Visualization Research Center (VISUS)

University of Stuttgart
Allmandring 19
D–70569 Stuttgart

Bachelorarbeit

Investigating the Design and Usability of 360° Image Annotations in the Context of Campus Accessibility

Solveigh König

Course of Study:	Medieninformatik B.Sc.
Examiner:	Prof. Dr. Michael Sedlmair
Supervisor:	Katrin Angerbauer, M.Sc. Markus Wieland, M.Sc.
Commenced:	November 7, 2023
Completed:	May 7, 2024

Abstract

Mobility enables equal participation in social life and fulfils basic human needs. Students with mobility impairments face many problems when travelling to target locations at a university caused by the design of the physical environment. This often forces them to choose longer and partially more complex routes. Consequently, they have different travel behaviours and need to develop a more detailed plan in advance than students without disabilities. For developing a plan, reliable and current accessibility information, especially for buildings is crucial. Currently, the amount and level of detail of information, particularly about the interior of university buildings, is rarely provided online. This makes virtual reality technology a promising solution.

In this thesis, we want to investigate the design and usability of a virtual 360° tour focusing on accessibility information for a university campus. Therefore a prototype for one building at the University of Stuttgart has been implemented, including visualizations with accessibility information. The requirements for the prototype were collected with a focus group, an online survey and literature research. The virtual tour allows users to individually assess the accessibility of the building by virtually walking around and receiving hints and navigations. The presented approach was evaluated in a user study and is considered a very helpful tool that should be extended to the whole university campus in the future. The results of this work show that visual information sources have great significance and that size data about doors, entrances and corridors is important when planning a campus visit.

Kurzfassung

Mobilität ermöglicht eine gleichberechtigte Teilnahme am gesellschaftlichen Leben und erfüllt menschliche Grundbedürnisse. Studierende mit Mobilitätseinschränkungen werden auf dem Weg zu Zielorten an einer Universität mit vielen Problemen konfrontiert, die durch die Gestaltung der physischen Umgebung verursacht werden. Dies zwingt sie oft dazu, längere und teilweise komplexere Wege zu wählen. Daher haben sie ein anderes Reiseverhalten und müssen im Vorfeld eine detailliertere Planung erstellen als Studierende ohne Behinderung. Für die Entwicklung eines Plans sind zuverlässige und aktuelle Informationen über die Zugänglichkeit, vor allem von Gebäuden, von entscheidender Bedeutung. Derzeit werden Informationen, insbesondere über das Innere von Universitätsgebäuden, nur selten in ausreichendem Umfang und Detaillierungsgrad online bereitgestellt. Das macht die Technologie virtuelle Realität eine vielversprechende Lösung.

In dieser Arbeit soll das Design und die Usability eines virtuellen 360°-Rundgangs mit dem Fokus auf Zugänglichkeitsinformationen für einen Universitätscampus untersucht werden. Dazu wurde ein Prototyp für ein Gebäude der Universität Stuttgart implementiert, der Visualisierungen mit Informationen zur Barrierefreiheit enthält. Die Anforderungen an den Prototyp wurden mit einer Fokusgruppe, einer Online-Umfrage und Literaturrecherche erhoben. Der virtuelle Rundgang ermöglicht es den Nutzern, die Barrierefreiheit des Gebäudes individuell zu beurteilen, indem sie virtuell umhergehen können und dabei Hinweise und Navigationen erhalten. Der vorgestellte Ansatz wurde in einer Nutzerstudie evaluiert und wird als eine sehr hilfreiche Anwendung angesehen, die in Zukunft auf den gesamten Universitätscampus ausgeweitet werden sollte. Die Ergebnisse dieser Arbeit zeigen, dass visuelle Informationsquellen eine große Bedeutung haben und dass Größendaten über Türen, Eingänge und Flure für die Planung eines Campusbesuchs wichtig sind.

Contents

List of Figures

1 Introduction

“No person shall be disfavoured because of disability.” This is a paragraph of the Basic Law for the Federal Republic of Germany [basicLaw22]. Despite various documents and commitments, people with disabilities are still confronted with barriers on a daily basis, according to the UN Convention on the Rights of Persons with Disabilities [unConvention24]. Accessibility is limited through the design of the physical environment, for example, road surface irregularities and high kerbs [SUU+12]. Especially public spaces, including educational institutions like universities, present significant challenges for persons with physical disabilities. In particular for universities, the access to courses, classrooms, laboratories and other campus programmes and facilities causes issues for students with impaired mobility. Narrow aisles, low tabletops and tall shelves are just a few commonplace examples [CSZ23; GBB03].
These scenarios of people with mobility impairments facing high barriers when visiting places, should not occur and every public space should allow equal access regardless of physical impairment. The UN Convention on the Rights of Persons with Disabilities clarifies that equal living conditions and the full realisation of all human rights and fundamental freedoms should be ensured for individuals with or without disabilities in all areas of social life. This also includes their full and effective participation and inclusion in society [unConvention24]. Social life often occurs in places that require travel. For individuals with limited mobility, it implies assessing whether a visit is possible for them at all. For example, wheelchair users need to consider information such as pavements and their surfaces as well as the accessibility of buildings, including entrances without stairs and access to lifts without barriers. Thus, individuals with mobility impairments often have to choose longer and partially more complex routes than other people. As a result, they have different travel behaviours and rely on significantly more information when travelling to unknown places. In advance, this makes developing a detailed plan necessary and raises the importance of how to access information. Additionally, it increases the need for reliable and current accessibility information, especially for buildings [MEL+22; Waa13]. To alleviate the problems caused by insufficient information and its provision can be done with little strategies such as better signposting. Additionally, assistive technology has great potential to provide information affordable and easy to operate. For instance, solutions like mobile navigation systems and mobile real-time information [SUU+12]. Finding or having better access to high-quality online travel information increases the confidence of people with disabilities who feel anxious and insecure before a journey. This affects the quality of journeys rather than their frequency [Waa13].
As a result, the idea of remotely assessing information became a significant necessity [CSZ23]. Virtual reality technologies could serve for this as they provide powerful and unique educational and informational experiences [GBB03]. The investment in cameras and depth sensors contributed to the success of tours captured by 360° cameras or smartphone cameras. Consequently, an expanding number of physical environments are being digitised with an ever-increasing fidelity [CSZ23]. These virtual tours are beneficial in situations where it is not possible to access physical places, as in times of pandemics, or in the everyday life of people with limited mobility [BRMP23]. However, these virtual tours are mostly implemented for outdoor environments, for example from systems

like Google Street View [googleMaps24]. Thus, it is essential to get access to more specific information about indoor environments as well [MEL+22]. Additionally, most existing virtual tours are not adapted for people with disabilities. For instance, the most common navigation systems only offer route planning depending on the user's current means of transport, but none of them offers specific support for users with limited mobility. This would include personalised navigation instructions such as urban features like curb ramps, steps, or other obstacles along the way [CSZ23; MCEB20].

This thesis attempts to gain a better understanding of these issues faced by people with limited mobility and to start filling the described gap at places like universities. Therefore, this work aimed to research, develop, conceptualise and prototype a web application for a university building. The application displays self-captured 360° images including annotations of their accessibility information. The design and content were defined through literature research on related work and through collaboration with target users via an online survey and an in-person workshop. It considers and implements central principles of usability and accessibility. Thereby various forms to visualise accessibility information and user experiences were explored. To evaluate the application, a user study was conducted, featuring a specifically designed scenario to assess its effectiveness and user satisfaction. The application represents a prototype of one university building and serves as a starting point for further research and exploration of the entire university, particularly for buildings with lecture halls. The results of this work demonstrate the great significance of visual information sources as they allow full insight into all obstacles of a building. Additionally, they point out the importance of textual measurement data about a building like doors, corridors and entrances when planning a campus visit for students with mobility impairments. In short, this thesis deals with the following research questions:

1. What is the current situation for students with mobility impairments when visiting a university campus?
2. Would a virtual 360° tour be a helpful tool to enable students with mobility impairments to visit a university campus more comfortably?

To address these questions, the chapters of this thesis are structured as follows: Chapter 2 introduces a background for this topic by providing statistics and demonstrating accessible design guidelines for public buildings. Chapter 3 describes related work to gain information and design proposals from similar implemented systems. Chapter 4 presents the procedure and the findings of the workshop and the online survey conducted to analyse the requirements for the prototype to be implemented. Chapter 5 illustrates the developed prototype of one building of the University of Stuttgart. Chapter 6 evaluates the presented application through a user study. Chapter 7 discusses the results. Chapter 8 draws a conclusion and takes an outlook. The appendix contains the Flyer of the workshop, the structure of the images as well as the results of both the online survey and the survey of the user study.

With these contributions, the aim is to facilitate the planning process for students with impaired mobility. This could assist current and prospective students in feeling more prepared for future semesters. It may also aid in lowering the hurdle to start a degree programme.

2 Background

"Disability is part of being human." stated by the World Health Organization [whoDisability24]. According to the Federal Mistery for Economic Cooperation and Development [bmzDisability24], disability is a broad and variable category that has no universal, legally binding definition. Rather, it can be interpreted individually according to personal preferences. A possible definition provided by the Federal Ministry for Economic Cooperation and Development is also known as the "social" definition and focuses less on individual characteristics such as physical impairments. It suggests that humans are not inherently disabled but rather become disabled due to environmental barriers that prevent them from participating equally in social life. The following sections are intended to introduce a background for the issues addressed in this thesis by stating statistics and guidelines on how public buildings should be constructed.

2.1 Statistics

Worldwide approximately 1.3 billion people experience significant disability as of March 2023, according to the World Health Organisation [whoDisability24]. This represents 16% of the world's population [whoDisability24]. In 2019, 7.9 million people in Germany had a disability rating of at least 50 and held a disabled person's pass. Of these, approximately 8.2% were under the age of 25. In total, 58% of individuals with severe disabilities had physical impairments [destatisGermany24]. In the summer of 2021, the German Student Union [DSW23] conducted a nationwide survey which ascertained that approximately 16% of students reported an impairment that hindered their studies. Of these students, 13% reported having a chronic illness. Among students with disabilities that make studying more difficult, 6% have an officially recognized disability with a degree of disability less than 50. An additional 4% reported having an officially recognised disability with a degree of more than 50 and holding a severely disabled person's pass.

The figures demonstrate that disability is not uncommon in our society. Nevertheless, individuals with disabilities in Germany still face significant restrictions on their mobility. This established the inclusion barometer for mobility [inclusionBarometer22] based on a representative online survey. Additionally, the survey shows that individuals with disabilities have fewer or worse options to move from one place to another compared to those without disabilities. Further, they are much more likely to encounter non-functional lifts and escalators, and only half of the car drivers with disabilities find sufficient accessible parking spaces. As a result, one in three individuals with disabilities sometimes do not feel confident when travelling independently and they are generally less likely to enjoy travelling than those without disabilities [inclusionBarometer22]. People with disabilities have the same rights as everyone else and therefore barriers that restrict those individuals on their mobility and thereby from fully participating in society must be removed [bmzDisability24].

2.2 Requirements for Accessible Design of Public Buildings

It is important to acknowledge that disabilities occur in many different forms, resulting in a wide range of demands being placed on the environment. The guideline for barrier-free building [accessibleBuilding16] defines disability across four categories and outlines specific fields of action. As this thesis focuses solely on individuals with mobility disabilities, it will only consider the category of users with limited motor skills, physical condition, and anthropometry. For these users, the fields of action are increased space demands and the need for no thresholds. This includes especially attention to horizontal and vertical access concepts and geometric specifications such as passage widths and the height of operating elements. The guideline is based on the premise that accessibility is a crucial element of sustainable building and, therefore, an essential characteristic for the future-proof built environment. Article 50 of barrier-free building (2) from the model building regulations [MBO22] says that buildings that are accessible to the public such as educational facilities must be barrier-free in the parts that serve the general visitor and user traffic. To implement this concept, the guideline for barrier-free building [accessibleBuilding16] introduced the term “protection goal”. It represents a change in the possibilities as it defines not the specific solutions but rather the characteristics to be achieved. The goals that are important for this thesis are listed in the following:

- Access and entrance areas must be easy to find and reachable without barriers.
- Parking spaces that are designated for people with disabilities must be labelled accordingly and should be located near the accessible entrance.
- Corridors and other traffic areas must be broad enough for wheelchairs or walking aids, even in case of encounter.
- Ramps must be easy to use and safe.
- Stairs should be suitable for individuals with, for example, motor impairments.
- Doors must be clearly perceptible, easy to open and close as well as safe to pass through.
- Operating elements must be recognisable, accessible and usable without barriers.
- Accessible restrooms must be designed in such as way that they can be used by people with, for example, wheelchairs and walking frames.

3 Related Work

In order to plan a visit to unfamiliar environments it is important for people with mobility disabilities to assess accessibility. This includes the arrival, the entrances and the indoor environment of the target place. The following chapter presents a selection of previous work done by researchers who have explored possibilities for supporting people with limited mobility to better plan their visits. Previous work [PCC+23] has already evaluated that remotely searching on websites for information is a common practice. In doing so, individuals are hoping to find accessibility-related descriptions, photos, videos or virtual tours. Online platforms like Google and Google Street View [googleMaps24] are almost always used in this process. Another helpful option is calling and asking contact persons for verbal descriptions, pictures and videos or questioning friends and family. However, getting information from other people is only accurate when the respective person is informed about the needs of people with disabilities [PCC+23].

3.1 Maps with Accessibility Information

There exist projects [wheelmap24; wheelMate24] that offer data on points of interest, which were developed in the past ten years. Most of them consist of or integrate crowdsourcing as an information source. Some of them are available as a smartphone application as well. Using platforms based on volunteer contributions allows people to improve the quality of life in their urban environment. The more they add places, the more accurate and informative the system gets.

Popular location technology platforms are Google Maps [googleMaps24] and the city guide from Foursquare [foursquareCityGuide24]. They were not originally designed for people with mobility disabilities but in the meantime extended in a way that they can help them to find their needed information. Google Maps introduced their feature "wheelchair accessible" routes in transit navigation. This means it lists possible routes that consider mobility needs [wheelchairGoogle24]. Foursquare [foursquare24] is a leading cloud-based location technology platform. It offers points of interest with attributes including for example user-generated reviews and tips. Through the increasingly publicised need of customers for rich and precise location information, Foursquare has extended significantly. Particularly for people with mobility impairment, the tags with information on certain features such as wheelchair accessibility can be useful. By providing high-quality and accurate location data, it ensures good reliability of the data which is particularly important for them. As its Places API and database are open, it enabled developers to create location-based systems. So did the platform Wheelmap [foursquare24]. Wheelmap [wheelmap24] is a promising crowdsourcing platform for people with mobility impairments which was initiated by the organisation Sozialhelden [sozialhelden24] from Berlin in 2010. It serves to help people with mobility impairments as well as others, for example, those travelling with buggies to plan their day more effectively. The platform is a map of wheelchair-accessible places and every registered user from all over the world can add and rate places. The platform is based on OpenStreetMap (OSM) [openStreetMap24] and therefore

works globally. In the meantime, it has grown into an extensive database of wheelchair-accessible places around the world. Wheelmap offers also a free mobile phone app [MDD17].
Another system designed for collecting data on urban and architectural accessibility is called mobile Pervasive Accessibility Social Sensing (mPASS) [PSM14]. It offers personalized geo-referenced information and routing services for people with specific needs related to urban environments. User preferences and needs are set in their profile and form the basis for the personalized offer. While a lot of data about urban accessibility already exists, it is dispersed across various systems. To maximize the density of information, mPASS combines its own data generated by sensors and obtained through crowdsourcing from users with the ones from other sources namely main geo-referenced social systems. To improve its validity, it also allows organizations responsible for official reviews to enhance and rectify information [PSM14].
Further systems that are aimed to support people with disabilities are WheelMate [wheelMate24], AXS Map [axsmap24] and Access Earth [accessEarthMap24]. The interactive app WheelMate should simplify the search for clean, wheelchair-friendly restrooms and parking spaces. No matter whether the user is local or travelling it offers a dynamic overview of the nearest public conveniences and user-rated locations. It can be freely downloaded and maps across 45 countries [PSM14]. The three-stage icon system of AXS Map gives users a quick overview of other users' ratings in regard to a venue's accessibility. Signed-in users can also add reviews to venues and it can be used as a smartphone app as well [axsmap24]. Access Earth is a disability-led company with a range of services to achieve sustainability and social responsibility aims. For example, it provides an accessibility feedback system where customers can provide feedback on the accessibility of a company by scanning a QR code [accessEarth24].

To conclude, these tools attempt solutions to offer accessibility information and meet mobility needs. As they are based on crowdsourcing and the addressed users are only a small part of the population, many places are missing. In addition, most of these tools focus on the outside of buildings such as their entrances and the journey towards them. However, information about the inside of buildings is rarely available. This is especially crucial in public places like universities where lectures and courses take place in large buildings. Therefore this thesis addresses this problem and suggests a prototype with collected requirements.

3.2 Collecting Data through Crowdsourcing

The systems mentioned in Section 3.1 place their attention on the ratings of users. However, they are dependent on the motivation of users to manually share their experiences. Sasha et al. [SSM+19] created a novel web-based virtual auditing and interactive tool called "Project Sidewalk". It aims to collect urban accessibility data by simply letting online crowd workers walk through city streets in Google Street View. In doing so, they have the ability to contribute physical-world accessibility information as well as label pedestrian-related accessibility problems. In their conducted study, Sidewalk was evaluated as enabling rapid data collection as well as gathering diverse perspectives on accessibility, among other things. A similar research approach was presented by Mascetti et al. [MCEB20]. They also came up with the idea of collecting information on accessibility through crowdsourcing, but this time directly from end users themselves. As it is unfavourable for wheelchair users to input data while on the move, they presented an automatic crowdsourcing mechanism called "SmartWheels". It aims to represent a solution to detect urban features such as curb ramps or steps through wheelchair movements.

These systems are based on a different approach than this thesis as they try to automate the crowdsourcing process. However, they do not eliminate the uncertainty of whether indoor environments or specific rooms are accessible as buildings are often more complex than outdoor areas.

3.3 Virtual Tours as an Information Source

Virtual tours represent real spots in a virtual environment and aim to previously allow users to experience a destination. In the meanwhile, they are a significant topic in contemporary information management due to their increasing usage in various industries such as tourism and real estate domain [KH19]. Additionally, they could be used as a further solution to support people with limited mobility. They could be a powerful tool to assess accessibility remotely and be more personalised. There is already existing work on the digitalisation of physical environments, including their creation, comparison and testing. Chi et al. [CSZ23] created digital replicas of several complex indoor environments and gained feedback in a study with 14 participants with different levels of mobility. They used the platform Matterport [matterport24], a commercially available 3D scanning technology, popular in virtual tour applications. Its feature of supporting measurements in virtual tours was particularly helpful for assessing space constraints for example for wheelchairs. To make the virtual tour experience even more realistic Pei et al. [PCC+23] presented an accessibility assessment approach called Embodied Exploration. It is a Virtual Reality (VR) technique that also allows users to explore a digital replica of physical environments. Whereas this time, in the virtual world the user is embodied by an avatar, generated through biometric information and user preferences. By using a VR headset, the exploration proceeds from the first-person perspective. It is supplemented with the interaction techniques visibility (looking around), locomotion (moving around) and manipulation (reaching out for objects and using them). In the research of Kim et al. [KBL+08] the focus was on the user's appearance to a lesser extent. They developed an Accessibility Assessment System (RAAS) that allows wheelchair users to evaluate the accessibility of physical target buildings within a virtualized reality. Therefore RAAS utilizes state-of-the-art digital imaging, 3D image reconstruction and photogrammetry technologies. Virtualized reality is a visual medium different to traditional virtual reality. Latter relies on simplistic computer-generated models. Virtualized reality, in contrast, starts with real-world scenes and virtualises them afterwards. This makes moving freely in the scene for viewers possible [KNR95].

All these researches have illustrated positive results and high levels of agreement, indicating that virtual tours allow one to remotely assess accessibility problems in built environments. This thesis is based on these findings, as it proposes the implementation of a virtual tour of a public place, specifically a university. This is urgently needed to also enable young individuals with mobility disabilities to continue their education after school.

3.3.1 Virtual Campus Experiences of Other Universities

The aim of virtual tours offered by universities may be varied, such as presenting the university online to pupils and prospective students. However, students with disabilities can also take advantage of it and use it for planning a real campus visit. A few universities already offer such campus tours on their websites, even though, the range of differences between the offerings is huge. For example, the University of Mainz [uniMainz23] allows students to walk through the campus in a computer-generated environment. Similar to a first-person video game, students can change their direction with their keyboard. Thereby information is provided at each building but one cannot walk inside of them. Other universities, such as the University of Mannheim [uniMannheim23], Passau [uniPassau23], Vechta [uniVechta23] and Bochum [uniBochum23] provide multiple 360° panorama images of the campus. In this offer, students have a fixed position from which they can zoom, look around, read the provided information, view the integrated 2D images or change location to the suggested areas. Some panoramas display the interiors of buildings and others show the exterior perspective. In Vechta [uniVechta23] the inside perspective including floors and lecture rooms is almost completely visible, while in Passau [uniPassau23], the possibility to walk inside buildings is not offered. The University of Erfurt [uniErfurt23] has uploaded a 360° campus tour in the form of a video of students showing various locations on the campus and a drone video including visual descriptions. Except for the library in which a 3D model exists, similar to Google Street View. The interiors of the other buildings are only occasionally visible in some pictures on the website. A wealth of information can be found on the website of the University of Karlsruhe [uniKarlsruhe24]. There is a very similar 360° tour to the one in this research for one building. Rooms and floors can be visited and information is displayed. However, the focus of this tour is not on accessibility and there are no guides or size information available. This research is conducted at the University of Stuttgart [uniStuttgart24] where there is currently no 360° campus tour or similar tool on official websites. On those, the students will find a list of buildings for which detailed descriptions exist. In addition to a few pictures, there is textual information about accessible toilets, elevators and doors among other things [accessibilityInfo24]. Further, there is a 2D site map of all buildings of the campus Vaihingen and Stadtmitte [layoutPlan24]. On the platform “C@mpus” [campusPlatform24] students can also click on lecture rooms to view a layout plan of the respective floor. A concrete search for virtual tours at the University of Stuttgart will yield few results published by private individuals. For example, an architect of the University of Stuttgart has published some virtual tours of the campus on his website [zitronenwolf20].

These findings demonstrate, that virtual offerings of parts of a university are already available online, but they rarely provide accessibility information that allows students with mobility impairments to assess them fully. Therefore, this thesis aims to implement an offering that goes one step further in providing visual content including accessibility information.

4 Requirement Analysis

To analyse the requirements for our prototype, an interactive development process was utilised including two steps. Firstly, related work was consulted including literature from other researchers and offerings of several other universities (see Chapter 3). As a result, the demand to digitise physical environments especially the interiors of public buildings not only for people with mobility impairments is huge. A few universities already offer virtual walk-throughs of certain locations on their website but implemented in many different ways.
Secondly, the requirements were collected through a workshop and an online study among people with mobility impairments. To recruit participants, emails were sent to local universities, containing the link to the online survey as well as a flyer promoting the workshop in person. The flyer is attached to this paper in Appendix A. For the online survey, the tool LimeSurvey [limesurvey24] was used and the results are also attached in Appendix C. To collect the results of the workshop, it was recorded and transcripted using the tool Condens [condens24]. For recording, informed consents were obtained before. As the workshop took place in German, the key statements of the participants were translated using DeepL [deepL24]. The participants' time was compensated with 12 euros per hour.
While the workshop analysed the opinions of individuals in order to gain subjective insights, the online study suggested specific problems and improvements, aiming for participants to evaluate them anonymously. As a result of both, the survey and the workshop, the participants unanimously agreed that a virtual tour of lecture buildings would facilitate their planning process for a university visit. This is mainly due to the fact that they would be able to get information about the interior of buildings.

4.1 Participants and Procedure

The online survey was completed by four participants, two females, one male and one non-binary, between the ages of 20 and 30. All participants were enrolled students at different universities in the winter semester of 2023/2024. Half of them have a disability and the other half are familiar with campus accessibility. Apart from one participant who uses an electric wheelchair, the others do not use any aids. In the results of the online study in Appendix C they are identified through the IDs 2,6,17 and 20.

The workshop was organised as a discussion round in which two students from local universities with different mobility impairments participated as well as the assistant of P1. At the beginning, the workshop started with a brief introduction round where the students named their top three aids in everyday life, among other things. For P1 they are an electrical wheelchair, a tablet and a corset/sitting orthosis. P1 explained, that the tablet facilitates them to write things down, especially long texts as they can type them. Additionally, the touchscreen makes it easier to use the device. The top three aids for the everyday life of P2 alternate based on the distances they have to cover. So far, P2 only used aids sporadically but in the future, particularly in winter, they want to integrate a normal walking stick or a crutch. In the long term, P2 has to think about using a wheelchair as well. However, the first and most important aid they mentioned is the help of other people. All in all, the discussion round consisted of five people, including two moderators who facilitated the talk. The participants' experiences varied based on their diverse diagnoses.

The focus of the requirement analysis was on two main questions. The first one was based on the research question of this thesis: 'What is the current situation for students with mobility impairments when visiting a university campus?'. It aimed to find out the current situation including challenges faced by individuals with mobility impairments. Here, the online survey used questions with ticks and free texts and the workshop addressed the following questions. 'How do you prepare for a campus visit?', 'What challenges do you face?' and 'How could you be supported in planning and navigation?'. The second main question of the requirement analysis aimed to gather ideas, wishes and impulses for future improvements as well as collecting requirements for the prototype. To do so, the online survey was a mix of free-text answers and suggestions that could be chosen and optionally rated with a comment. The workshop invited the participants here to express constructive thoughts and suggestions, also in creative form.

4.2 Results of the Requirement Analysis

To gather ideas for the prototype, the participants of the workshop put themselves in different perspectives while answering the questions. In the online survey, they were asked to imagine the scenarios where they have to visit an unfamiliar as well as a familiar university. In the first part of the workshop, the participants were requested to answer the questions from the perspective of both a future student and an experienced student for example before a new semester.
In the following sections, the results of the workshop and the online study are presented together as both aimed to collect requirements for the prototype. Thereby thematic analysis was used by structuring the findings in different topics [BC06].

4.2.1 Block One: Determine the Current Situation

The first main part of the requirement analysis focused on determining the current situation. To plan a journey as a person with mobility impairment, specific information is needed and therefore it is important to have full insight into the accessibility of the target location itself as well as the path to reach it. It took a lot of research in advance before starting a journey. The following sections give an insight into the topics information needs and sources, reliability and satisfaction of information as well as time effort for preparation.

Information Needs

In the following, the collected information needs mentioned by the focus group are summarised. For travelling by car, the participants of the online survey search for available parking spaces for people with disabilities, their number and distance to the university or the target building. When arriving by public transport they search for an accessible route and the connection from the train

station to the university or target building. If necessary, they also look for a connection from the train station or parking spaces to the university by public transport. These are also criteria they looked at when choosing a future university after school graduation. For public transport, it is essential to be informed about the existence and functionality, completion and instruction work of lifts and escalators. Especially at the campus Vaihingen (Stuttgart), where reaching the upper ground requires walking many stairs. Generally, they focus on potential barriers such as steps, minimal distance and incline for every path they have to cover on their own. For the situation on-site the accessibility of the location plays a significant role. It includes entrances, rooms and lecture halls to be wheelchair-accessible or have access without barriers. Sometimes this needs information about the door width and the dimensions of doorways and lifts. Another point of interest here is the navigation to certain rooms. Especially before the start of a new semester or before the first semester, the students search for the location of their lecture halls and course rooms by their number. They give the chance to see on which floor and building they will take place. This allows concrete search at these buildings for accessibility information and information on how to reach them without barriers namely the incline of floors and corridors, the presence and location of lifts, ramps and the amount of steps.
More criteria regarding accessibility for choosing a future university besides the mentioned ones are accessible buildings and rooms of cafeterias, the library and other places to meet fellow students. For lectures, they look up for “wheelchair places in lecture halls which are not awkward placed (like not in the first or last row)” and virtual accessibility, which means “providing lecture recordings and more in digital form to secure access to education even if students are not able to attend the lecture physically” (ID2). For lecture halls, it is also a criterion that every one of them “is accessible by an elevator, or that the ramps are not too steep making them not too strenuous to navigate” (ID20). One important question they clarified before they started studying was whether it was even possible to study a degree programme such as environmental protection engineering, which includes internships and lab days, with their mobility impairment. Last but not least they searched for information about whether their prioritised study programme includes location changes to another campus.

Information Sources

To get the listed information (Section 4.2.1), the students mentioned the internet as the primary source from all questioned perspectives. There they can find digital maps such as Google Maps and Google Street View [googleMaps24], which are for all participants fixed assistive devices for route planning. One reason for this is that these sources allow users to have a detailed overview. The website Wheelmap [wheelmap24] is only used occasionally because too many places are missing there at the moment as well as only information about entrances of buildings is available. Additionally, visiting the website of the place to visit, for example, the university website, is for all students an integral part of the research. Sometimes there can be found pictures of the target locations. Moreover, items like “plan your visit”, “parking” and “how to get here” (ID6) are often available on these websites, which can serve as useful sources too. Even though drone videos are controversial as they fly very fast and thereby cannot guarantee a high level of detail, they can represent an information source as well. Therefore one participant indicated in the online survey to visit YouTube [youTube24] as well, because sometimes there exists a drone shot of certain areas of a location for example of the campus of a university.
In the online survey, three of the participants ask people they know, who already visited the place. The other students conducted, that “due to the lack of information, it is often necessary to contact

university staff to get to the necessary detailed information" (ID2). "They know their campus" (ID2) which is often more helpful than asking other people. As a future student, the participants of the workshop mentioned to directly search for links to contact persons of the university. At the University of Stuttgart [uniStuttgart24], they quickly came into contact with the relevant persons which influenced their decision to start studying in Stuttgart back then. If the situation is unclear for visits to unknown places, it is often a solution to travel to the location in advance.

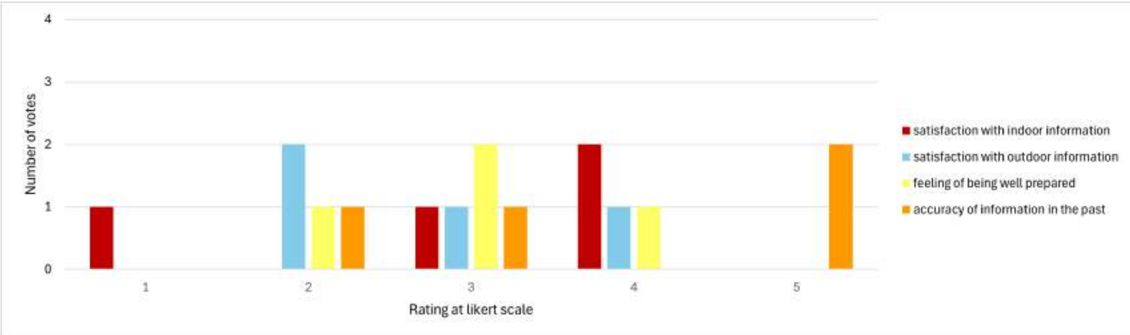

Figure 4.1: Satisfaction with the currently offered accessibility information inside and outside of buildings as well as the feeling of being well-prepared for a campus visit and the accuracy of the information in the past

Reliability and Satisfaction of Information

At the workshop, the participants were asked about the reliability of the collected information. Especially for choosing public transportation, it is often unclear whether escalators and lifts are working as the information on the completion of their instruction work is very unreliable. On the platform C@mpus of the University of Stuttgart [campusPlatform24], all rooms of lectures and courses are published before the start of a new semester. Students can then view this information about their registered subjects. However, there are always a few changes before they are finally determined, which means that they are at first not fully reliable. More beneficial is Google Maps as it offers a creation date. Based on it, the participants can estimate how likely it is that there will be changes. The situation is different with other websites on the internet for example the website of the university, which is not regularly maintained or kept up to date. About the tool Wheelmap the participants reported that it only assists as an orientation, but it cannot be relied on. A reliable source is always asking other people who have already been there. However, the participants mentioned that it is sometimes helpful when the person is informed about their needs. Reliability of information is, of course, strongly related to satisfaction with them and the feeling of being well informed for a visit. In the online survey, the students should rate their answers to these questions on a five-point Likert scale [DB16]. The results are illustrated in Figure 4.1. Firstly, it demonstrates the distribution of votes for the satisfaction with currently offered accessibility information inside of buildings of the home university and secondly, it shows the satisfaction with information outside of buildings. Both were rated on a scale from 1 (very dissatisfied) to 5 (very satisfied). On average the satisfaction for the interior offering was 3 and for the exterior was 2,75. Thirdly, the figure specifies the distribution of votes for the feeling of being well-prepared for a campus visit after finding accessibility information. This was rated on a scale of 1 (not at all), 2 (slightly), 3 (moderately), 4 (very) and 5 (extremely) and the average voting was 3. Finally, it displays the distribution of votes for the accuracy of the accessibility information of the campus in the past from 1 (very high) to 5 (very low). On average this question was rated with 3,74.

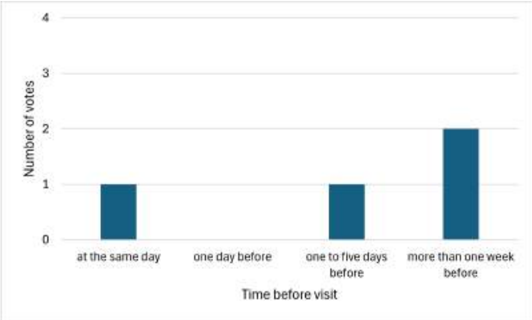

Figure 4.2: Start of planning for an unfamiliar university

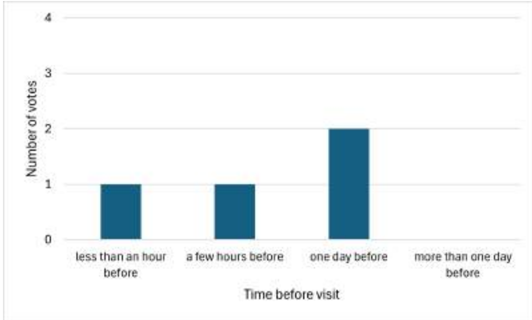

Figure 4.3: Start of planning for a familiar university

Figure 4.4: Time of preparation for unfamiliar university

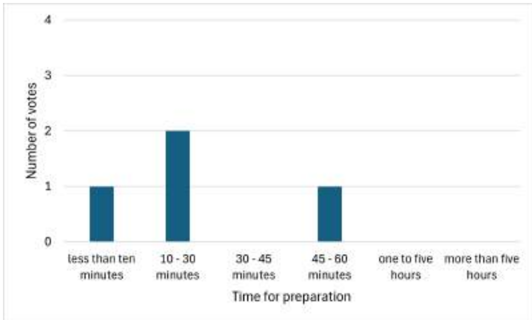

Figure 4.5: Time of preparation for familiar university

Time Effort for Preparation

The time for preparation and how long before the visit they start planning depends on different aspects. In the online survey, the scenarios of generally visiting a familiar versus an unfamiliar location were compared. Figure 4.4 shows the amount of time the students need to collect their needed information for visiting an unfamiliar university. Most of them need less than an hour. In comparison to this scenario, Figure 4.5 displays the amount of time the students need to collect information for a visit to a familiar university. Most of them prepare themselves between ten and 30 minutes. Therefore they start planning before visiting an unfamiliar place as shown in Figure 4.2 and before visiting a familiar place as shown in Figure 4.3. Here the majority indicated that for the former, to start planning more than one week before and for the latter, one day before.
In the workshop, the participants described the scenario of being an experienced student and planning the visits for a new semester. P1 needs a little more time because they have to contact the relevant professor if something does not suit them. Then everything has to be changed, which takes plenty of time. That's why two weeks in advance is a realistic amount of time to take care of it. P2 normally looks one day before at which rooms to go to and then searches them on the plan to

find out any more detailed information to get there like lifts at the corresponding building. All in all, potential visits to the campus or specific locations in advance must be considered in the time management.

4.2.2 Block Two: Wishes for Improvements

Following the first block, the second main part of the requirement analysis focused on challenges, improvements and the use of existing technologies. Therefore the workshop addressed questions like 'What could be improved?', 'What ideas and suggestions do you have to enhance your campus experience?' and 'Would a virtual campus tour serve as a useful aid?'. For this, the students were invited to be creative and express even surreal suggestions. The following sections present the results structured in the topics wishes for improvement, creative ideas to enhance campus experience, requirements for a virtual tour and usefulness.

Wishes for Improvement

The participants could be supported in planning and navigation with guidance systems inside buildings. For example, they desire improved labelling of lifts and accessible toilets, on walls or display stands. A great support would be videos that show more detailed information about spaces and distances, or even include information on the characteristics of entrances and the gradient of ramps. It would also be beneficial to always see the ground conditions. This means outside of buildings, pavements like cobblestones, asphalt or concrete, and inside of buildings flooring like carpet, tiles, laminate or wood. In this aspect, Google Street View is already helpful. Concerning a student with a mobility impairment at the University of Stuttgart, several challenges are faced daily, that need to be improved. Firstly, there is a lot of room for improvement regarding the accessibility of the canteen at the campus Vaihingen. Currently, the restaurant on the first floor is not reachable without facing a lot of steps. That's because there is no official lift but only spiral stairs. Furthermore, the entrances are difficult to enter. The two options are a revolving door and a door that is difficult to open manually and has no option to let it open automatically. During pandemic times the restaurant on the ground floor was closed so there was only the option for people with mobility impairment to eat at the Cafeteria next door. However, no canteen meals are offered here, but curry sausage. This was no option in the long term according to P2. Moreover not being able to eat everywhere led to social exclusion. Additionally, a great wish for improvement is maps. Offering a ground plan is a good idea, but for the moment, they are hard to find on the one hand. For example at the platform C@mpus is the possibility to look at a building for detail. This feature is unknown to most students as it is not publicised or made aware of it. On the other hand, the available maps are confusing and difficult to read. They include a lack of information about lifts and stairs. Therefore the participants desire accurate, usable and intuitive digital side maps, which are easier to find and understand. Ideally, they would show the location of stairs and other barriers and the footage of some buildings and rooms. In addition, the time planning for changes between lectures could be improved. The distances between the lecture halls in different buildings and even different campus locations are not clearly communicated and partly very large but the time to change is really short. Especially as a future student at the University of Stuttgart P2 mentioned that they didn't feel sufficiently informed about which study programme includes a change between the campus Vaihingen and downtown. Further, they mentioned the problem of people who are prevented from going to the lecture because they have various doctor's appointments and get sick very often and easily, caused by a poor healthcare system. For these people, it would have been nice to get the lecture materials online as well. Even after the pandemic, this is not provided in all courses and the participants at the workshop experienced a lack of understanding on the part of the university when made aware of it. In addition, the limited accessibility in lecture halls is an important aspect which could be upgraded. With limited mobility reaching the best places is impossible as they are in the middle of the room. Wheelchair places are always in the very back of the room and wheelchair users are sitting very low, which leads to having a bad view during lectures especially if someone is sitting in front.

In the online survey, the participants could value the suggested improvements to better prepare for first visits to universities in the future. All students would find it helpful to have pictures of the entry and the inside of buildings. Pictures of the campus, drone tour videos, virtual tours of the university and digital side maps were ticked by 75% and textual information about accessibility by half. Besides the already mentioned aspects, one student stated, that they would like to have the "path from start to goal in the university's guidance system 'Horst' " (ID6). "On the outside of the buildings, near the entrance" (ID6), the students could be hugely supported by clearly providing the following information. House numbers and an overview of numbers and floors and important rooms on the floors of the buildings. Last but not least, beneficial information would always be information about available paths without stairs.

Creative Ideas to Enhance Campus Experience

The following creative ideas resulted while the participants brainstormed surreal imaginations at the workshop. P3 expressed his wishful thoughts of planning the outdoor area of the university as a network, where buildings are connected by straight and flat pathways for example without paving stones. Entries of buildings and parking spaces have a clear location in their idea. A positive result in winter would be the saved time to get from one building to another when it is cold outside and the ability to better keep the paths free from slipperiness. Generally, it would guarantee accessibility without detours because of obstacles.
For lecture halls, a surreal idea would be something like a lift inside to give wheelchair users access to the centre where the best places are located.
Frequently terms for locations are 'accessible' or 'not accessible'. P2 expressed their thoughts on this. "I always find it very difficult when it says 'not accessible'. It usually means it's not accessible by a wheelchair, but what does that mean for me? Are there a vast amount of steps or are there only three steps that couldn't be negotiated with a wheelchair, but I could?". These declarations especially for buildings or rooms should be defined more precisely. Due to the broadly diversified diagnoses of people and their different progression led to different skills. This means that some people with mobility impairment can overcome a few steps.
Another creative thought, already leaning a little bit on the idea of this research, was to upgrade the way information can be retrieved. The participants of the workshop imagined a website that is accessible for example for people with blindness, where all needed information for campus visits is collected and offered well-prepared. Optimally, from other platforms like C@mpus, a link should exist to this website for example in the form of an accessibility button that pops up when looking at the inside of lecture rooms. Proposals that may be convenient on the website would be to sort the rooms by the number of steps and floors required to reach them. Additionally, it would be a nice

feature to specify a type of user such as a wheelchair user or a pedestrian with/without a walking stick, walker or other aid and the website would adapt accordingly. For this research, the planned campus tour could be available as well on this imagined website.

Requirements for a Virtual Campus Tour

This point aimed to specify the wishful thoughts to concrete ideas for a virtual campus tour consisting of 360° images that was implemented later in the prototype. Important requirements about a building, derived from the needed information is the appearance of its entrance and doors inside. This includes especially their size like height and width and whether doors open automatically or do so by pushing a button. In the latter case, the location of door buttons and their height is useful information. In the case of stairs, it would be helpful to know the height and amount of steps and the existence of handrails. Another requirement for a digital replica of a university building is the location of the lifts and toilets (accessible toilets) as well as in buildings with lecture halls, the path and distance between lecture halls and both lifts and toilets.

Often the guidance inside of buildings could be improved with signs indicating the way to lifts and restrooms. An upcoming idea for the virtual tour was to show the shortest accessible paths to toilets, lifts and lecture rooms as well as the different distances. P1 annotated for the tour, that it should be considered that one picture per room is not enough to get all the needed information. Additionally, in order to fulfil the aim that students with mobility impairment take advantage of the virtual tour, its focus should be on doors, doorways and floors in terms of accessibility information. The perspective from which the pictures are taken should be one where as much information as possible can be seen. This would allow users to look beyond their own perspective to get more information than they would normally get. Hence the initial idea to display the tour from a wheelchair user's point of view was declined.

Further desired features for a whole campus tour would be to show the shortest accessible path to the canteen in the tour or even the combination with a route planner, where users can enter their aid, for example, a wheelchair and the route would adapt regarding the input.

Within the discussion round were mixed opinions about the ability to contribute information through users. Due to various disabilities among people, too much information (like the diagnosis, etc.) is needed to fully understand another person's perspective. Therefore, sharing personal experiences may not be helpful for someone else. The option for users to indicate their use aids through categories was rated as moderately helpful. Instead, a useful feature would be some form of information box or comment section that allows users to write and share their thoughts such as reliability, the correctness of information, and hints to the admin about missing details.

Generally, the ability to zoom inside the tour would allow users to take a closer look at some points. A possible scenario for the students was to be able to walk around like in Google Street View and when looking at a door, get displayed the door information such as the size, whether it opens automatically, the location of door buttons and so on. For a whole campus tour, they imagined walking around virtually and seeing here and there something popping up where information is provided.

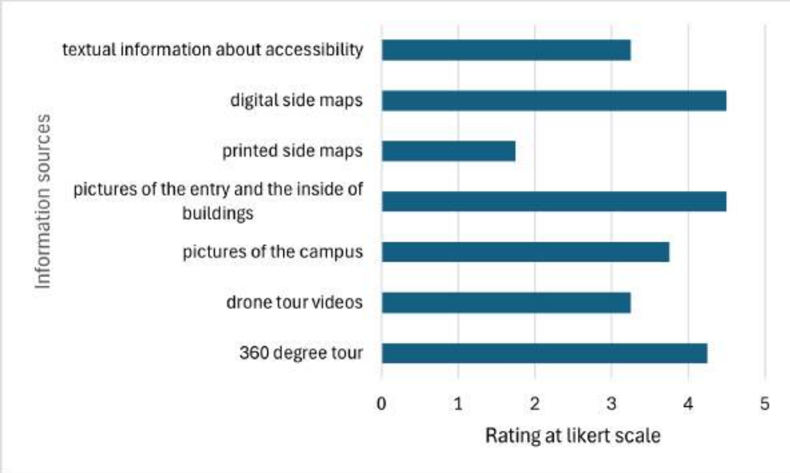

Figure 4.6: Information sources rated by usefulness on average

Usefulness

To evolve the usefulness of a virtual campus tour in comparison to other information sources, the students were asked to rate the usefulness of a few suggested information sources. Figure 4.6 displays the average results of their ratings made on a Likert scale from one to five. The available options are listed on the y-axis and their corresponding rating on average is shown on the Likert scale on the x-axis. Printed maps received the least usefulness at 1,75 while both digital side maps and pictures of the entry and the inside of buildings received the most usefulness at 4,5. Digital tours were close behind with an average rating of 4,25.

To gather further aspects about these information sources, the survey aimed to find out past experiences of the students with them. One of the participants could find a 360° tour of their university in the past. Another one saw a drone tour video. However, they mentioned that it was "helpful to get a first impression, but doesn't cover many details" (ID2). Beyond that, the participant added that it "is only used in big lecture halls or buildings" (ID2). Three of the participants from the online survey could find both, pictures of their campus and digital side maps. For the pictures, they remarked, that they "are not very expressive" (ID2). The side maps were commented by one participant as "extremely helpful" but sadly at their "university incomplete and not intuitive implemented" (ID2). Two participants could find pictures of the entry and the inside of buildings which were as they said "extremely helpful to assess if the entry is accessible" and therefore it "would be fine to find the entrances of the different buildings on the internet" (ID6). Besides this, one of the participants already came upon textual information about accessibility. They categorise it as "helpful if the text is detailed and contains information that cannot be told via pictures or videos" (ID2). However, one of the students could not find any of these information sources at his university in the past. They explained that "there were only contact details for designated individuals who could assist with questions, which is great, but it means one has to independently handle reaching out by email for each question" (ID20).
At the University of Stuttgart, the implementation of a virtual tour would be particularly suitable for older buildings, because they are even less accessible than the newer ones.

Eventually, the planned virtual campus tour was considered useful, because it would replace the laborious search for information on different sources. Additionally, it has the advantage that it consists of images which always say more with one look than a thousand words. This makes it much easier than text, both for readers and writers. For people with mobility impairments, pictures or rather virtual tours already provide important characteristics of whether they can enter a room unproblematic or not.

4.3 Resulting Requirements for the Prototype

The participants of the workshop and the online study provided numerous ideas, many of which can be used for our prototype. Briefly summarized, the following requirements have resulted:

R01 One website instead of many different sources is needed where all accessibility information is collected and offered well-prepared.

R02 Textual information should be clear and detailed as well as contain information that cannot be told via picture.

R03 Visual information in the form of pictures should be informative and also illustrate the way to the entrance, the entrance itself and the interior of a building.

R04 The focus of the pictures should be on rooms, doorways, corridors and stairs and the perspective of the camera should be one where as much information as possible is visible.

R05 A guidance system is needed inside of buildings including the navigation to key points like lifts, accessible toilets and certain important rooms like lecture halls.

R06 Important spots like disabled toilets, lifts, lecture halls, etc. should be labelled.

R07 The location of available door pushes, handrails and potential barriers on the way should be marked.

R08 Measurement data is needed for the size of doors, gradient of ramps, dimension of doorways and lifts, height of obstacles such as steps, amount and height of steps of stairs and height of buttons like door pushes.

R09 Information about existing disabled parking spaces and their location should be labelled as well as their way to the entrance of the building should be visible.

R10 Existing information boxes or comment sections should allow users to write and share their thoughts such as reliability, the correctness of information and hints to the admin about missing details.

R11 It is wished for a zoom function and getting visual information about accessibility while exploring a location.

R12 All information should allow users to assess in advance whether a location is wheelchair-accessible or has access without barriers.

4.4 Discussion

The results of the focus group and the online survey both show that students with mobility impairments face a lot of challenges and often find less and incomplete accessibility information about the inside of university buildings in advance. Especially for important appointments like exams, it plays a significant role that the location is wheelchair-accessible. This includes entrances, rooms and, for university buildings, lecture halls. A point of interest is also the navigation to certain rooms or key points like toilets and lifts. As a future student, getting insight into the accessibility of places to meet fellow students such as cafeterias and libraries, helps to decide on a university. This shows that the need to get access to all currently available as well as required accessibility information is huge. The concrete numbers from the rating in the online survey illustrate the current situation of students.
This also answers the first research question of this thesis: What is the current situation for students with mobility impairments when visiting a university campus? The reliability of information is especially difficult for websites that are obviously not regularly maintained or kept up to date. It varies depending on the source and the illustration whether textual or visual. This influenced the resulting numbers when rating the satisfaction with information about the interior and the exterior of buildings. With an average of 3 and 2,75, both perform moderately. Similar outcomes were achieved when asked about the feeling of being well prepared with an average vote of 3. The accuracy of the accessibility information on the campus in the past was equally rated with 3,74 on average. This is also reflected in the results about the duration of the planning process for a university visit. Due to many uncertainties, the participants start planning far enough in advance and take sufficient time for the process itself. In the online survey, the majority indicated to start planning a visit to an unfamiliar university, one week before and for a familiar university one day before. These results indicate that the current situation must be improved in any way.
To find out, which kind of improvement would help students to better prepare for their visits, the online survey let the participants value suggested sources. All students voted for pictures of the entry and the inside of buildings and three-quarters for pictures of the campus, drone tour videos and virtual tours of the university. These results underline the great significance of visual sources as they allow individual assessment. Videos such as drone shots were controversial in the focus group as they sometimes fly very fast and therefore do not allow seeing concrete details. This increases the importance of informative pictures and is also confirmed by the statistics on the usefulness of information sources. With an average of 4,5, the most usefulness received pictures of the entry and the inside of buildings. Close behind are digital tours with an average rating of 4,25. For aspects that cannot be told via pictures and videos, detailed textual information is welcomed. Even though the statistics of the online survey do not show a clear superiority in this voting, the focus group responded positively to the idea of having a 360° virtual campus tour including accessibility information. It would replace the laborious search for information from different sources and allow students to recognise important characteristics of whether they can enter a room unproblematic or not.

5 Prototype Virtual 360° Tour

As a proof of concept for a virtual campus tour with accessibility information, a prototype of just one selected building was implemented. Therefore, the building of the Visualization Research Center of the University of Stuttgart (VISUS) [visus24] was chosen. It is equipped with an accessible toilet, a lift and an automatic door opener on both sides of the entrance door. However, only two of the three floors are accessible to wheelchair users. The third floor is only fully accessible to people who are able to overcome steps. These characteristics allowed the tour to show both positive and negative examples of accessibility for people with limited mobility.

5.1 Features

The implemented features are primarily inspired by the ideas gathered during the workshop and listed in Section 4.3. From all the inspirations, even the unlimited creative ones, we selected the most sensible ideas to finally implement a tour that is self-contained and not overloaded with features.

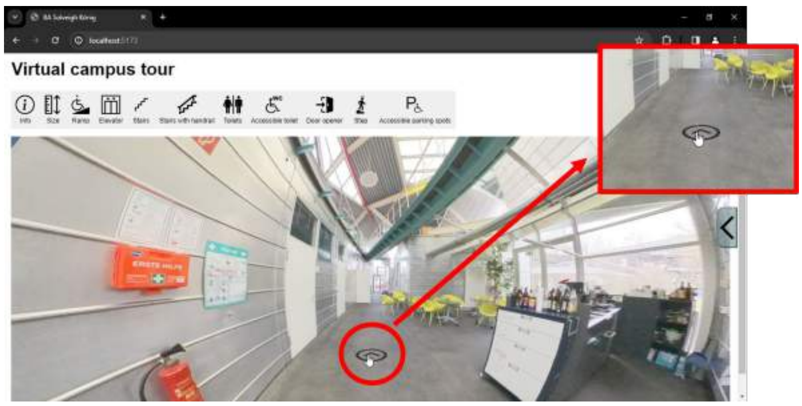

Figure 5.1: Scene with navigation arrow on mouse hover

5.1.1 Zoom and Rotate

Inside the tour, user can 'look around' at their current position. As the images contain a 360° view, the users can rotate themselves 360° around their own axis. This makes it possible to change the direction at any point and simulates the feeling of a real visit. In addition, users are able to zoom, for example, to take a closer look at things, as desired in R11.

Figure 5.2: Scene inside open lift and hovering over close button

5.1.2 Navigation Arrows

To navigate through the tour, black navigation arrows are placed in the tour. For each succeeding and preceding image, they're placed in the respective direction. When the user hovers over them the mouse turns into a pointer, which gives the intention to click on it. This scenario is shown in Figure 5.1.

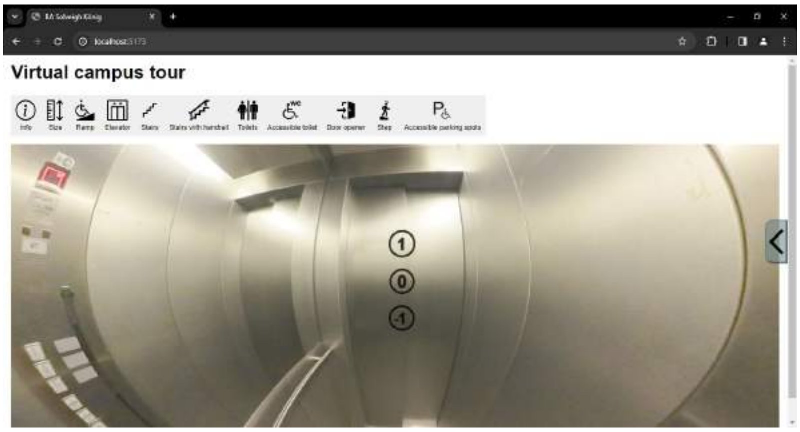

Figure 5.3: Scene inside closed lift, seeing floor numbers

For the lifts, the navigation arrows are replaced with different icons but their behaviour remains the same. When standing inside a lift with the door still open, the user can either exit by clicking on a normal arrow outside the lift or close the door by clicking on the displayed close icon, as illustrated in Figure 5.2. In case the user has closed the door, he will see the numbers 1, 0 and -1 instead of any navigation arrows as seen in Figure 5.3. They act as targets for the floor where the lift should be moving. No matter which number will be chosen, the user will stand on the aimed floor, still inside the lift, but with the lift door open. Now the scenario in Figure 5.2 and explained above is repeating, now for the new floor. As a result, users experience a lift ride close to reality with this kind of implementation.

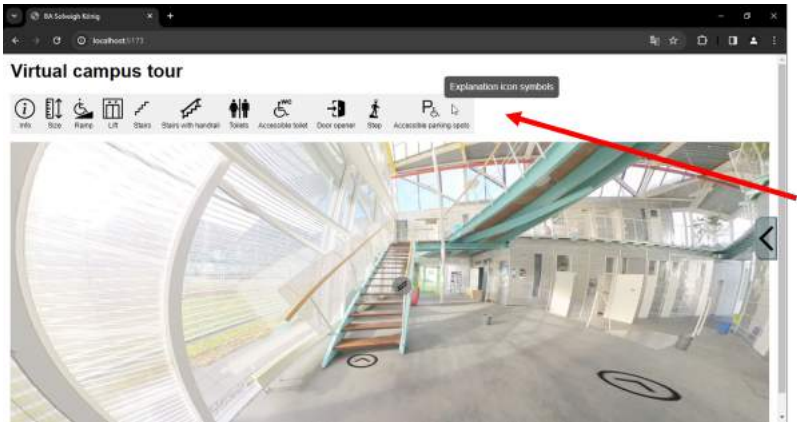

Figure 5.4: Icon legend on mouse hover

5.1.3 Visualisations

In addition to the navigation arrows, visualisations enhance the tour with the aim of providing information for the user as described in R12. They are divided into two types with different designs, appearance and information offerings, which complement each other. Both types are illustrated with icons because they save space and are already familiar to users as they encounter them almost every day. For the prototype, it was attached importance to icons that are self-evident, consistent and clear. This supported their purpose of quickly conveying meaningful information to the user at a glance and without a lot of text. In case of confusion, the legend above the tour briefly explains all the icons found within the tour. These include info, size, ramp, lift, stairs with and without handrails, toilets, accessible toilet, door opener, step and accessible parking spots as seen in Figure 5.4. The choice of the used icons was based on the data to be visualised, derived from the list of requirements for the prototype in Section 4.3. They should include important key points of a building as well as barriers.

Figure 5.5: Scene with interaction lift icon on mouse hover

On the one hand, the tour provides interactions, that are placed in the tour depending on the scene. For example, when standing in front of a lift, as demonstrated in Figure 5.5, the lift icon is displayed for the user. Similar to the navigation arrows, the interaction icons have a round shape and also give the illusion of being clickable when the user hovers over them, which is also visible in Figure 5.5. Upon clicking, a pop-up appears containing important measurement information based on the icon. It aims to fulfil the requirements R02, R06, R07 and R08. In the case of lifts, the user finds their width, height and depth, illustrated in Figure 5.6. By clicking on the close button on the right top corner, the pop-up disappears. Differently from the other icons, the info icon is only displayed on the start image and is intended to give users a rough general overview of the building at the beginning of the tour, as seen in Figure 5.7

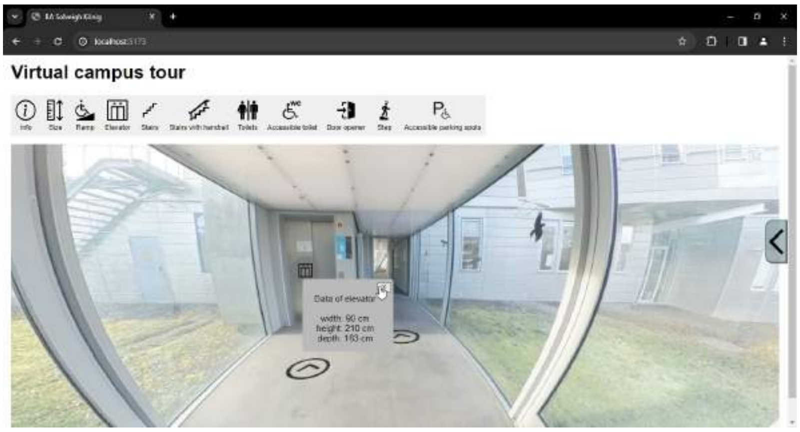

Figure 5.6: Interaction icon with open popup

On the other hand, the tour provides navigation guide signs on almost all images based on the requirements R05 and R09. Their shape is rectangular to simulate guide signs as they would hang on the walls of a building. This distinguishes them from the other visualisations and makes them consistent with the rectangular icon legend. Like these, the navigation guide signs do not trigger any user interaction. Instead, they aim to offer directional information through arrows indicating the path to the toilets, the accessible toilet, the lift or the accessible parking spots, as shown in Figure 5.8. This should facilitate the process of gathering information about important locations, especially on a first visit.

Figure 5.7: Open info popup

Figure 5.8: Scene with guide signs

5.1.4 Comment Sidebar

Besides these features inside the tour, a comment bar was implemented based on R10. It is positioned on the right side of the tour and is folded by default. The bar can be opened through an arrow button. It is based on the location of the user inside the tour and thus differs for each image. For one thing, it consists of comments from previous users, their given name and used aid, illustrated as speech bubbles. For example in Figure 5.9 are the comments for the image in front of the entrance. Secondly, the comment sidebar provides the option to leave a comment yourself. For this purpose, two fields are available in which the user can enter a name, optionally indicate a using aid and write their comment. As a result, users are able to share their thoughts about topics like the reliability and correctness of the information as well as give hints to other users about missing details or else read comments about it from previous users. This extends the tour with personal experiences of people with different disabilities and using aids.

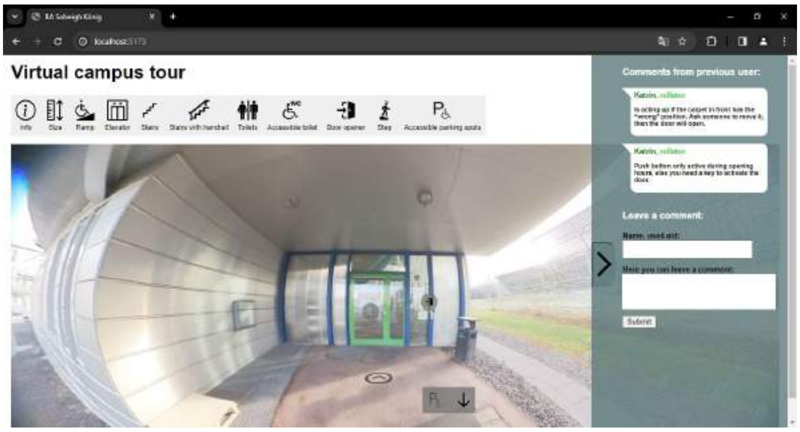

Figure 5.9: Open comment side bar

5.2 Used Technologies

In this project, the frameworks “Node.js”, “Three.js” and “Vite” are used as well as the programming language JavaScript [installThreeJS24]. Node.js [nodeJS24] forms the foundation of the development environment, enabling the use of JavaScript on the server. It serves as an asynchronous event-driven, open-source and cross-platform JavaScript runtime environment. Running a single process without creating a new thread for every request prevents JavaScript code from blocking [nodeJS24]. To realise the virtual tour with user interaction and more, Three.js [threeJS24] was chosen, as it is a powerful JavaScript framework for easily creating and displaying 3D visualisations on the web. To run the Three.js application it requires at least one HTML and CSS file to define the web page and one JavaScript file to execute the code [discoverThreeJS24]. The third component is Vite [vite24], which is used as a build tool. It optimises the development and deployment process with its significantly fast dev server start time. Vite is a tool that crawls, processes and concatenates source modules into files that can be run in the browser. Thereby it separates the modules in an application into the categories “dependencies” and “source code” [vite24].

5.2.1 Shooting and Processing of 360° Images

The virtual tour is made up of interconnected 360° images. The images were shot with an insta360 x3 camera standing on a tripod. To take full advantage of the camera, it was connected to a dedicated phone app. With the app, the camera can be controlled with the mobile phone up to a distance of 10 to 15 meters [insta36024]. While shooting the images, the settings were set to a resolution of 12k. Before including the images in the tour, they were transferred from the storage card to the computer and converted to JPEG files.

5.2.2 Structure of Images

In total, the tour consists of 39 pictures from the VISUS building based on the requirements R03 and R04. Each picture is labelled with an explicit name and a unique number. To represent the actual building, the images are organised into a structured layout with fixed connections to each other, as illustrated in the figures in the Appendix B. In an external configuration folder, there are individual JSON files for each picture containing all individual information about it. This includes its title and index number, paths to its direct neighbouring images and accessibility information for the visualisations. The visualisations are saved with a type to define whether it is a navigation or interaction as well as with content to specify the icon that will be displayed. Even though the comments are also related to the images, they are saved in a separate JSON file.

5.2.3 Three.js

In Three.js the scene was constructed by running an initialisation function at the start of the tour. The function creates a sphere and adds it to the scene. Additionally, it creates a loader, a material and a texture. For the start, the picture of the outside of the VISUS building is loaded and assigned to the texture. Then a material for the scene is created that receives an object as a parameter that defines the properties of the material. One of them is the map property that represents a texture.

Therefore the previously created texture with the assigned picture is used as a parameter to map the texture onto the material of the shpere. This makes the 360° image visible as a sphere. To position the viewer inside the picture, the camera position is set to the centre point of the sphere. As soon as the image changes, the loader loads the new image, assigns it to the texture and updates the material. Apart from the sphere, all objects such as visualisations get created once inside the initialisation function. Initially, however, only the objects of the start image are added to the scene and become visible to the user. When the user moves to the next image, all objects from the previous picture are removed and those from the new one are added to the scene. This concept saves computing power because the objects get reused when repeatedly entering the same image, rather than being created each time again. Similarly, the images are only replaced when the user moves. Everything is defined based on the current image index, which ensures that always the correct content is visible.

As explained in Section 5.1, clicking or hovering over a navigation plane or an interaction element triggers an event. This was implemented using a raycaster [raycaster24]. Each time the mouse hovers or is clicked, a raycaster is created and sent from the camera position in the direction of the mouse cursor. Subsequently, it is checked whether there was any intersection along his path with an object. In case of a collision, the corresponding action is triggered.

5.2.4 Used Technologies for Development Process

Preceding the actual implementation phase, the requirements derived from the requirement analysis presented in Chapter 4 were documented within the project's Git repository wiki. In order to include these requirements later in the virtual tour, design suggestions and ideas were brainstormed using Figma [figma24]. As this was done after the images had been captured, selected ones were extracted as stakeholders to enable the prototypical realization of potential future designs.

The prototype is integrated into a website and therefore fulfils R01. To achieve the desired behaviour it is best reached with the browser Chrome because it is able to interpret the application correctly.

6 User Study

This section describes the structure and results of the user study conducted to evaluate and gain feedback for the implemented prototype. On the one hand, the study aimed to evaluate additional results to the requirement analysis for the first research question mentioned below. On the other hand, it primarily addresses the second of the following research questions:

1. What is the current situation for students with mobility impairments when visiting a university campus?
2. Would a virtual 360° tour be a helpful tool to enable students with mobility impairments to visit a university campus more comfortably?

6.1 Methodology

In the final study to evaluate the prototype, four participants took part. Three students between the ages of 20 and 26 and one former student of the University of Stuttgart [uniStuttgart24] who is familiar with Campus accessibility between the age of 46 and 67. P3 took part together with his assistant. The participants indicated using or being familiar with the following mobility aids in everyday life: electrical and manual wheelchair, walking stick and the help of fellow humans. To recruit participants emails were sent around, and the participants from the requirement analysis were contacted. Prior to the user study, a pilot test was conducted. The study consisted of an interview with each participant separately via online meetings. For transcription and evaluation purposes, all meetings were audio and video recorded. Therefore informed consent was obtained at the beginning. As the meetings took place in German, the key statements of the participants were translated using DeepL [deepL24]. The study took around 60 minutes for each participant and their time was compensated with 12 euros. The goal was to evaluate the implemented prototype and explore the potential of virtual tours in accessibility assessment.

The study was structured into three parts, with the aim of comparing the currently available information sources with the implemented prototype. For the first two parts, the participants got the task of planning a visit to the VISUS [visus24]. In doing so, they were instructed to focus on key points such as (accessible) toilets and lifts inside the building and share their screens during the process. Finally, they were asked to fill out a questionnaire. Therefore the survey tool LimeSurvey [limesurvey24] was used and the results are attached in Appendix D.

6.2 Results of User Study

In this section, the results of the user study regarding the currently available information sources and the information findings derived from them as well as the gathered feedback of the prototype are illustrated. The results were evaluated with thematic analysis by structuring the findings into topics [BC06].

6.2.1 Current Available Information Sources

To plan an upcoming visit to a location using the currently available information sources, all participants first used Google. First of all, they used it for textual search. This aimed to check for a website or any information about the target building. Additionally, P2 and P3 would look at the number of the target room and adapt their search to it. For example, if the room number indicates to be located on the first floor, P2 would concretely search for a lift. P3 mentioned that sometimes information about specific rooms is available on the website of the building. When finding such a website, P2 looked for buttons like “arrival” and “contact”. The latter often leads to site maps or other important information. P4 also informed themselves about the age of the building. This is important at universities, as in particular, older buildings are less accessible than the newer ones. Secondly, all Participants used Google Maps [googleMaps24] to get a rough overview of the situation and to identify possible problems. In case of arriving with the car, it is important to check for disabled parking spaces. If arriving by public transportation, it is crucial to search for a nearby train or bus station. In both cases, they focused on the distance and the path to go in order to reach the entrance. Therefore, all participants turned on the satellite view as well as Google Street View to manually seek these things as well as to identify possible obstacles like steps along the path. P2 also respected the incline because if possible they would choose a route with the lowest gradient. Finally, P3 and P4 used the pictures from Google of the target building. P4 mentioned that there are often images available of the outside of university buildings including the entrances. Another source of information for students at the University of Stuttgart is the C@mpus platform [campusPlatform24]. This is because for some buildings it is possible to display a floor layout plan. Last, but not least, P1 searched for the VISUS building on the platform Wheelmap [wheelmap24]. They make use of this platform occasionally, but if so then normally as an app on their smartphone. Generally, P4 noted that they mainly do such a planning process on their smartphone because it is easier to operate.

Information Findings

With the aforementioned tools, the participants discovered the website of the VISUS as well as the accessibility-building information website of the University of Stuttgart [accessibilityInfo24]. These websites contain beside of a few small pictures of the building and the entrance, a site map and a drop-down menu with textual information. Latter provides interesting categories for them like “wheelchair access to the building”, “disabled parking spots”, “lifts”, and “disabled toilet”. Even though this covered a lot of their information needs, some descriptions were not fully clear. For example “one bridge is only partially accessible”. At these parts, P2 wished for a more detailed explanation. In case of no existing lift, P2 would have wished for detailed information about the stairs inside the building. For instance, continuously available handrails and the number of steps. In return to the drop-down menu, the available site map on the website, was only moderately helpful as it solely showed a very rough plan with no further labelling of things like parking spaces. However, P2 could employ the textual information below on how to get there. For example, the hint on which side to exit the train station could have prevented unnecessary detours. In contrast to these information sources, the platforms Wheelmap and C@mpus do not provide any information about the VISUS building. For the latter, P4 reported that the site maps on C@mpus are only available to parties and are often semi-obvious. In turn with Google Maps, they could identify the locations of the disabled parking spaces, mentioned on the website and get an insight into the route to the entrance. Although they could not exclude existing small steps in front of the entrance, the path initially looked step-free with Google Maps. Google Pictures displayed images of the outside building and one of the inside. P4 pointed out, that single images of the inside of a building are only moderately helpful. This is because they do not know how to categorise them as their exact shooting location is unknown.

In summary, a lot of accessibility information about the VISUS is available on the internet. However, this information is scattered across different web addresses making their collection time-consuming. Consequently, the amount of information obtained and the level of preparedness ultimately depends on the individual's effort.
For the user study, the first part containing the information search, has been stopped after about ten minutes. P1 was all in all satisfied even though they would have liked to know the width of the entrance door in advance. P2 was able to conclude from the obtained information that the building is accessible to them resulting in feeling well-prepared for a visit. Additionally, they appreciated the orientation about the time to walk on the official website. In contrast, P3 noted that they received very little information about the appearance of the interior of the building. So if they had an important appointment requiring a successful journey, they would drive by beforehand to inspect everything in person and maybe write an email to the contact person. However, they could derive from the information that they would need an assisting person for their visit, which is beneficial to know in advance. P4 would take enough time to prepare for an important appointment and weigh up whether it's worth driving by beforehand. For example, they would do so in case of a new upcoming semester with various unfamiliar rooms and lecture halls. Apart from the VISUS building, P4 pointed out that generally at the University of Stuttgart, a few more pictures are missing online, especially from lecture halls and the main entrances from the inside perspective. That's why in a planning process like the one for the VISUS, it is often unclear how it looks like from the inside. Nevertheless, P4 brought up, that the University of Stuttgart is much better at providing information about accessibility than the other universities they are familiar with.

6.2.2 Implemented Prototype

After the information search on the internet, the implemented prototype was provided to the participants. The tour started with a picture located a few metres ahead of and towards the entrance. The first impressions of all participants were positive regarding their feedback.

The first opinion of P2 was that they prefer pictures as an information source over other sources. Pictures offer visual proof which is safer and reassuring for P2 than trusting written words on websites from unknown authors. For the latter, they never know whether the information is up to date as well as whether all information is considered. For instance, a small detail like a single step can be crucial for wheelchair users. The prototype counteracts this, as it allows one to evaluate

the place to visit by oneself. P2 expressed, that the feature of turning around inside the pictures supports the exploration process. For example, it allows looking for obstacles on the whole path from the entrance to the parking spots in contrast to the images on the website, which only showed the last metres of the entrance. P4 confirmed this, as they interjected to have a better view with the virtual tour. Additionally, the zoom function was well-received as it allows the user to take a closer look at some points.
At the start of the tour, P1, P2 and P3 favoured the info button for directly achieving important information that extended those already found. For example, the hint that the lift travels to all three floors. For the first pictures of the tour illustrating the outside of the entry, P2 and P4 were only sure with the help of the prototype that the path towards the entry is completely on ground level without any steps. P4 directly noted the door push which indicated that the entrance door is able to open automatically. This contradicted the information they had previously received from the website: "entrance doors not automated" [accessibilityInfo24]. In addition, in their previous search, they could not recognise a door push on the images.
With the virtual tour, the participants could individually assess spots and issues which were not transparent on the currently available information sources. P1 was able to estimate distances and sizes inside the tour by comparing points with other objects of known size. Therefore, missing information about heights could be easily followed in comparison to the textual information on the websites, which only left room for individual interpretation. For example, the emergency box on the ground floor. P1 concluded that it is positioned too high for wheelchair users to reach based on the surrounding objects. That's why they appreciated that it is well visible inside the tour and suggested incorporating its height as an interactive popup. For P2 the virtual tour allowed them to look up for the stairs inside the building to reach the upper floor beside the option to take the lift. For instance, they would choose the stairs depending on their appearance to save walking distance to lifts, especially downwards. When having the ability to explore a place in advance with a virtual tour P2 would look at information such as the kind of stairs inside the building as well as their number of steps and whether a continuous handrail is available. This would help them to better plan their route inside a building to a target room already in advance as this information is normally not available in the currently provided information sources. Another important piece of information only visible with the prototype is that even though there is more than enough space inside, the disabled toilet is not appropriately furnished as P1 noted. To name an example, they missed a changing table and a hook or similar. For existing changing tables or working surfaces generally, they find it useful to include their height as a popup. Additional remarks were made by P3, focusing on obstacles along the way. They annotated that e.g. at a spot on the upper floor, space in the trafficable area is limited due to the bridge's construction. For the whole upper floor, P1 remarked that the virtual tour clarifies wheelchair users of all obstacles by giving them a complete inside.

Guide Signs and Interaction Elements

The interaction popups were positively received by all participants, as they provide important measurement information that is not visible in enough detail on the pictures to fully evaluate the individual accessibility. P4 pointed out that accessibility has many facets, making the declaration of a website as "not accessible" in some cases useless. This is because whether paths are accessible for someone depends on their individual abilities. Individuals with narrow wheelchairs may have greater mobility than others. Even the skill to overcome steps varies depending on factors such as the height of the step and whether someone can rely on the help of another person. The prototype provides concrete numbers of steps helping everyone to assess the situation in advance. Beyond that, P3 and P4 generally appreciated the detailed information given throughout the tour such as door width, ramp incline and lift depth. This is attributable to Participants' previous experiences. For example, P3 already faced lifts that were too small for their wheelchair and P4 was already standing in front of a building with a ramp that was too steep for them. These things are good to know in advance and save the effort of travelling in person. Similarly is the maximum weight capacity of lifts. P2 injected that this is particularly relevant for large and heavy wheelchairs. Although this information is already visible inside the prototype, it was suggested by P2 to integrate it into the lift popups as well. A further suggestion was made by P4. They would find it helpful to display the height of the pushbuttons inside the lift too. They pointed out that particularly the keybuttons in older lifts are positioned too high to be reachable for a wheelchair user and that especially for people with severe physical limitations this could be important to know. Nevertheless, the implementation of the lift has received positive feedback. According to P2, they had permanent clarity of their location due to the smooth transitions without any jumps. P3 especially highlighted the feature of choosing the floor to travel to and getting there like in reality. Moreover, P1 mentioned that the prototype allows users to recognize that the lift has doors to both sides. This is important for wheelchair users as they don't have to turn around. Besides the lift, P4 made some suggestions for the displayed information on the ramp. They would add the width of it as they had already experienced a ramp in a university building that was too small for their wheelchair and therefore they could not reach the lecture hall. Additionally, they are yet more familiar with the information about the gradient of a ramp in percentage rather than in degrees as indicated in the prototype. All in all, P2 thinks that the used icons are clearly understandable and expressive. However, P1 commented that they are “a little bit small in some places”. P3 would also prefer the black icons within the tour to be more highlighted as their contrast to the grey background is very low. Further, in many places inside the building, they are difficult to recognise namely, in front of the already grey walls on the upper floor. In addition, the icon legend above the tour gave the participants the impression that they could click on an icon at the legend to navigate elsewhere. Likewise, the guide signs also give the appearance of triggering a click event through their similar colour design to the interactions.

Comment Sidebar

Throughout the virtual tour, all participants evaluated the comment sidebar as helpful. P3 described it as a “really nice idea”. The possibility of leaving a used aid was perceived as positive. Even for P2, who mostly does not use any assistive devices, the term “used aids” leaves the latitude to indicate pedestrian as well. P4 evaluated it as useful, especially for information that conflicts with those provided at the currently available information sources. For example, the already mentioned inconsistency about the option to automatically open the entrance door. P4 was not sure whether the doorpush is working or not and could find a comment on the functionality in the sidebar. All in all, P3 mentioned, that with more users, the comment sidebar would quickly fill up, enhancing the overall quality of the tour.

Camera Perspective

P3 and P4 injected that due to the camera perspective elements like the ramp appeared differently from reality. For example, its width appeared very small and its gradient appeared not as steep as the degree value incidates. Moreover, the participants only became aware of some things through the icons. For example, the steps on the upper floor were hard to see at first. Therefore P3 determined that their dependence on the popup information was increased in contrast to the visual information source. P4 suggested that the height of the eye perspective should also be included in the prototype. This would address their concern that the height of objects such as buttons should be always clear. Additionally, P3 expressed the idea of including the number of rooms in the prototype as they are mostly hard to read in the pictures. Particularly the right door of the disabled toilet was not directly obvious. Such a labelling would also be helpful for planning a visit to a concrete room. Moreover, P4 sometimes found it difficult to orientate inside the tour because for some images it was necessary to turn around to keep the walking direction. The general orientation was also influenced by the transitions between the images as noted by P3. For instance, for huge jumps of the images inside the building, it would be helpful to implement a smooth visual transition in the movement direction. To work against it, P4 would find it beneficial to get a layout plan of the building inside the prototype. Especially for complex buildings, this would help them to get a better and quicker overview.

Parking Spaces

As the tour provides looking from the entrance in the direction of the disabled parking spaces and mentions their existence, they are not passable. P3 and P4 would have explored them in detail to check whether they would suit them as well as their real exact location and distance from the entrance. A premium idea expressed by the assistant of P3 would be the feature to click on the parking symbol inside the tour and get to a map where the current location is marked and the distance from this point to the disabled parking spaces is displayed. This would save the previous search on maps and show the distance that has to be covered for a visit.

6.2.3 Direct Comparison of both Information Sources

In the third part of the survey, the participants should rate the two different information sources in the questionnaire on a Likert scale [DB16]. In Figure 6.1 the results of the average answers are contrasted with each other. These show a slight tendency towards the prototype in all four categories.

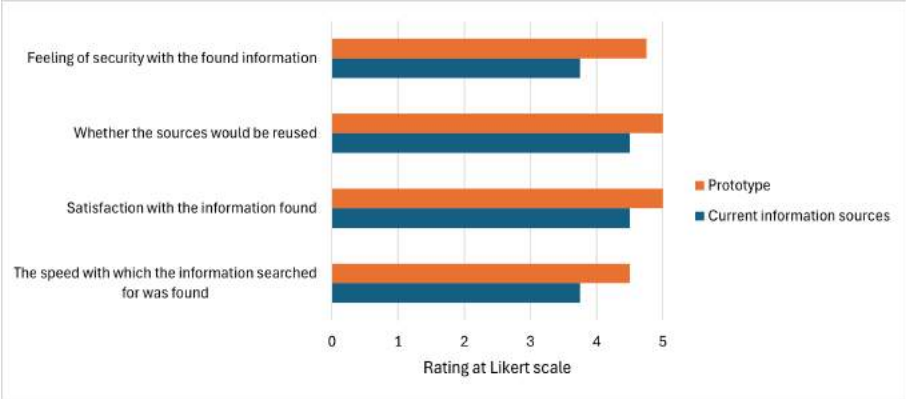

Figure 6.1: Rating satisfaction of information sources

At the end of the study, the users gave some general feedback. P1 said: “The virtual tour is a very cool thing. As a student with a disability, I would be very happy about this”. P3 indicated that “it is a nice concept and definitely better than what is available now” as well as it offers “a good insight into the building and the accessible areas”. P4 emphasised: “It is a good thing to already know where what is located in the building. For example, one can read on the website where the toilets are located, but the tour revealed the exact location and a picture of what it looks like”. “Even if it would probably not be necessary for every building, lecture halls and workrooms plus the route to them are particularly important.” Similar feedback was collected from the anonymous free-text answers in the questionnaire. There the prototype was rated as “a fantastic tool for initial orientation inside the building, as all possible weak points or dangers can be recognised in advance” (ID2). To the currently available information sources, it was told that “they lacked more detailed photos in order to better imagine some things (especially for the interior building)” (ID5). As “it feels safer to receive visual information than written ones” (ID3) for the participants, it underlines the positive results of the prototype in Figure 6.1. “The more buildings that can be included in the virtual tour, the better” (ID2).

Additionally, P4 gave an outlook for the future at the end of their interview. This thesis as well as related research are important steps for a future with more equal access opportunities. They start with the establishment and the documentation as well as address important questions such as "How is the situation on-site?", "Where are what barriers?". Nevertheless, it must be considered that simply the process of identifying changes nothing. To be more precise, just because people with mobility disabilities do know where they can access and where they can not, does not resolve the circumstance that they are not able to enter certain locations. It only changes their state of knowledge. This alludes to the definition of disability in Chapter 2, that humans are not inherently disabled but rather become disabled due to environmental barriers. Therefore the ultimate goal should be complete accessibility in the long term according to P4. This means concretely that when documenting an obstacle in the first step, it should be removed or be circumvented by other solutions in the second step.
In terms of our thesis, this means that our prototype provides the baseline for the possibility of improvement in the long term by setting a starting point that can be continued in the future.

7 Discussion

This section builds upon the evaluation of the requirement analysis by discussing the results of the user study in relation to the entire thesis. In the introduction and the background chapter, we demonstrated the huge need for improvement in the areas of campus accessibility and information provision for students with mobility impairments. This was further underlined by the first part of the requirement analysis, where the focus group and the participants of the online survey provided personal insights into their experiences. The results of the user study also confirmed the findings when looking at the currently available information sources. It was revealed that these sources rarely provide information about the interior of buildings. Platforms that attempt to address a solution for people with disabilities, such as Wheelmap [wheelmap24], still have a significant gap in their provided information. Consequently, they are only infrequently used by all participants of the focus group and the user study. Students tend more to use sources such as Google Maps [googleMaps24], Google Street View, Google Images or the official university websites. This confirms that visual information is a valuable source in the assessment of accessibility for indivuduals with mobility impairments. Additionally, the search for obstacles along the way with Google Street View already presents the character of a virtual tour. The preparation with the current sources for a visit to the VISUS [visus24] inside the user study demonstrated that there are yet uncertainties among the students. In particular, in regard to the interior of the building, it was not possible to determine with certainty that no obstacle would be encountered along the way. These findings answer the first research question and validate that there is a significant potential for improvement at the moment.
In order to identify a solution for the presented problem, this thesis makes use of the great potential of visual information sources. Related work has shown that virtual offerings of parts of a university are already available online [uniKarlsruhe24; uniPassau23], but they rarely provide information about accessibility. At this point, our work builds upon and aims to implement an offering that goes one step further in providing visual content including accessibility information. Accessibility information is another key aspect in developing a solution, as identified in the second part of the requirement analysis. The students indicated that size information about doors, lifts and so on is of great importance for fully assessing the accessibility of a building. Therefore, the prototype was equipped with the resulting requirements, which were designed in different ways, such as visualizations and guide signs.
The user study created further space for discussion and interpretation. Generally, it should be noted that disability is multifaceted. The existence of a norm, such as the construction guidelines for an accessible building or a personal assessment of an affected person like the ones at the platform Wheelmap, does not imply that all aspects are covered. For example, some individuals use narrower wheelchairs, which affords them greater mobility, resulting in overcoming more obstacles than others. Consequently, it is crucial to ensure that accessibility remains individual when documenting barriers and developing platforms such as our prototype. The approach of this thesis includes this aspect, as it provides the possibility to individually assess the accessibility as well as the issues inside of buildings rather than selected information like it is common on websites. This is achieved through the aforementioned two key aspects implemented with the 360° images and

the measurement data appearing in textual form inside the visualizations. The user study showed that the combination of visual and textual information gives users a more comprehensive view, making things like obstacles along the way or automatic door openers become more visible. The integration of both information sources offers the ability to complement each other. In cases where, for example, the image perspective leaves uncertainty about a specific width or gradient, the textual information gives detailed information. As a result, students can better plan an interior route to a target room in advance and directly search for the specific information they require. Nevertheless, the user study evaluated that in the prototype, the participants exhibited a raised dependence on the textual in contrast to the visual.
However, comparing the satisfaction among the participants with the currently available information sources and the prototype was not straightforward, as seen in Figure 4.1. All participants indicated on average that they felt well-prepared, despite the lack of detailed information about the interior of the building. For the results of the user study and those of the entire research project, it must be taken into account that the VISUS and the whole University of Stuttgart [uniStuttgart24] already provide a lot of information online [accessibilityInfo24]. In addition, students have full access and insight into everything at the university in contrast to individuals who are not currently studying. This includes platforms like C@mpus [campusPlatform24], as well as specific buildings. As a future student, for example, it might be a hurdle to just go everywhere and look at it. This allows us to conclude, that the quantity of data about the VISUS online is very high in comparison to usual and that the expectations to find information about accessibility in buildings are very low. This influenced the results as it is not common for public places like universities to be able to find this amount of information. As a result, for other buildings especially older and larger ones as well as for other universities in general, the results would be more unambiguous which was also confirmed by the participants of the user study. Information in the direction of this thesis even to a small extent would still be a great improvement. For example, the provision of just one 360° image of each important spot such as lecture halls and main entrances from the interior view of each university building would allow students to better assess accessibility.

Finally, the user study answered the second research question of whether a virtual 360° tour would enable students to better plan their campus visits. It was discovered that the accessibility information inside the prototype has a huge impact on making the experience much more pleasant and the feeling before a visit more secure. However, a few modifications came up in the user study to enhance the prototype, including the improvement of the visibility of the icons as well as labelling room numbers in any visual form. Nevertheless, in contrast to the current situation, it would be a significant advancement to extend the prototype for the entire campus and fully implement the approach of this work as an available web application. Despite that, the process of establishing and documenting the current situation represents a baseline for the ultimate goal of achieving complete accessibility in the long term. This means the documentation of an obstacle in the first step enables the removal or circumvention by other solutions in the second step. Additionally, the prototype can lower the hurdle for future students to start studying and feel better prepared for their first semester. As a result, the prototype helps to fill the gaps in the existing information sources and represents a tool for students with mobility disabilities to visit a university more comfortably.

8 Conclusion and Outlook

This thesis explored the design and usefulness of 360° images with a focus on campus accessibility. Through a requirement analysis, ideas and needs of students with mobility impairments were collected in the context of a campus visit. Additionally, literature research was conducted. These researches illustrated the information gap about the interior of buildings as well as giving insight into the planning process of individuals with mobility disabilities to a target location. The results show that pictures are a promising information source and present the desired requirements for a virtual tour. Based on the participants' experiences, ideas and specifications, a virtual prototype of the VISUS [visus24] building was implemented. The approach of this thesis was evaluated in a user study that provided both subjective and objective feedback. All in all, a virtual campus tour as an information source for planning purposes was rated as useful. Especially, the deep insight into buildings through images as well as concrete accessibility information including measurement data, support students in their planning process by a huge amount. The user evaluation also discovered ideas for further additions and future improvements, which are illustrated in the section following the limitations of this work.

8.1 Limitations

In general, the results of this thesis are limited due to a number of factors. First of all, the prototype should be tested by more students. On the one hand, the design is based on the requirements of a small group of students. On the other hand, diagnoses are very different and therefore also the needs and requirements of such a tour. This has already been shown through the user study where each participant brought up various new aspects. Consequently, it could be continued with further test persons. Secondly, two of the participants could not open the virtual tour on their devices. As a solution, they experienced the tour through screen sharing and gave instructions for action. This anticipated misunderstandings and did not reveal any problems that might have arisen. It is possible that this may have influenced the results. Thirdly, the function to submit a comment on the sidebar is limited. Currently, the user comments can not be saved due to the missing backend. Last but not least, the correct functionality of the prototype is limited to the browser Chrome.

8.2 Future Directions

In the future, the approach of this thesis could be evaluated, extended, and improved. An application as implemented in this thesis, which is intended to address users and in the long term be available for them, can always be further developed. Not to mention the technical development, which will continue to improve in the future, but also the needs of users, which will constantly change over the years. Therefore the following segments address general ideas as well as the ones of the user study and the requirement analysis that could not be realised within this project. These segments are divided into conceptual and technical sides.

Firstly, the implemented application was intended as a prototype for testing the concept of this thesis. In order to fully implement the idea of the thesis, other university buildings, especially those with lecture halls, but possibly also connections between the buildings and public parking areas, need to be integrated into the virtual tour. Secondly, the perspective of the camera, the zoom function, the number of images and the distances between them should be optimised to provide even more realistic insights. This also includes the transitions of the images which would support users' orientation inside a building. For example, a zoom animation in the walking direction would be a possible solution for that. Additionally, the tour could be expanded to include more features and data as evaluated in the user study like extending the current focus from key points such as toilets and lifts to rooms. To help users find a particular room, their numbers could be highlighted even more with visualisations. This may not be necessary for all rooms but for the most important ones in a building since, strictly speaking, the images already show the banner in front of the rooms. Another example feature is the independent measurement of objects. This could either be realised by including a virtual scale that can be dragged and dropped between two points. Or it could be implemented by creating a beam of a user-defined length (e.g. the width of their wheelchair) to use as a sort of template within the tour. This was discarded during the implementation process as it could be a research project in itself.
These are just a few examples of features on the conceptual side. However, it should be kept in mind that such a tool can get overloaded with functions and therefore a limited number of them should be chosen. To make the virtual tour reachable when it exists as a finished application, it would make sense to integrate it into an existing website itself or as a link. A possible website at the University of Stuttgart [uniStuttgart24] would be the one with accessibility information on buildings [accessibilityInfo24].

On the technical side, a few things could be further developed away from the concept of a prototype to a finished application for users. At first, the architecture could be extended through a backend and a database. As the implemented prototype focused more on basic functionality before undertaking more in-depth development, it was not necessary to implement a backend initially. However, it would make sense in the long term, to add a backend for future features that require one, or that will in sum degrade the efficiency. With the proposed architecture the images including their navigation and accessibility data can be outsourced and the routing can be moved to the backend. This would improve efficiency and thus also usability. Another add-on in regard to usability is Bootstrap [bootstrap24]. It ensures a consistent layout of HTML elements such as headings as well as responsiveness. This was not included in the prototype as it served to get quick feedback from participants focusing on user needs and less on aesthetics. This is often easier for users when the prototype is unfinished and does not have a high-fidelity design. Nevertheless, it would simplify the solution to better label the icon legend, as the users misinterpreted it. Concrete features that are partly implemented inside the prototype are automatic animations to the toilet and to the lift. As it has not been running smoothly, it was temporarily commented out. It allows users at the start of the tour to click a play button to start the animation. The animation consists of a sequence of images presenting a selected route to the toilet or the lift. When reaching the target, the animation stops and the user can continue to explore the building inside the virtual tour. This should help to quicker find key points like disabled toilets or lifts.

All in all, further research is required on this topic. Although some researchers have already developed systems to contribute to this field, such as Shasha et al. [SSM+19] with their project Sidewalk and Chi et al. [CSZ23] by creating digital replicas of indoor environments, further work is still required, particularly in universities. Young people with mobility impairments should be able to study at the university of their choice which starts with documenting and providing the necessary information. This thesis suggested only one possible approach by implementing a virtual tour with 360° images but there are a lot of other possible scenarios of how a remote campus experience may look like. One example would be mapping the complete university in a virtual reality in which users can move around freely.

Bibliography

[accessEarth24] Access Earth. *Access Earth website*. 2024. URL: https://www.accessearth.com/ (cit. on p. 16).

[accessEarthMap24] Access Earth. *Access Earth Map*. 2024. URL: https://app.access.earth/map (cit. on p. 16).

[accessibilityInfo24] University of Stuttgart. *Accessibility information of the University of Stuttgart*. 2024. URL: https://www.uni-stuttgart.de/universitaet/lageplan/barriere-informationen/ (cit. on pp. 18, 40, 42, 48, 50).

[accessibleBuilding16] Bundesministerium des Innern, für Bau und Heimat. *Leitfaden Barrierefreies Bauen - Hinweise zum inklusiven Planen von Baumaßnahmen des Bundes*. 2016. URL: https://www.fib-bund.de/Inhalt/Leitfaden/BarriefreiesBauen/ (cit. on p. 14).

[axsmap24] AXS Map. *AXS Map*. 2024. URL: https://axsmap.com/ (cit. on p. 16).

[basicLaw22] Federal Ministry of Justice. *Basic Law for the Federal Republic of Germany*. 2022. URL: https://www.gesetze-im-internet.de/englisch_gg/index.html#gl_p0027 (cit. on p. 11).

[BC06] V. Braun, V. Clarke. "Using thematic analysis in psychology". In: *Qualitative research in psychology* 3.2 (2006), pp. 77–101 (cit. on pp. 20, 40).

[bmzDisability24] Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung. *Definition von Behinderung*. 2024. URL: https://www.bmz.de/de/themen/rechte-menschen-mit-behinderungen/definition-behinderung-20364 (cit. on p. 13).

[bootstrap24] Bootstrap. *Bootstrap and Vite*. 2024. URL: https://getbootstrap.com/docs/5.2/getting-started/vite/ (cit. on p. 50).

[BRMP23] S. Bertani, V. Rubano, S. Mirri, C. Prandi. "Accessibility for Virtual Tours: on Designing a Prototype for People with Visual Impairments". In: *2023 IEEE 20th Consumer Communications & Networking Conference (CCNC)*. IEEE. 2023, pp. 1–6 (cit. on p. 11).

[campusPlatform24] University of Stuttgart. *Campus platform of the University of Stuttgart*. 2024. URL: https://campus.uni-stuttgart.de/cusonline/ee/ui/ca2/app/desktop/#/home?$ctx=lang=de (cit. on pp. 18, 22, 40, 48).

[condens24] Condens Insights GmbH. *Condens*. 2024. URL: https://condens.io/ (cit. on p. 19).

[CSZ23] H.-Y. Chi, J. Sha, Y. Zhang. "Bring Environments to People–A Case Study of Virtual Tours in Accessibility Assessment for People with Limited Mobility". In: *Proceedings of the 20th International Web for All Conference*. 2023, pp. 96–103 (cit. on pp. 11, 12, 17, 51).

[DB16] N. Döring, J. Bortz. "Forschungsmethoden und evaluation". In: *Wiesbaden: Springerverlag* (2016) (cit. on pp. 22, 44).

[deepL24] DeepL SE. *deepL*. 2024. URL: https://www.deepl.com/de/translator (cit. on pp. 19, 39).

[destatisGermany24] Statistisches Bundesamt (Destatis). *7,9 Millionen schwerbehinderte Menschen leben in Deutschland*. 2024. URL: https://www.destatis.de/DE/Presse/Pressemitteilungen/2020/06/PD20_230_227.html (cit. on p. 13).

[discoverThreeJS24] Lewy Blue. *Discover three.js - everything you need to know to create stunning 3D web applications using three.js*. 2024. URL: https://discoverthreejs.com/ (cit. on p. 36).

[DSW23] Deutsches Studierendenwerk. *Die Studierendenbefragung in Deutschland: best3 - Studieren mit einer gesundheitlichen Beeinträchtigung*. 2023. URL: https://www.studierendenwerke.de/beitrag/die-studierendenbefragung-in-deutschland-best3-studieren-mit-einer-gesundheitlichen-beeintraechtigung (cit. on p. 13).

[figma24] Figma GmbH. *figma*. 2024. URL: https://www.figma.com/ (cit. on p. 37).

[foursquare24] Foursquare. *Foursquare*. 2024. URL: https://foursquare.com/ (cit. on p. 15).

[foursquareCityGuide24] Foursquare. *Foursquare city guide*. 2024. URL: https://de.foursquare.com/city-guide (cit. on p. 15).

[GBB03] C. Germann, J. K. Broida, J. M. Broida. "Using computer-based virtual tours to assist persons with disabilities". In: *Journal of Educational Technology & Society* 6.3 (2003), pp. 53–60 (cit. on p. 11).

[googleMaps24] Google. *Google Maps*. 2024. URL: https://www.google.com/maps (cit. on pp. 12, 15, 21, 40, 47).

[inclusionBarometer22] Aktion Mensch e.V. und das Marktforschungsinstitut Ipsos. *Inklusionsbarometer Mobilität 2022*. 2022. URL: https://www.aktion-mensch.de/presse#/documents/am-inklusionsbarometer-mobilitaet-a4-bf-punkt-pdf-426894 (cit. on p. 13).

[insta36024] Insta360 Arashi vision inc. *Features of insta360 x3 camera*. 2024. URL: https://www.insta360.com/product/insta360-x3 (cit. on p. 36).

[installThreeJS24] Three.js. *Steps for installing three.js*. 2024. URL: https://threejs.org/docs/index.html#manual/en/introduction/Installation (cit. on p. 36).

[KBL+08] J. Kim, D. M. Brienza, R. D. Lynch, R. A. Cooper, M. L. Boninger. "Effectiveness evaluation of a remote accessibility assessment system for wheelchair users using virtualized reality". In: *Archives of physical medicine and rehabilitation* 89.3 (2008), pp. 470–479 (cit. on p. 17).

[KH19] M. J. Kim, C. M. Hall. "A hedonic motivation model in virtual reality tourism: Comparing visitors and non-visitors". In: *International Journal of Information Management* 46 (2019), pp. 236–249 (cit. on p. 17).

[KNR95] T. Kanade, P. Narayanan, P. W. Rander. "Virtualized reality: Concepts and early results". In: *Proceedings IEEE Workshop on Representation of Visual Scenes (In Conjunction with ICCV'95)*. IEEE. 1995, pp. 69–76 (cit. on p. 17).

[layoutPlan24] University of Stuttgart. *Layout plan of the University of Stuttgart*. 2024. URL: https://lageplan.uni-stuttgart.de/?lon=48.781267&lat=9.174833&zoom=15 (cit. on p. 18).

[limesurvey24] LimeSurvey GmbH. *Limesurvey*. 2024. URL: https://www.limesurvey.org/de (cit. on pp. 19, 39).

[matterport24] Matterport. *Matterport - Capture, share, and collaborate the built world in immersive 3D*. 2024. URL: https://matterport.com/de (cit. on p. 17).

[MBO22] Bauministerkonferenz. *Musterbauordnung*. 2022. URL: https://www.bauministerkonferenz.de/suchen.aspx?id=762&o=7590762&s=musterbauordnung (cit. on p. 14).

[MCEB20] S. Mascetti, G. Civitarese, O. El Malak, C. Bettini. "SmartWheels: Detecting urban features for wheelchair users' navigation". In: *Pervasive and Mobile Computing* 62 (2020), p. 101115 (cit. on pp. 12, 16).

[MDD17] A. Mobasheri, J. Deister, H. Dieterich. "Wheelmap: the wheelchair accessibility crowdsourcing platform". In: *Open Geospatial Data, Software and Standards* 2 (2017), pp. 1–7 (cit. on p. 16).

[MEL+22] K. Müller, C. Engel, C. Loitsch, R. Stiefelhagen, G. Weber. "Traveling more independently: a study on the diverse needs and challenges of people with visual or mobility impairments in unfamiliar indoor environments". In: *ACM Transactions on Accessible Computing (TACCESS)* 15.2 (2022), pp. 1–44 (cit. on pp. 11, 12).

[nodeJS24] Open JS Foundation and Node.js contributors. *Introduction to Node.js*. 2024. URL: https://nodejs.org/en/learn/getting-started/introduction-to-nodejs (cit. on p. 36).

[openStreetMap24] OpenStreetMap Stiftung (OSMF). *Open Street Map*. 2024. URL: https://www.openstreetmap.org/#map=14/48.7051/9.1387&layers=C (cit. on p. 15).

[PCC+23] S. Pei, A. Chen, C. Chen, F. M. Li, M. Fozzard, H.-Y. Chi, N. Weibel, P. Carrington, Y. Zhang. "Embodied Exploration: Facilitating Remote Accessibility Assessment for Wheelchair Users with Virtual Reality". In: *Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility*. 2023, pp. 1–17 (cit. on pp. 15, 17).

[PSM14] C. Prandi, P. Salomoni, S. Mirri. “mPASS: integrating people sensing and crowdsourcing to map urban accessibility”. In: *2014 IEEE 11th Consumer Communications and Networking Conference (CCNC)*. IEEE. 2014, pp. 591–595 (cit. on p. 16).

[raycaster24] Three.js. *Raycaster from Three.js API*. 2024. URL: https://threejs.org/docs/#api/en/core/Raycaster (cit. on p. 37).

[sozialhelden24] Sozialhelden e.V. *Sozialhelden - Einfach mal machen*. 2024. URL: https://sozialhelden.de/ (cit. on p. 15).

[SSM+19] M. Saha, M. Saugstad, H. T. Maddali, A. Zeng, R. Holland, S. Bower, A. Dash, S. Chen, A. Li, K. Hara, et al. “Project sidewalk: A web-based crowdsourcing tool for collecting sidewalk accessibility data at scale”. In: *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 2019, pp. 1–14 (cit. on pp. 16, 51).

[SUU+12] G. Sammer, T. Uhlmann, W. Unbehaun, A. Millonig, B. Mandl, J. Dangschat, R. Mayr. “Identification of mobility-impaired persons and analysis of their travel behavior and needs”. In: *Transportation Research Record* 2320.1 (2012), pp. 46–54 (cit. on p. 11).

[threeJS24] Three.js. *Fundamentals of Three.js*. 2024. URL: https://threejs.org/manual/#en/fundamentals (cit. on p. 36).

[unConvention24] Der Beauftragte der Bundesregierung für die Belange von Menschen mit Behinderungen. *Die UN-Behindertenrechtskonvention - Übereinkommen über die Rechte von Menschen mit Behinderungen*. 2024. URL: https://www.behindertenbeauftragter.de/DE/AS/rechtliches/un-brk/un-brk-node.html (cit. on p. 11).

[uniBochum23] University of Bochum. *Virtual campus tour of the University of Bochum*. 2023. URL: https://studium.ruhr-uni-bochum.de/de/digitale-campustour (cit. on p. 18).

[uniErfurt23] University of Erfurt. *Virtual campus tour of the University of Erfurt*. 2023. URL: https://www.uni-erfurt.de/universitaet/profil/rundgang (cit. on p. 18).

[uniKarlsruhe24] University of Karlsruhe. *Virtual campus tour of the University of Karlsruhe*. 2024. URL: https://www.idschools.kit.edu/360-virtual-tour.php (cit. on pp. 18, 47).

[uniMainz23] University of Mainz. *Virtual campus tour of the University of Mainz*. 2023. URL: https://dwls.uni-mainz.de/campusrundgang/ (cit. on p. 18).

[uniMannheim23] University of Mannheim. *Virtual campus tour of the University of Mannheim*. 2023. URL: https://www.uni-mannheim.de/campusrundgang/?lng=0 (cit. on p. 18).

[uniPassau23] University of Passau. *Virtual campus tour of the University of Passau*. 2023. URL: https://virtualtour.uni-passau.de/ (cit. on pp. 18, 47).

[uniStuttgart24] University of Stuttgart. *University of Stuttgart*. 2024. URL: https://www.uni-stuttgart.de/ (cit. on pp. 18, 22, 39, 48, 50).

[uniVechta23] University of Vechta. *Virtual campus tour of the University of Vechta*. 2023. URL: https://www.uni-vechta.de/rechenzentrum/campus-rundgang (cit. on p. 18).

[visus24] University of Stuttgart. *Visualization Research Center of the University of Stuttgart (VISUS)*. 2024. URL: https://www.visus.uni-stuttgart.de/ (cit. on pp. 31, 39, 47, 49).

[vite24] Evan You Vite Contributors. *Why Vite*. 2024. URL: https://vitejs.dev/guide/why.html (cit. on p. 36).

[Waa13] N. Waara. "Traveller information in support of the mobility of older people and people with disabilities". In: *User and provider perspectives* (2013), pp. 1–166 (cit. on p. 11).

[wheelchairGoogle24] Google. *Introducing "wheelchair accessible" routes in transit navigation*. 2024. URL: https://blog.google/products/maps/introducing-wheelchair-accessible-routes-transit-navigation/ (cit. on p. 15).

[wheelmap24] Wheelmap.org. *wheelmap*. 2024. URL: https://wheelmap.org/ (cit. on pp. 15, 21, 40, 47).

[wheelMate24] Coloplast Group. *wheelMate*. 2024. URL: https://www.coloplast.com/products/bladder-bowel/wheelmate/#section=What-is-WheelMate%e2%84%a2_443671 (cit. on pp. 15, 16).

[whoDisability24] World Health Organization. *Disability*. 2024. URL: https://www.who.int/news-room/fact-sheets/detail/disability-and-health (cit. on p. 13).

[youTube24] YouTube. *YouTube*. 2024. URL: https://www.youtube.com/ (cit. on p. 21).

[zitronenwolf20] Zitronenwolf Medien - Dipl.Ing. Heiko Stachel. *Universität Stuttgart*. 2020. URL: https://www.zitronenwolf.com/rundgaenge/uniStuttgart.php (cit. on p. 18).

All links were last followed on May 01, 2024.

A Workshop Flyer

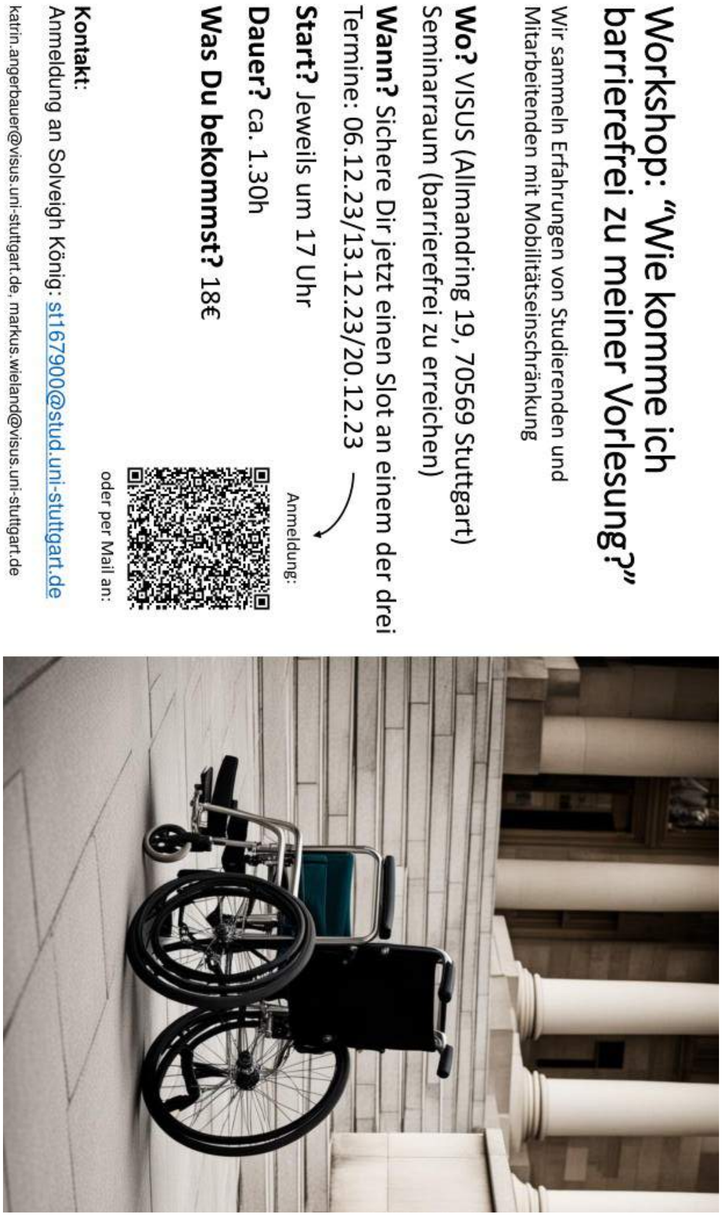

Figure A.1: Participant recruitment with flyer

B Structure of Connected Images

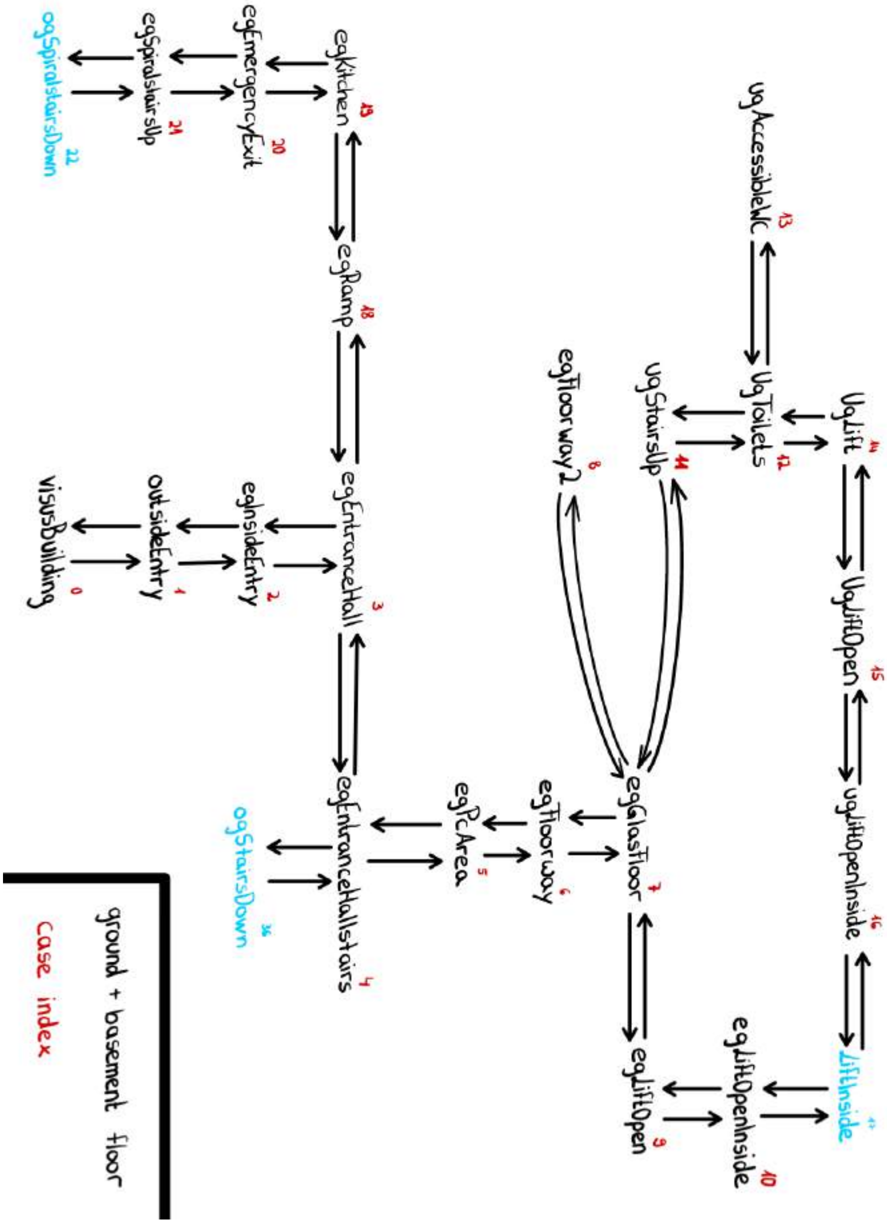

Figure B.1: Image plan of ground and basement floor

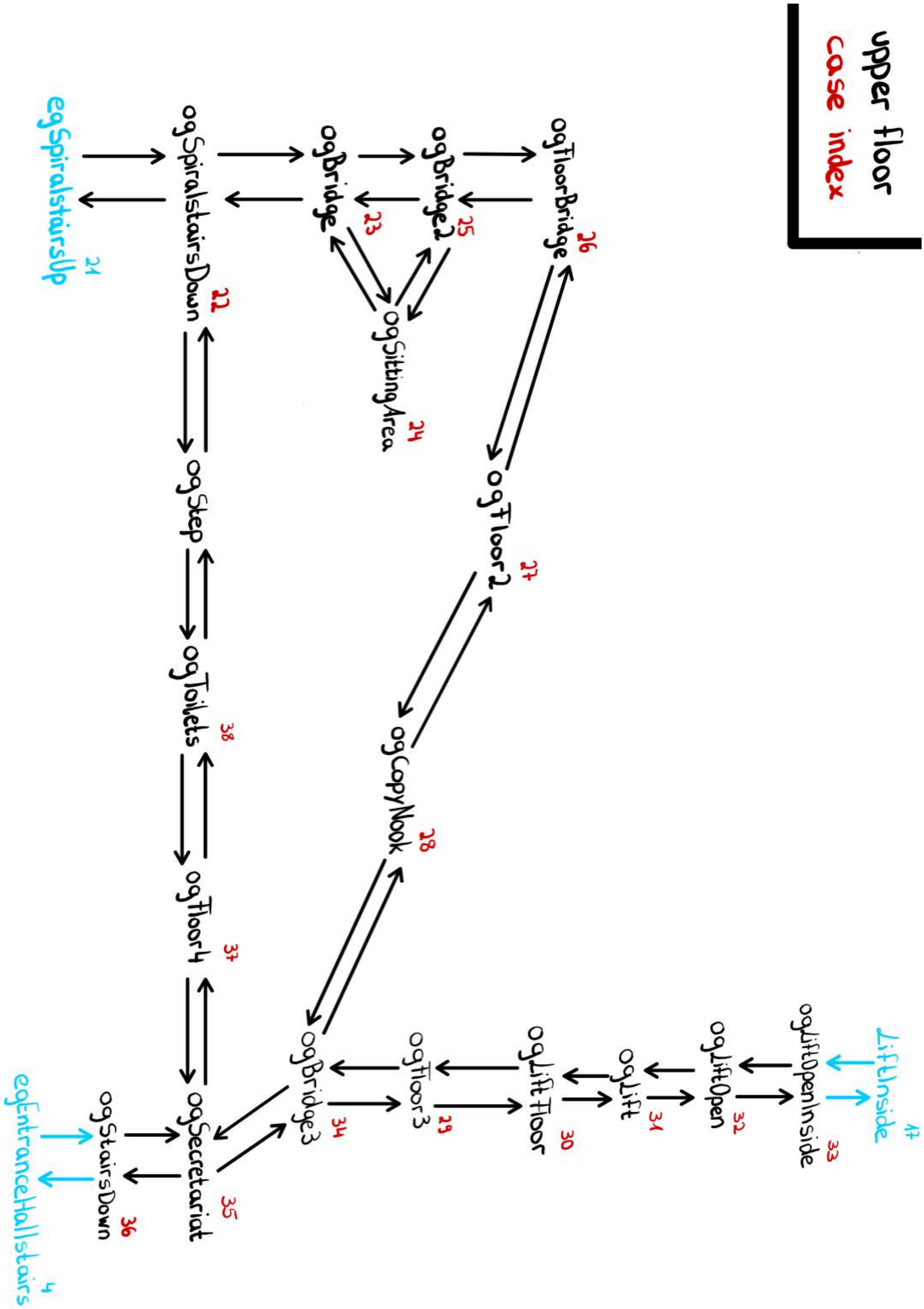

Figure B.2: Image plan of upper floor

C Result Data of the Online Survey

Survey on Campus Accessibility

Ergebnisse

Umfrage 232741

Anzahl der Datensätze in dieser Abfrage:	4
Gesamtzahl der Datensätze dieser Umfrage:	4
Anteil in Prozent:	100.00%

What is your gender?

Antwort	Anzahl	Prozent
Female (f)	2	50.00%
Male (m)	1	25.00%
Other (o)	1	25.00%
Prefer not to answer (f1)	0	0.00%
Sonstiges	0	0.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

ID	Antwort

How old are you?

Antwort	Anzahl	Prozent
< 20 (AO01)	0	0.00%
20 - 25 (AO02)	3	75.00%
26 - 30 (AO04)	1	25.00%
> 30 (AO03)	0	0.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

Are you already studying or are you interested in studying at university?

Antwort	Anzahl	Prozent
I am currently studying (AO01)	4	100.00%
I am interested in studying at university (AO02)	0	0.00%
I have already completed my degree (AO03)	0	0.00%
Sonstiges	0	0.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

ID	Antwort

What applies to you?

Antwort	Anzahl	Prozent
I have a disability (AO01)	2	50.00%
I don't have any disabilities, but I am familiar with campus accessibility (AO02)	2	50.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

Do you need any mobility aids and if yes, which one?

Antwort	Anzahl	Prozent
No, I don't use any aids (SQ001)	3	75.00%
Walking cane (SQ002)	0	0.00%
Electrical wheelchair (SQ003)	1	25.00%
Manual wheelchair (SQ006)	0	0.00%
Wheeled walker (SQ004)	0	0.00%
Mobility scooter (SQ005)	0	0.00%
Sonstiges	0	0.00%

ID	Antwort

Which assistive devices do you use for route planning?

Antwort	Anzahl	Prozent
No, I don't use anything (SQ001)	0	0.00%
Digital maps (e.g. Google Maps) (SQ002)	4	100.00%
Printed maps (SQ005)	0	0.00%
Images (SQ006)	0	0.00%
University website (SQ003)	2	50.00%
Google Street View (SQ004)	3	75.00%
Sonstiges	1	25.00%

ID	Antwort
2	wheelmap.org

You want to visit an unfamiliar university - How do you prepare for this? Please name your steps

Antwort	Anzahl	Prozent
Antwort	4	100.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

ID	Antwort
2	1. Research: Use information available on the internet (university websites, Google Maps/Streetview etc.) to search for disabled parking space, wheelchair-accessible entrance and other potential barriers 2. Contact university: due to the lack of information, it's often necessary to contact university staff to get to the necessary detailed information 3. Exploration: Besides all the preparation, it's sometimes necessary to see the situation in person, to make sure everything I need is accessible before the "official" visit
6	I use Google Maps to get an idea of the terrain: I look for parking spaces and how long it will take to get there with public transport. I usually take the car if I need at least 30 minutes less time than by public transport. When there are parking spaces shown in Google Maps I look up its price via linked website or the university's website.
17	Use google maps
20	1. I'm assessing how accessible the university and the city are. 2. I'm considering whether I have the physical strength to manage it.

You want to visit an unfamiliar university - How long do you usually need to prepare for such a visit?

Antwort	Anzahl	Prozent
< 1 hour (AO01)	3	75.00%
1 - 5 hours (AO02)	1	25.00%
6 - 10 hours (AO03)	0	0.00%
one day (AO04)	0	0.00%
multiple days (AO05)	0	0.00%
Sonstiges	0	0.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

ID	Antwort

How long before the visit of an unfamiliar university do you start planning?

Antwort	Anzahl	Prozent
at the same day (AO01)	1	25.00%
one day before (AO02)	0	0.00%
one to five days before (AO03)	1	25.00%
five to seven days before (AO04)	0	0.00%
more than one week before (AO05)	2	50.00%
Sonstiges	0	0.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

ID	Antwort

You want to visit an unfamiliar university - What information are you searching for?

Antwort	Anzahl	Prozent
Antwort	4	100.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

ID	Antwort
2	- disabled parking space - barrier-free access to buildings, rooms & lecture halls (sometimes even door-width and incline of the floor is important) - location of elevators - building plans to navigate to a certain room
6	time to get there by car and by public transport, number of parking spaces, price for parking, distance from the parking spaces to the university, distance from the train station to the university, if necessary: connection from train station/parking spaces to university by public transport, price of the ticket for the public transport
17	route
20	1. I'm checking how to get to the university using public transportation with minimal distance and incline (Google Maps). 2. I'm looking at the university's website. 3. I'm checking on which floor the rooms are located – are there elevators?

You want to visit an unfamiliar university - Where do you search for information?

Google street view	4	100.00%
Website of the place to visit	4	100.00%
Pictures of this place on the internet	2	50.00%
Ask people you know, who already visit this place	3	75.00%
Books/analog maps	0	0.00%
Sonstiges	1	25.00%

ID	Antwort
2	To find parking space & accessible doorways
20	How steep is the incline? Are there stairs?
2	To navigate to a room and find information about elevators, doorways and their location
6	menu items like "plan your visit", "parking", "how to get there"
20	Are there elevators?
2	To get an idea of the situation and recognise potential barriers
2	Sometimes helpful, but I prefer talking directly to the staff because they know their campus
6	I ask them about parking spaces + prices, public transport in the city, Are there railway (s-bahn), underground, trams and busses? Wich is the best to take?
20	How accessible is the location?
2	Sometimes there exists a drone shot of certain areas of the campus which is helpful to get an overview of the situation

You want to visit a familiar university - How long do you usually need to prepare for such a visit?

Antwort	Anzahl	Prozent
< 10 minutes (AO01)	1	25.00%
10 - 30 minutes (AO04)	2	50.00%
30 - 45 minutes (AO06)	0	0.00%
45 - 60 minutes (AO05)	1	25.00%
1 - 5 hours (AO02)	0	0.00%
> 5 hours (AO03)	0	0.00%
Sonstiges	0	0.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

ID	Antwort

How long before the visit of a familiar university do you start planning?

Antwort	Anzahl	Prozent
less than an hour before (AO03)	1	25.00%
a few hours before (AO01)	1	25.00%
one day before (AO02)	2	50.00%
more than one day before (AO04)	0	0.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

You want to choose a future university for yourself - What criteria regarding to accessibility are important for you?

Antwort	Anzahl	Prozent
Antwort	4	100.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

ID	Antwort
2	- accessible public transport to university - available parking space for disabled people - barriers-free accessible buildings & rooms like lecture halls, cafeteria, library & other places where I can meet fellow students - wheelchair-places in lecture hall which aren't awkward placed (like not in the first or last row) - virtual accessibility: providing lecture recordings and more in digital form to secure access to education even if students are not able to attend the lecture physically
6	distance from home to university, time to get there, number of parking spaces, short walking distance between parking spaces and university / between stop of public transport and university, short distance to the next stopt of public transport, few changes when taking public transport from home to university
17	train stations
20	1. Every lecture hall is accessible by an elevator, or the ramps are not too steep, making them not too strenuous to navigate. 2. Learning spaces and the cafeteria are wheelchair accessible. 3. There are contact persons available for addressing issues.

How satisfied are you with the currently offered accessibility information inside of buildings of your home university / prospective university? (1 very satisfied - 5 very dissatisfied)

Antwort	Anzahl	Prozent	Summe
1 (1)	1	25.00%	25.00%
2 (2)	0	0.00%	
3 (3)	1	25.00%	25.00%
4 (4)	2	50.00%	
5 (5)	0	0.00%	50.00%
Keine Antwort	0	0.00%	0.00%
Nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	3		
Standard Abweichung	1.41		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

How satisfied are you with the currently offered accessibility information outside of buildings of your home university / prospective university? (1 very satisfied - 5 very dissatisfied)

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	50.00%
2 (2)	2	50.00%	
3 (3)	1	25.00%	25.00%
4 (4)	1	25.00%	
5 (5)	0	0.00%	25.00%
Keine Antwort	0	0.00%	0.00%
Nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	2.75		
Standard Abweichung	0.96		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

After finding accessibility information for planning your campus visit. How well prepared or informed do you feel about it? (1 not at all - 2 slightly - 3 moderately - 4 very - 5 extremly)

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	25.00%
2 (2)	1	25.00%	
3 (3)	2	50.00%	50.00%
4 (4)	1	25.00%	
5 (5)	0	0.00%	25.00%
Keine Antwort	0	0.00%	0.00%
Nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	3		
Standard Abweichung	0.82		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

How accurate has the accessibility information of the campus been in the past? (1 very high - 5 very low)

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	25.00%
2 (2)	1	25.00%	
3 (3)	1	25.00%	25.00%
4 (4)	0	0.00%	
5 (5)	2	50.00%	50.00%
Keine Antwort	0	0.00%	0.00%
Nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	3.75		
Standard Abweichung	1.5		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

I would like the following offer from universities to better prepare for my first visits...

Antwort	Anzahl	Prozent
Pictures of the campus (SQ001)	3	75.00%
Pictures of the entry and the inside of buildings (SQ002)	4	100.00%
Drone tour videos (SQ003)	3	75.00%
Virtual tours of the university (SQ004)	3	75.00%
Printed site maps (SQ005)	0	0.00%
Digital side maps (SQ007)	3	75.00%
Textual information about accessibility (SQ006)	2	50.00%
Sonstiges	2	50.00%

ID	Antwort
2	Information about dimensions of doorways & elevators (and if they're currently functioning)
6	path from start to goal in the university's guidance system "Horst"

Which information about the inside of buildings do you miss?

Antwort	Anzahl	Prozent
Antwort	4	100.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

ID	Antwort
2	- dimensions & other information about doorways & elevators - an accurate and intuitive digital side map which is easy to understand and shows the location of stairs and other barriers - footage of some buildings and rooms
6	in the buildings: Guidance system e. g. at walls, display stands ...
17	nothing
20	How do I access the cafeteria without barriers?

Which information about the outside of buildings do you miss?

Antwort	Anzahl	Prozent
Antwort	4	100.00%
Keine Antwort	0	0.00%
Nicht gezeigt	0	0.00%

ID	Antwort
2	- clear location of entries and parking spaces - routes without paving stones and with minimal incline between buildings
6	on the outside of the buildings, near the entrance: house numbers, overview over numbers of floors + important rooms at the floors
17	nothing at the moment
20	Which paths without stairs are available?

Tick all the all the information you were able to find in the past regarding your university and state why they were or were not helpful.

No, I haven't	1	25.00%
360 degree tours of the university	1	25.00%
Drone tour videos	1	25.00%
Pictures of the campus	3	75.00%
Pictures of the entry and the inside of buildings	2	50.00%
Printed side maps	0	0.00%
Digital side maps	3	75.00%
Textual information about accessibility	1	25.00%
Sonstiges	0	0.00%

ID	Antwort
20	There were only contact details for designated individuals who could assist with questions, which is great, but it means one has to independently handle reaching out by email for each question.
2	Helpful to get a first impression, but doesn't cover many details and is only used in big lecture halls or buildings
2	Depends on the pictures, but often these pictures are not very expressive
2	Extremely helpful to assess if the entry is accessible
6	would be fine to find the entrances of the different buildings on the internet
2	Extremely helpful! Sadly at my university incomplete and not intuitive implemented
2	Helpful if the text is detailed and contains information that can't be told via pictures or videos

Rate the following information sources according to its usefulness (1 not at all - 2 slightly - 3 moderately - 4 very - 5 extremely)

360 degree tours of the university:

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	0.00%
2 (2)	0	0.00%	
3 (3)	1	25.00%	25.00%
4 (4)	1	25.00%	
5 (5)	2	50.00%	75.00%
Keine Antwort	0	0.00%	0.00%
Nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	4.25		
Standard Abweichung	0.96		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

Drone tour videos:

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	25.00%
2 (2)	1	25.00%	
3 (3)	2	50.00%	50.00%
4 (4)	0	0.00%	
5 (5)	1	25.00%	25.00%
Keine Antwort	0	0.00%	0.00%
Nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	3.25		
Standard Abweichung	1.26		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

Zusammenfassung G03

Pictures of the campus:

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	0.00%
2 (2)	0	0.00%	
3 (3)	1	25.00%	25.00%
4 (4)	3	75.00%	
5 (5)	0	0.00%	75.00%
Keine Antwort	0	0.00%	0.00%
Nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	3.75		
Standard Abweichung	0.5		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

Pictures of the entry and the inside of buildings:

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	0.00%
2 (2)	0	0.00%	
3 (3)	0	0.00%	0.00%
4 (4)	2	50.00%	
5 (5)	2	50.00%	100.00%
Keine Antwort	0	0.00%	0.00%
Nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	4.5		
Standard Abweichung	0.58		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

Printed side maps:

Antwort	Anzahl	Prozent	Summe
1 (1)	1	25.00%	100.00%
2 (2)	3	75.00%	
3 (3)	0	0.00%	0.00%
4 (4)	0	0.00%	
5 (5)	0	0.00%	0.00%
Keine Antwort	0	0.00%	0.00%
Nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	1.75		
Standard Abweichung	0.5		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

Digital side maps:

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	0.00%
2 (2)	0	0.00%	
3 (3)	0	0.00%	0.00%
4 (4)	2	50.00%	
5 (5)	2	50.00%	100.00%
Keine Antwort	0	0.00%	0.00%
Nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	4.5		
Standard Abweichung	0.58		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

Textual information about accessibility

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	25.00%
2 (2)	1	25.00%	
3 (3)	1	25.00%	25.00%
4 (4)	2	50.00%	
5 (5)	0	0.00%	50.00%
Keine Antwort	0	0.00%	0.00%
Nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	3.25		
Standard Abweichung	0.96		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

Anything else you like to mention?

Antwort	Anzahl	Prozent
Antwort	0	0.00%
Keine Antwort	4	100.00%
Nicht gezeigt	0	0.00%

ID	Antwort

D Result Data of the User Study

Studie zur virtuellen Campus Tour

Ergebnisse

Umfrage 354944

Anzahl der Datensätze in dieser Abfrage:	4
Gesamtzahl der Datensätze dieser Umfrage:	5
Anteil in Prozent:	80.00%

Welches Geschlecht haben Sie?

Antwort	Anzahl	Prozent
Weiblich (AO01)	2	50.00%
Männlich (AO02)	2	50.00%
Divers (AO04)	0	0.00%
Möchte ich nicht beantworten (AO03)	0	0.00%
Sonstiges	0	0.00%
Keine Antwort	0	0.00%
Nicht beendet oder nicht gezeigt	0	0.00%

ID	Antwort

Wie alt sind Sie?

Antwort	Anzahl	Prozent
< 20 (AO01)	0	0.00%
20 - 26 (AO02)	3	75.00%
27 - 45 (AO03)	0	0.00%
46 - 67 (AO06)	1	25.00%
> 67 (AO05)	0	0.00%
Keine Antwort	0	0.00%
Nicht beendet oder nicht gezeigt	0	0.00%

Wählen Sie Ihren Studierendenstatus aus:

Antwort	Anzahl	Prozent
Ich studiere derzeit (AO01)	3	75.00%
Ich bin daran interessiert an der Universität zu Studieren (AO02)	0	0.00%
Ich habe mein Studium bereits abgeschlossen (AO03)	1	25.00%
Sonstiges	0	0.00%
Keine Antwort	0	0.00%
Nicht beendet oder nicht gezeigt	0	0.00%

ID	Antwort

Was trifft auf Sie zu?

Antwort	Anzahl	Prozent
Ich habe eine Einschränkung (AO01)	3	75.00%
Ich habe keine Einschränkung aber bin vertraut mit der Barrierefreiheit auf dem Campus (AO02)	1	25.00%
Keine Antwort	0	0.00%
Nicht beendet oder nicht gezeigt	0	0.00%

Benutzen Sie Mobilitätshilfen oder kennen sich mit solchen im Alltag aus? Wenn ja, welche?

Antwort	Anzahl	Prozent
Nein, ich bin bisher mit keinen Hilfsmitteln in Kontakt gekommen (SQ001)	0	0.00%
Gehstock (SQ002)	1	25.00%
Elektischer Rollstuhl (SQ003)	3	75.00%
Manueller Rollstuhl (SQ004)	2	50.00%
Rollator (SQ005)	0	0.00%
Elektromobil (SQ006)	0	0.00%
Sonstiges	1	25.00%

ID	Antwort
3	Hilfe von Mitmenschen

Zusammenfassung G02

[Wie schnell haben Sie die gesuchten Informationen gefunden?]

Bewertung der aktuell verfügbaren Informationen zur Bewältigung des Tasks (1 - schlecht, 5 - sehr gut):

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	25.00%
2 (2)	1	25.00%	
3 (3)	1	25.00%	25.00%
4 (4)	0	0.00%	
5 (5)	2	50.00%	50.00%
Keine Antwort	0	0.00%	0.00%
Nicht beendet oder nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	3.75		
Standard Abweichung	1.5		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

[Wie zufrieden sind Sie mit den gefundenen Informationen?]

Bewertung der aktuell verfügbaren Informationen zur Bewältigung des Tasks (1 - schlecht, 5 - sehr gut):

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	0.00%
2 (2)	0	0.00%	
3 (3)	0	0.00%	0.00%
4 (4)	2	50.00%	
5 (5)	2	50.00%	100.00%
Keine Antwort	0	0.00%	0.00%
Nicht beendet oder nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	4.5		
Standard Abweichung	0.58		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

[Würden Sie die Quellen wieder verwenden?]

Bewertung der aktuell verfügbaren Informationen zur Bewältigung des Tasks (1 - schlecht, 5 - sehr gut):

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	0.00%
2 (2)	0	0.00%	
3 (3)	1	25.00%	25.00%
4 (4)	0	0.00%	
5 (5)	3	75.00%	75.00%
Keine Antwort	0	0.00%	0.00%
Nicht beendet oder nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	4.5		
Standard Abweichung	1		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

[Wie sicher fühlen Sie sich mit den Informationen?]

Bewertung der aktuell verfügbaren Informationen zur Bewältigung des Tasks (1 - schlecht, 5 - sehr gut):

Antwort	Anzahl	Prozent	Summe
1 (1)	1	25.00%	25.00%
2 (2)	0	0.00%	
3 (3)	0	0.00%	0.00%
4 (4)	1	25.00%	
5 (5)	2	50.00%	75.00%
Keine Antwort	0	0.00%	0.00%
Nicht beendet oder nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	3.75		
Standard Abweichung	1.89		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

Möchten Sie noch weitere Anmerkungen machen zu den bisher verfügbaren Informationen?

Antwort	Anzahl	Prozent
Antwort	3	75.00%
Keine Antwort	1	25.00%
Nicht beendet oder nicht gezeigt	0	0.00%

ID	Antwort
2	Zur ersten Orientierung in diesem Gebäude ist es ein fantastisches Tool, da hier all möglichen Schwachstellen oder Gefahren vorab erkannt werden können.
3	Es fühlt sich sicherer an visuelle Informationen zu erhalten als geschriebene.
5	Mir fehlten genauere Fotos, um mir manches (gerade im Gebäude) besser vorzustellen

[Wie schnell haben Sie die gesuchten Informationen gefunden?]

Bewertung des Prototypen zur Bewältigung des Tasks (1 - schlecht, 5 - sehr gut):

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	0.00%
2 (2)	0	0.00%	
3 (3)	0	0.00%	0.00%
4 (4)	2	50.00%	
5 (5)	2	50.00%	100.00%
Keine Antwort	0	0.00%	0.00%
Nicht beendet oder nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	4.5		
Standard Abweichung	0.58		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

[Wie zufrieden sind Sie mit den gefundenen Informationen?]

Bewertung des Prototypen zur Bewältigung des Tasks (1 - schlecht, 5 - sehr gut):

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	0.00%
2 (2)	0	0.00%	
3 (3)	0	0.00%	0.00%
4 (4)	0	0.00%	
5 (5)	4	100.00%	100.00%
Keine Antwort	0	0.00%	0.00%
Nicht beendet oder nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	5		
Standard Abweichung	0		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

[Würden Sie den Prototypen wieder verwenden?]

Bewertung des Prototypen zur Bewältigung des Tasks (1 - schlecht, 5 - sehr gut):

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	0.00%
2 (2)	0	0.00%	
3 (3)	0	0.00%	0.00%
4 (4)	0	0.00%	
5 (5)	4	100.00%	100.00%
Keine Antwort	0	0.00%	0.00%
Nicht beendet oder nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	5		
Standard Abweichung	0		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

[Wie sicher fühlen Sie sich mit den Informationen?]

Bewertung des Prototypen zur Bewältigung des Tasks (1 - schlecht, 5 - sehr gut):

Antwort	Anzahl	Prozent	Summe
1 (1)	0	0.00%	0.00%
2 (2)	0	0.00%	
3 (3)	0	0.00%	0.00%
4 (4)	1	25.00%	
5 (5)	3	75.00%	100.00%
Keine Antwort	0	0.00%	0.00%
Nicht beendet oder nicht gezeigt	0	0.00%	0.00%
Arithmetisches Mittel	4.75		
Standard Abweichung	0.5		
Summe (Antworten)	4	100.00%	100.00%
Anzahl Fälle		0%	

Möchten Sie noch weitere Anmerkungen zum Prototypen machen?

Antwort	Anzahl	Prozent
Antwort	1	25.00%
Keine Antwort	3	75.00%
Nicht beendet oder nicht gezeigt	0	0.00%

ID	Antwort
2	je mehr Gebäude in die virtuelle Tour aufgenommen werden können, umso besser.

Declaration

I hereby declare that the work presented in this thesis is entirely my own. I did not use any other sources and references than the listed ones. I have marked all direct or indirect statements from other sources contained therein as quotations. Neither this work nor significant parts of it were part of another examination procedure. I have not published this work in whole or in part before. The electronic copy is consistent with all submitted hard copies.

place, date, signature