lösung, aber denke schon, dass die Infos der Webseite auch auf der Handy praktisch und übersichtlich erscheinen. Deine Webseite ist super strukturiert.

Im Vergleich mit und ohne AR App, wie hat sich das Erlebnis verbessert (oder verschlechtert)? Hast du es als leichter empfunden dich in die Personen, denen durch die Stolpersteine gedacht wird, hineinzusetzen?

Elena Sagerer Durch die App erhält man deutlich mehr Informationen über die Person als durch die wenigen Zeilen, die auf dem Stein stehen. Vor allem durch die Ergänzung von Bild- und Audioinhalten wird ein viel näherer Bezug zur Person hergestellt und zur Auseinandersetzung mit den Verfolgten angeregt.

Außerdem ist die App für alle Zielgruppen gleichermaßen gut geeignet. Seien es Touristen, Stadtbewohner oder Schulklassen. Durch die Kombination aus Lokalgeschichte und digitalen Medien wird sicherlich vor allem das Interesse der jüngeren Generation geweckt, bei der es besonders wichtig ist, ein Geschichtsbewusstsein zu fördern.

Stefan Schöffmann Aus gegenwärtiger Sicht können wir uns niemals in historische Personen hineinversetzen. Wir können ihr damaliges Leben (Ängste, Schicksaalschläge Leid) in keinster Weise nachempfinden. Allerdings lassen sich mithilfe dem Projekt Stolpersteine (Objekte, Webseite, App) die Erinnerungen an die Personen vor Ort (Lokalgeschichte) aufrechterhalten. Hiermit können ihre Lebensstationen auf reale und digitale Weise aufgezeigt werden. Stolpersteine sind zu einem Teil unserer NS-Erinnerungskultur geworden.

Part C: General Feedback and Suggestions

Stefan Schöffmann Weitere Anregungen:

- Symbole für die Lebensabschnitte (beim Daraufklicken erscheinen dazu die Textfelder)
- Stolpersteine Manager App weiterbetreiben (gegebenenfalls veröffentlichen)

Herzlichen Dank für deine Arbeit und Mühe zur Erstellung und Verbesserung der Webseite und App. Es machte mir großen Spaß und erweiterte nicht nur mein historisches Wissen mit den Stolpersteinen, sondern auch die wichtige und wertvolle Tätigkeit eines Informatikers, um geschichtliche Inhalte auf digitale Weise allen Interessierten zur Verfügung zu stellen. Insgesamt eine informative, tolle und wunderbare Übung zu Geschichtsdidaktik. Dank an alle Beteiligten.

5.3.3 English Translation

In this section an English translation of the answers listed in section 5.3.2 is given. The translation aims at reciting the essentials of those answers.

Part A: Questions about the *Stolpersteine Manager*

(Technology): Have there been any issues that (repeatedly) annoyed you while using the app? This can be things that were cumbersome or frustrating while handling the application, but also technical issues.

Elena Sagerer At the beginning some data was not saved properly but this was fixed quickly. It would be great if *Stolpersteine* locations could be edited after creation.

Stefan Schöffmann In general I did not encounter any serious problems while using the *Stolpersteine Manager*. However it was difficult to enter life stations outside of Germany. I would prefer entering a street name or city which is then automatically registered with the correct coordinates instead of manually searching these places on a map. Also it is not easy to enter the life stations in the correct order because I could not change the order. All in all it's a good website.

(User Friendliness): Were the form fields for creating Stolpersteine easy to understand? If so, what did you like in particular? If not, where did you have problems?

Elena Sagerer Apart from the minor issues listed in the previous answer there were no difficulties with the application. I was very pleased that my wishes for more text boxes and also the upload of an audio file were made possible.

Stefan Schöffmann I liked the ease of use and understandable language for entering information about people with a *Stolperstein*. The interface was clear and everything

was clearly visible.

(Content): In your opinion, what is missing? From the point of view of a person who is adept in history, which data fields were useful, unnecessary and which information was missing?

Elena Sagerer Wishes for additional content:

- Upload multiple images, also for the text boxes, so that the AR application displays text together with an image
- Create relations with people who don't have a Stolperstein (yet). These relations could be presented with a different symbol in the app
- The possibility to create a text field for reference sources that can be accessed from within the application
- The possibility to integrate links that give access to additional information outside the app
- The "Allgemeine Informationen" text field could be improved by for example adding a short description what should be added here (e.g. give a short overview about the person)

All other fields and functions were really great and useful!

Stefan Schöffmann The possibility to add symbols could be useful (e.g. wedding rings for a wedding life station) because learning about history is more effective with graphic objects.

Part B: Questions about the AR application

Was the information you entered on the website displayed to your satisfaction in the AR app? Did you expect that something was presented differently?

Elena Sagerer The picture with name, birth and death date, together with the 3D symbols beneath to access additional information encourages to engage with the application. It is really well displayed and vivid.

Also the added functionality that shows the distance to the next Stolperstein location is really helpful. Unfortunately the text is partially hidden by the front camera of my mobile phone.

Text boxes that were not filled in (e.g. "Allgemeine Informationen") are also displayed in the application. It would be better if these text boxes would not be shown then.

For text boxes it would be helpful - to create a nicer user experience - if font and text box color, as well as font type could be altered.

Stefan Schöffmann Unfortunately I cannot not judge this aspect because I was not able to install the APK-file on my phone.

In comparison with and without the AR application, how was the experience improved (or worsened)? Did you find it easier to empathize with the people that were mentioned by the Stolpersteine?

Elena Sagerer With the app one gets far more information about the person than simply by the few lines of text on the stone. Especially with images and audio files a closer connection to the person can be established. This can lead to further engagement with the life of these victims. Furthermore the app is suitable for all kinds of audiences like tourists, locals or school classes. By combining local history with digital media I believe that especially the younger generation can develop more consciousness for this part of history which is highly important.

Stefan Schöffmann From our present point of view we can never fully empathize with historical people. In no way we can understand their life (their fears, sorrow and strokes of fate). However with the Stolpersteine project (including the physical Stolpersteine, web-application and mobile application) the memories about these people (and their local history) can be kept alive. With these tools their life stations can be shown in a real as well as digital manner. Stolpersteine have become a part of our collective commemorative culture of the Nazi time period.

Part C: General Feedback and Suggestions

Stefan Schöffmann Additional Suggestions:

- Symbols for life stations (clicking on them displays the text box)
- Continue operation of the Stolpersteine Manager App (possibly publish it)

Many thanks for developing and improving the website and AR application. I had great fun and extended my historical knowledge. I am also pleased that we could profit from the important and valuable skills of a computer scientist to provide historical data to anyone interested. It was an informative, great and wonderful exercise about history didactics. Thanks to all who were involved.

5.4 Interpretation and Lessons Learned

The general reception of the AR app and the web-interface throughout is very positive and continuing development and operation of the applications is wished for. The web-interface is received as a useful and easy to handle tool for creating AR content for the Stolpersteine. The form to enter the Stolpersteine is clear and most data fields

are thought to be useful. Also the AR app received positive feedback and according to the two testers it also fulfills the intention that users can easier empathize with the people who have a dedicated Stolperstein. Additionally it was pointed out that the AR application should be useful for broad public. Especially interesting could be the usage of the application with school classes because the Holocaust plays an important role in their history lessons. Expanding their consciousness for this time period is vital so that the Holocaust and the lessons learned from it are not forgotten.

Technical issues that could possibly interfere with the handling of the web-interface or AR application were fixed right away. At the time of writing no remaining issues are known that lead to erroneous behavior of the two programs. However a number of improvements are wished for the future which mostly have to be implemented in both programs.

The first topic for improvements can be summarized as search functionalities. At places where options to enter a geo-location are present, users currently can use a map to select the location. One of the testers points out that he would sometimes rather have the opportunity to search for the city or street name textually with an auto completion functionality so that the web-application also recognizes locations by their name and fills in the the coordinates appropriately. However this functionality could be harder to realize since not only the search functionality has to be implemented but also the translation of e.g. a city name to geographical coordinates. Although not specifically mentioned in the survey, we believe that a general search functionality would be useful in a number of places of the program because it would allow users to find more quickly what they are looking for. They could profit from a search functionality when looking for a specific Stolperstein location, Stolperstein or simply a Stolperstein within the form field of creating a new relation between two people with Stolpersteine.

Also the wish to sort content has been expressed. Here life stations are mentioned, however in the current way these life stations are presented within the AR application it is not necessary to sort them. Nevertheless it should be kept in mind since it might help users to structure their researched data. A place where this sorting functionality seems to be necessary is the newly implemented text box selection. This can be derived from the request of being able to sort life stations because here it can often be intentional in which order the buttons for the text boxes appear in the selection menu.

The last topic revolves around the text box feature of the AR application. It is said that the text field of "Allgemeine Informationen" probably needs a description of what to enter in this text box. With the implementation of the feature to add various text boxes with variable title and text this text box and also the "Informationen zur Familie" text field can be thought of being obsolete. Users are now able to enter this information in one of the text boxes which is probably more intuitive and overall less restrictive in terms of which information to add. One of the users also wishes that relations could also be entered with people who do not have a Stolperstein. Here the general need to make the interface and mobile application less restrictive can be seen. Being more flexible is potentially positive since not every person and their fate is similar. Therefore

a reasonable amount of flexibility is beneficial. Another point is the improvement of the text boxes. A suggestion is made to be able to choose color and font of the text and also to select a background color for the text boxes. Additionally one of the users would appreciate the possibility to add an image per text box which is then displayed above or beneath the text. This idea seems promising since textual information on its own can be received as deterrent, especially in the case of text boxes since it is a 2D display where the benefits of augmented reality do not apply. Synergy between real and virtual world is the great advantage of AR which aims at improving the engagement with Stolpersteine in our work. This could be achieved with a suggestion made by one of the testers to be able to select descriptive symbols for life stations like wedding rings. This feature also would be applicable to the selection of text boxes. Using 3D objects for selecting content seems more suitable in the context of an AR application than a plain list of buttons. Potentially this could increase the engagement with the real world scene by not startling the user out of the 3D scene with the presentation of too much 2D content.

6 Outlook

In chapter 5 we have discussed feedback to the *Stolpersteine Manager* and the mobile application. A number of wishes and suggestions have been analyzed how future versions of the Stolpersteine AR project can be improved and in which direction development of the applications should be continued. Most changes to the AR application also require a respective change in the web-interface. Therefore we will structure the outlook into two parts. First potential additions and changes to the augmented reality application are discussed. Most of these changes have to be taken into account for the future development of the *Stolpersteine Manager* as well. Part two of this outlook then focuses on improvements to the web-interface which are decoupled from the AR application. The suggested improvements and future development options given here are not intended to be exhaustive. An outlook on other important improvements especially on performance is not part of this thesis but can be found in [Len21].

6.1 Future Development Process of the AR Application

The augmented reality application is currently still in a prototype stage. The major motivation for improving this application is the possibility to make the app available for the broad public, potentially also reaching out to the creator of the Stolpersteine, Gunter Demnig.

6.1.1 User Interface

Due to the early development stage a lot of the graphics and menus of the AR app still have to be improved.

- 3D objects which are used for the augmentation of the scene are mostly rudimentary and require a rework. Also additional objects are needed if functionality like specifying symbols to access certain bits of information is implemented. Another example is the necessary refinement of life station markers that are displayed on a map. A person with experience in 3D modeling could be helpful for this task.
- The user interface in general still needs improvements in the form of menus that are visually more appealing. Common symbols for navigation buttons and the support of standard functionality like scrollable texts need to be implemented. This has been verified in informal email traffic with one of the testers who presented the prototype application to a school class. The students there also wished for a “prettier” user interface.

- Text boxes are a simple way of providing information. One of the testers however wishes for more customization options for these boxes. The ability to add images to text boxes has been suggested, as well as choosing the font type and font color. Also changing the background color of text boxes is a desired option.[†]
- Minor improvements like deactivating the camera in text box scenes already have been implemented. However this created new issues because deactivating the main camera also means that previously shown content is frozen. This leads to the problem that often menus which should no longer be shown, can still be seen in the background. A more elaborate and visual appealing implementation of this feature would be a non-transparent background overlay rendered over the camera image.

6.1.2 Features

The implementation of the augmented reality application is a first iteration. Experience with using the application and conducting formal and informal feedback sessions show that still a lot of functionality can be added and existing features have to be refined.

- A general concern is, making the AR application more flexible in terms of which information is necessary per Stolperstein. This in turn calls for a rework of the 3D scene augmentation. One suggestion made in an informal discussion is creating a 3D information panel that is rendered near the currently augmented Stolperstein and gives access to additional information. From this information panel e.g. text boxes or the audio player could be accessed.[†]
- The 3D augmentations could also be used to guide the user to interesting places which stand in relation with the current Stolperstein or Stolpersteine location. A viable option could be displaying a 3D dimensional arrow which directs the user to a near point of interest like a life station or another Stolperstein.
- Accessing external information is also a promising future improvement. As a first iteration a text box could be integrated which allows to access relevant web links for the current Stolperstein. Also displaying reference sources falls into this category. When offering reference sources it should be possible for users to access these sources if they wish to engage with external resources providing information about the current Stolperstein. Furthermore in an advanced version of the application external sources could be directly integrated within the AR application. This for example could mean including images, audio and video content which is downloaded from third party providers.[†]

[†] This task also requires respective changes in the web-interface

6.2 Web-interface

While some changes in the AR application also require changes in the web-interface, other improvements to the *Stolpersteine Manager* solely require modification of the web-application. The qualitative feedback collected from two test users shows that the web-interface in general is accepted very well and development should continue on the current basis.

- Stolpersteine locations should be made editable. It is important to be able to change the geographical coordinates of locations to correct mistakes in the placement of a location. Additionally changing the name of a location should be implemented together with this feature.
- Adding a search functionality for Stolpersteine locations and Stolpersteine. Locations could also be filtered according to parameters like radius around a reference point, city or country. This is one of the more urgent tasks because as soon as more locations are added, it gets more difficult to search for the correct location manually when adding or editing a Stolperstein.
- At places in the program where geo-coordinates are entered by selecting the location from a map, it was suggested to also be able to enter the location by name, i.e. the name of a city or street, which then automatically fills in the correct coordinates.
- Adding an option to sort items associated with a Stolperstein seems to be especially useful for the newly added text boxes, since the order in which they appear in the mobile application is the order they are created. Determining an order here is therefore helpful to create a chronological sequence. Also other content like life stations and relations could be made sortable to make it easier for editors to structure their researched information. However in the current AR app implementation, the order for the latter is not relevant.
- Currently all localization texts of the web-interface are consistently presented in German. Internationalization should be added to support also other languages which might be necessary in the future since Stolpersteine can be found in various countries where non German speaking experts might also have an interest in adding Stolpersteine data. At least the option to switch to English should be added as a start.
- More mobile optimizations could be added to the application and also the transformation into a PWA could be performed so that the *Stolpersteine Manager* feels like a native app on mobile phones. Mobile devices are widely available today and having a solid mobile support lowers the threshold for getting in touch with the application.

- To make the application available for the broad public it would be necessary to add a moderation feature because Stolpersteine deal with the sensitive topic of the Holocaust. The web-application therefore has to be protected from abuse. An administrative area would be necessary to realize this, where unpublished Stolpersteine can be reviewed and only people with the right permission are allowed to accept and publish them.
- A potential feature which would be straightforward to realize is adding the option to present the data entered for a Stolperstein directly within the web-interface. This would equal a 2D view of the content presented in the mobile application and could be complementary to the AR approach. An evaluation should be conducted first on this matter if such a view is needed.

7 Conclusion

In the scope of this thesis, the development of a mobile augmented reality application for the *Stolpersteine* memorial was continued. The main focus of this work lies on the improvement of the web-interface used for entering data for this application. Therefore a new web-application called *Stolpersteine Manager* has been created which is based on the Angular framework. This new interface fixes the issues with the original web-interface and implements previously missing functionality. Additionally new features for the AR application have been added which are also reflected by the new web-interface. To be able to test the applications the web-interface and backend application have been hosted publicly for the first time.

A qualitative, formal evaluation was conducted on the usability of the *Stolpersteine Manager* and the general reception of the augmented reality mobile application. This evaluation was performed as an expert survey since supplying data for the *Stolpersteine* application requires historical knowledge and research skills to acquire the necessary information. The survey itself consisted of a system usability scale test and a number of questions targeting the general user experience with web-interface and mobile application, also with the intention of collecting suggestions for future development steps.

The evaluation proves that the augmented reality application as well as the new web-interface are perceived as positive and development should continue on the foundation of the currently existing software. The test users confirmed that they think the application helps people to get in touch with local history and the important topic of the Holocaust. It has been pointed out that especially the younger generation, also in the form of school pupils can profit from this application by providing a more vivid experience than the *Stolpersteine* on their own. This coincides with informal evaluations performed with the initial AR application prototype [Len21]. The web-interface has been described as clear and easy to handle. It is important to note that the test users had no computer science background in order to perform an evaluation that is as close to the planned regular operation of the application as possible.

The *Stolpersteine Manager* has proven to be a valuable tool which should be developed alongside the AR application. We also believe that such a web-interface can lay the foundation for similar cultural heritage based projects. The augmented reality application is still in a prototype state and suggestions have been collected on how web-interface and mobile application can be further enhanced. This thesis therefore provides valuable information for the continuation of this work. However not all topics which are important for a future development are covered by this thesis and need to be considered for future work which namely is the performance of the AR application.

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Acronyms

AR augmented reality	1
VR virtual reality	2
app application	1
HMD head-mounted display	2
IMU inertial measurement unit	10
REST representational state transfer	12
API application programming interface	12
PWA progressive web app	17
RBAC role based access control	21
CLI command line interface	30

Bibliography

- [AE12] K. Attila and B. Edit. “Beyond reality: The possibilities of augmented reality in cultural and heritage tourism.” In: *2nd International Tourism and Sport Management Conference, Debrecen*. Vol. 5. 6. 2012.
- [Ang22] *Angular. The modern web developer’s platform*. URL: <https://angular.io/> (visited on 01/28/2022).
- [Anm22] *Angular Material. Material Design components for Angular*. URL: <https://material.angular.io/> (visited on 01/28/2022).
- [ARC22] *ARCore XR Plugin Documentation*. URL: <https://docs.unity3d.com/Packages/com.unity.xr.arcore@4.1/manual/index.html> (visited on 02/07/2022).
- [ARF22] *AR Foundation Documentation*. URL: <https://docs.unity3d.com/Packages/com.unity.xr.arfoundation@4.1/manual/index.html> (visited on 02/07/2022).
- [Azu97] R. T. Azuma. “A survey of augmented reality.” In: *Presence: teleoperators & virtual environments* 6.4 (1997), pp. 355–385.
- [BKM09] A. Bangor, P. Kortum, and J. Miller. “Determining what individual SUS scores mean: Adding an adjective rating scale.” In: *Journal of usability studies* 4.3 (2009), pp. 114–123.
- [Bro96] J. Brooke. “Sus: a “quick and dirty” usability scale.” In: *Usability evaluation in industry* 189.3 (1996).
- [BSY10] P. Belimpasakis, P. Selonen, and Y. You. “Bringing user-generated content from Internet services to mobile augmented reality clients.” In: *2010 Cloud-Mobile Convergence for Virtual Reality Workshop (CMCVR 2010) Proceedings*. 2010, pp. 14–17. DOI: 10.1109/CMCVR.2010.5560611.
- [Čej+21] J. Čejka, M. Mangeruga, F. Bruno, D. Skarlatos, and F. Liarokapis. “Evaluating the Potential of Augmented Reality Interfaces for Exploring Underwater Historical Sites.” In: *IEEE Access* 9 (2021), pp. 45017–45031. DOI: 10.1109/ACCESS.2021.3059978.
- [DH22] G. Demnig and J. Heuper. *Stolpersteine Webseite*. 2022. URL: <http://www.stolpersteine.eu> (visited on 02/03/2022).
- [Fie00] R. T. Fielding. “Architectural Styles and the Design of Network-based Software Architectures.” PhD thesis. University of California, Irvine, 2000.

- [HK12] A.-C. Haugstvedt and J. Krogstie. "Mobile augmented reality for cultural heritage: A technology acceptance study." In: *2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. 2012, pp. 247–255. DOI: 10.1109/ISMAR.2012.6402563.
- [HMC99] P. J.-H. Hu, P.-C. Ma, and P. Y. Chau. "Evaluation of user interface designs for information retrieval systems: a computer-based experiment." In: *Decision Support Systems* 27.1 (1999), pp. 125–143. ISSN: 0167-9236. DOI: [https://doi.org/10.1016/S0167-9236\(99\)00040-8](https://doi.org/10.1016/S0167-9236(99)00040-8). URL: <https://www.sciencedirect.com/science/article/pii/S0167923699000408>.
- [Ibá+14] M. B. Ibáñez, Á. Di Serio, D. Villarán, and C. Delgado Kloos. "Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness." In: *Computers & Education* 71 (2014), pp. 1–13. ISSN: 0360-1315. DOI: <https://doi.org/10.1016/j.compedu.2013.09.004>. URL: <https://www.sciencedirect.com/science/article/pii/S0360131513002571>.
- [Jea12] M. Jeater. "Smartphones and site interpretation: The Museum of London's Streetmuseum applications." In: *Archaeology and Digital Communication: Towards Strategies of Public Engagement*. London: Archetype Publications (2012), pp. 66–82.
- [JEW22] *Stolpersteine: the world's largest project of commemoration*. URL: <https://j-e-w-s.org/holocaust-stolpersteine/> (visited on 02/03/2022).
- [Jul11] M. A. e. a. Julie Carmigniani Borko Furth. "Augmented reality technologies, systems and applications." In: *Multimed Tools Appl* 51 (2011), pp. 341–377. DOI: <https://doi-org.eaccess.ub.tum.de/10.1007/s11042-010-0660-6>.
- [Kru14] S. Krug. *Don't make me think! - Web & Mobile Usability: Das intuitive Web*. mitp Verlag, 2014.
- [Len21] N. Lenßen. "Development of an Augmented Reality App for Stolperstein Memorials." Bachelor's thesis. Technische Universität München, 2021. unpublished.
- [MK94] P. Milgram and F. Kishino. "A taxonomy of mixed reality visual displays." In: *IEICE TRANSACTIONS on Information and Systems* 77.12 (1994), pp. 1321–1329.
- [Pac+14] D. Pacheco, S. Wierenga, P. Omedas, S. Wilbricht, H. Knoch, and P. F. Verschure. "Spatializing experience: a framework for the geolocalization, visualization and exploration of historical data using VR/AR technologies." In: *Proceedings of the 2014 virtual reality international conference*. 2014, pp. 1–4.
- [Pac+15] D. Pacheco, S. Wierenga, P. Omedas, L. S. Oliva, S. Wilbricht, S. Billib, H. Knoch, and P. F. Verschure. "A location-based Augmented Reality system for the spatial interaction with historical datasets." In: *2015 Digital Heritage*. Vol. 1. IEEE. 2015, pp. 393–396.

- [PMR18] C. Panciroli, A. Macaуда, and V. Russo. "Educating about art by augmented reality: new didactic mediation perspectives at school and in museums." In: *Multidisciplinary Digital Publishing Institute Proceedings*. Vol. 1. 9. 2018, p. 1107.
- [RF13] M. Richter and M. D. Flückinger. *Usability Engineering kompakt*. Springer Vieweg, Berlin, Heidelberg, 2013. DOI: <https://doi-org.eaccess.ub.tum.de/10.1007/978-3-642-34832-7>.
- [SH16] D. Schmalstieg and T. Höllerer. *Augmented Reality: Principles and Practice*. Addison-Wesley Professional, 2016.
- [Sto11] S. Stoll. *Mit Füßen getreten? Jüdische Kritik an "Stolpersteinen"*. 2011. URL: <https://www.evangelisch.de/inhalte/104016/11-03-2011/mit-fuessen-getreten-juedische-kritik-stolpersteinen> (visited on 02/07/2022).
- [Tak18] D. Takahashi. *Holocaust Memorial Museum uses augmented reality to make history visceral*. 2018. URL: <https://venturebeat.com/2018/08/31/holocaust-memorial-museum-uses-augmented-reality-to-make-history-visceral/> (visited on 02/07/2022).
- [USH18] *Connecting to History through Augmented Reality*. United States Holocaust Memorial Museum. 2018. URL: https://www.youtube.com/watch?v=HHyWLy4Ik&ab_channel=UnitedStatesHolocaustMemorialMuseum (visited on 02/07/2022).
- [Wet20] J. Wetzel. *Umstrittenes Gedenken an Nazi-Opfer*. Süddeutsche Zeitung. 2020. URL: <https://www.sueddeutsche.de/muenchen/muenchen-stolpersteine-aegyptisches-museum-1.5091221> (visited on 02/07/2022).