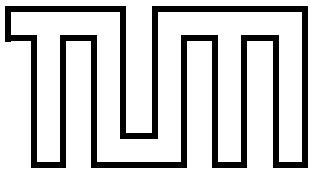


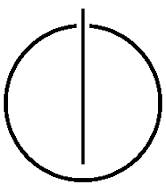
DEPARTMENT OF INFORMATICS

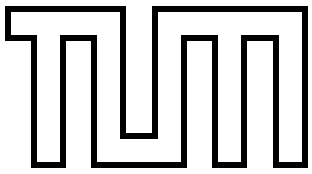
TECHNICAL UNIVERSITY OF MUNICH

Master's Thesis in Information Systems

Virtual Tourism Applications: Categorization, Implementation and Evaluation

Maria Potzner





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Virtual Tourism Applications: Categorization, Implementation and Evaluation

Virtuelle Tourismusanwendungen: Kategorisierung, Realisierung und Evaluierung

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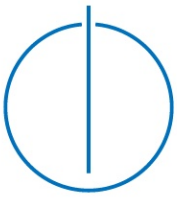
Submission date:	15.01.2021



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

Munich, 15.01.2021 Maria Potzner

Abstract

Virtual tourism applications have become increasingly important, especially in the present time with the spread of COVID-19. Virtual tourism allows to discover different countries, cities or sights remotely. In this work, the term virtual tourism is defined and an overview of the different applications is given by dividing them into categories and showing their characteristics. Furthermore, a user study is developed in which the interaction and navigation types of two applications are investigated. The results from the evaluation of the user study are then used to improve each navigation type. These changes are implemented and presented in mockups. Finally, guidelines are presented that can be applied independently of the presented navigations when implementing a virtual tourism application.These include how to highlight a navigation type, how to best bring its functionality closer to the user, and how many navigation types should be used.

Zusammenfassung

Virtuelle Tourismusanwendungen sind besonders in der jetzigen Zeit, vorallem wegen der Verbreitung von COVID-19 immer wichtiger geworden. Virtuelle Tourismusanwendungen ermöglichen es von Zuhause aus verschieden Länder, Städte oder Sehenswürdigkeiten zu entdecken. In dieser Arbeit wird zuerst der Begriff des virtuellen Tourismus definiert und ein Überblick über die verschiedenen Anwendungen gegeben, indem sie in Kategorien gegliedert werden und deren Charakteristiken aufgezeigt werden. Des Weiteren wird eine Nutzerstudie entwickelt, in der die Interaktion und die Navigationstypen von zwei Anwendungen untersucht werden. Die Ergebnisse aus der Auswertung der Nutzerstudie werden anschließend verwendet, um die einzelnen Navigationstypen zu verbessern. Diese Änderungen werden in Mockups umgesetzt und dargestellt. Abschließend werden Guidelines vorgestellt, die unabhängig von den vorgestellten Navigationen bei einer Realisierung einer virtuellen Tourismusanwendung angewandt werden können. Diese beinhalten wie man einen Navigationstyp hervorheben kann, wie seine Funktionalität dem Nutzer am besten näher gebracht wird und wie viele Navigationstypen verwendet werden sollten.

Acknowledgment

I would like to express my gratitude to my advisor Dr. Wolfgang Wörndl for his guidance, quickly scheduled meetings, and his continuous and valuable feedback throughout the past month.

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ANOVA Analysis of variance 35

AR Augmented Reality 3

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ICT Information and Communication Technology 5

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VT Virtual Tourism 2

1 Introduction

1.1 Motivation

The tourism industry was hit by the COVID-19 pandemic like no other. Border closures and travel restrictions significantly limited the number of tourists across the globe. According to the United Nations World Tourism Organization (UNWTO) international tourist arrivals declined by 70% in the first ten months of 2020 compared to the same period in 2019 (UNWTO, 2020). This means 900 million fewer international arrivals and worldwide loss of 935 billion US$ in tourism revenue. Further, the International Air Transport Association (IATA) estimates that a recovery on 2019 tourism flight levels will only happen by 2024 (IATA, 2020).

Out of necessity, tourist boards and popular destinations began to offer Virtual Tourism (VT) experiences. For example, Singapore's Tourism Board has initiated virtual tours and events to support its tourism industry (Keng, 2020). Similarly, in Japan online tours are offered that cover sightseeing spots across Tokyo. Both of these examples of VT allow to take a tour from home but there is no universally accepted definition of the term VT. The term is used by different websites to describe watching a promotional video[1], visiting an interactive museum[2] or to visit historic sights in a game[3]. As the first contribution in this work, we will define Virtual Tourism (VT) for our purposes and differentiate it from related terms, such as digital tourism and Virtual Reality (VR).

Already before the pandemic, VT was gaining importance. A 2019 report[4] by Research and Markets suggests that a strong growth of virtual technology in tourism can be expected in the coming years. However, before the pandemic, the use case of virtual technology was mostly decision-support before the actual trip or as additional sights at the destinations. It was expected that travelers will want to use virtual technologies to choose the right trip, destination and hotel and theme parks and other attractions use virtual technology to offer different experiences. The pandemic and resulting travel restrictions spurred this process and lead to VT experiences

[1] https://bit.ly/3i8sOUz
[2] https://omnia360.de/virtueller-rundgang/kultur
[3] https://bit.ly/3smMrNp
[4] https://bit.ly/3nEyTth

that are designed to replace physical travel. The potential of VT was also seen by known companies such as *Amazon*[5] and *AirBnB*[6]. Both firms launched platforms where tour guides and local residents in countries around the world can offer virtual experiences.

Even now, not all VT applications are designed to replace conventional tourism, but to keep tourists' interest during the pandemic, so when the situation improves they will be keen to travel. In an interview with the BBC, Petra Hedorfer, the chief executive of the German National Tourist Board (GNTB), explains: "Digital applications cannot, and are not intended to replace the experience of real-world travel. But VR and Augmented Reality (AR) applications are essential elements in keeping interest in Destination Germany alive during travel restrictions, getting potential customers excited about our product and providing inspiration for real-world travel" (BBC News, 2020). For this purpose, the GNTB has created 360° videos on German cycling routes[7], VR videos of playing piano with Beethoven[8] or AR representation of famous sights, such as the castle Neuschwanstein in *Luftschlösser*[9], which can be viewed on the Microsoft HoloLens as part of the "DiscoverGermanyFromHome" campaign.

These examples show that VT encompasses many different use cases and technologies. While VT became popular recently, academic studies on it are scarce. Most publications focus on VR and virtual environments in general, and seldom consider tourism. Therefore, we conduct an exemplary but systematic literature review of existing VT applications and publications as part of this thesis. We study each application and categorize them according to their use case, technology and other derived criteria. Based on this categorization, we are able to derive common features of different applications.

Sherman and Craig, 2003 outline five key elements of a VR experience:
1. the participants, 2. the creators, 3. the virtual world, 4. the feeling of immersion and 5. interactivity. We argue that these key elements also apply to VT experiences, because VT and VR are closely related. In this thesis, we focus on the 5th element and study and evaluate the interactivity of different VT applications.

The interactivity is one of the key criteria that differentiated VT and virtual tours from traditional media formats, such as standard videos. While online videos can be paused, rewound, forwarded, and stopped, users cannot change the viewing angle

[5] https://www.amazon.com/b?node=19419898011
[6] https://www.airbnb.com/s/experiences
[7] https://www.youtube.com/watch?v=mgN8BAmj_hE&feature=youtu.be
[8] https://www.youtube.com/watch?v=VmJ6WFYlmts
[9] https://www.tageskarte.io/technologie/detail/augmented-reality-in-der-touristik.html

or zoom in at objects they would like to inspect closer (Spielmann and Mantonakis, 2018). They can also not decide what is shown and discussed and for how long. The possibilities in VT lead to a more customized and personalized experience for the user.

In the web-based VT applications, which this thesis covers, the interactivity is achieved via mouse input (e.g. clicking, moving the view of the environment with the mouse, zooming in and out using a touch pad). User input should resemble the behavior one would actually experience in the physical environment that is shown. For example, a tour composed of 360° photos allows the user to move in an environment that is meant to replicate reality. Just as in reality, the user can move forward and backward, change his point of view and zoom in at objects of interest by clicking on arrows or maneuvering the mouse. As such, users are virtually transported and immersed in that environment because of the interactivity, and their experience is determined by them (Spielmann and Mantonakis, 2018).

It is evident that interactivity plays an important role to enhance the VT experience and improve the quality of VT applications. For this purpose, we investigate how interaction elements for navigation should be designed, so that they are easy to use, to find, and can support different usage scenarios. These scenarios could be users who just want to get an overview of an attraction or others that want a detailed tour with a near real-life experience. To investigate the navigation, we chose two applications with different navigation types and conducted a user study. Based on the results of the user study we derive guidelines that should be adhered to when implementing interactivity and navigation in any VT application.

1.2 Research Objectives

Summarizing the aims of this thesis, we want to define the term VT, as this term has not generally established in literature and we provide an overview of already existing applications, which are divided into categories whereby their characteristics are described. Further, this thesis aims to identify how the navigation and interaction in VT applications can be enhanced. Therefore, an user study is conducted, which uses two VT applications to examine how the interaction and navigation types can be improved. In the end, the user study is evaluated and the findings are used to improve the applications' navigation types. Additionally, guidelines are developed to implement successful navigation types and enhance the interaction independently from the tested applications.

Based on these considerations three research questions are defined:

- What is VT and how is it distinguished from other related concepts?
- Which VT applications do exist, how can they be categorized and which characteristics do they have?
- What are important aspects when designing interaction elements for the navigation?

1.3 Definition of Virtual Tourism

An essential part of this thesis is to define the term Virtual Tourism (VT) and its scope. In this section, the term VT will be clarified based on definitions from papers and websites. As this term has no generally established definition in the literature, we define a working definition for this thesis. For that purpose, other definitions are considered related to technology in tourism.

The Oxford English Dictionary, 2017 defines virtual as "*made to appear to exist by the use of computer software, for example on the Internet*".
Tourism is defined as "*the business activity connected with providing accommodation, services and entertainment for people who are visiting a place for pleasure*". A more precise definition is given by the United Nations World Tourism Organization (UNWTO)[10] : "*Tourism is a social, cultural and economic phenomenon which entails the movement of people to countries or places outside their usual environment for personal or business/professional purposes*".

As the term virtual implies that technology is used, the following terms for technology in tourism are examined: *E-Tourism*, *Digital Tourism*, *Smart Tourism* and *Virtual Tourism (VT)*. All these terms make use of Information and Communication Technologies (ICT's). ICT's encompass all technical tools and systems that support the collection and processing of data (Kundisch and Sackmann, 2012). Examples in tourism are booking and reservation systems as well as planning systems for hotels and touristic sights.

E-Tourism utilizes ICT's to support the interactivity among customers and tourism companies. Customers can easily access tourism related information and book or make reservations online, instead of asking travel agencies. Companies can use

[10] https://www.unwto.org/glossary-tourism-terms

ICT to distribute touristic offers worldwide and administrate bookings or requests efficiently (Buhalis et al., 2011).

Digital Tourism focuses on the tourists' experience before, during and after their trip. The tourist experience is improved by providing digital support. It can include recommendation systems to find suitable offers before traveling, mobile tour guide applications which are used on-site, or the capability to explore holiday photos after the journey. To offer this support, different tools and approaches are used. These include, for example, interactive maps, tourist assistants or personalized recommendations (Benyon et al., 2014) (Xu et al., 2020). Apart from these aspects, Benyon et al., 2014 includes the ability to immerse people in remote and inaccessible sites.

ICT's are also an important part in *Smart Tourism*, which includes, according to Gretzel et al., 2015, three components:
The first component are *Smart Destinations*. These own a modern infrastructure, which provides digital support to tourists during their travel. For instance, bicycles can be booked throughout the city by an mobile application or tourists get information to points of interest on their phone. These information are sent automatically when a tourist approaches a beacon[11].
The second component is *Smart Experience* which focuses on the tourists' experience. Thereby, ICT's provide services or products that meet the preferences of visitors and immerse them in activities within the destinations (Buhalis and Amaranggana, 2015). To enhance the experience, not only smart devices are used but also technologies such as Augmented Reality (AR) and Virtual Reality (VR) (Pai et al., 2020). AR is a visual technique which combines the view of the physical world with virtual 3D images or information. The virtual content superimposes the real view and it appears as they coexist in the same space. In this way, the user keeps the connection to the real world and sees additional virtual information (Chiappa et al., 2015). Compared to AR, VR immerses the user into a virtual world and isolates him from the real world completely. In order to make the user feel present in the virtual scene, he can interact and move in the virtual world. Various senses, especially sight and hearing, have to appeal to increase the feeling of presence (Yapp et al., 2019) (Guttentag, 2010).
The third and last component is *Smart Business* which creates and supports touristic resource planning to ensure a good tourist experience.

Xu et al., 2020 characterizes *Virtual Tourism (VT)* as a new tourism experience, which can be performed from home via the Internet. To simulate a real tourism

[11] A beacon is a wireless transmitter which sends signals to devices nearby

scene and make the user feel like being on-site, different technologies such as 360° views, VR or 3D objects are used. 360° views are recorded photos or videos, which represent a view in every direction, so that the user can move his point of view and sees the surrounding as he would look around him in real life. 3D objects are interactable items that can be moved and changed by the user.
IGI Global[12] defines VT as "*an ICT-based tool that uses digital images and sensory feedback to simulate tourist attractions available at remote destinations.*"
The websites *Traveltrend*[13] and *TourismTeacher*[14] describe VT as a technology that is used to simulate a travel destination, which is accessible 24/7, to enhance the user experience in various attractions. Mostly sequences of film and images are used, which can also include 3D objects and sensory experiences. The websites list the following use cases for VT: virtually trying out hotels or destinations before booking, exploring real places from home including places that are not accessible, visiting places that do not exist and traveling in time.

Based on the definitions above, in this thesis we define VT as follows:

1. VT describes the visit of a virtual replication, either of a real or invented world, remotely, without traveling.

2. VT provides additional virtual information on-site.
   These are blended into the view of the visitor and include reconstructions, avatars or additional multimedia content.

3. In all VT applications interactivity with the virtual elements must be available. This includes the movement in the virtual world and interaction with content, objects or avatars.

Commonly used technologies for VT applications are VR, AR, 3D Models and 360° views in the format of photos or videos.

According to this definition watching a movie or YouTube videos only showing sights or touristic destinations is not considered as VT. An example is the music video from *Beyonce*[15], which is recorded in the Louvre. YouTube videos with an integrated interactable 360° view, such as the video of the city *Stuttgart*[16], where the watcher can pan around while a guide is walking and talking, is considered as VT. Travel institutions that are providing information about travel arrangements and housing[17],

[12] https://www.igi-global.com/dictionary/virtual-tourism-and-its-potential-for-tourism-development-in-sub-saharan-africa/60244
[13] https://www.trvltrend.com/technology/virtual-tourism
[14] https://tourismteacher.com/virtual-tourism/#0-what-is-virtual-tourism
[15] https://www.youtube.com/watch?v=kbMqWXnpXcA
[16] https://www.youtube.com/watch?v=N6J2MIMWhbg
[17] https://www.travelessence.de/laendervortraege

as well as documentations[18] or reports[19] are not considered as VT. In chapter 2 examples for VT are listed and described.

Finally, we delimit our definition of VT from *E-Tourism*, *Digital Tourism* and *Smart Tourism*. As *E-Tourism* describes the digitalization of processes and facilitates planning and organization in the tourism sector, it is not part of VT because the visitor does not gain virtual experience.
But *Digital Tourism* and *Smart Tourism* include VT in their definition. *Digital Tourism* includes VT according to our definition, when the tourist is supported by technology during the tourist activity. For example, a virtual tour guide fits the criteria for VT and *Digital Tourism*. The technological support before and after the tourist activity, we do not consider as VT anymore.
Smart Tourism overlaps with VT in the components *Smart Destinations* and *Smart Experience*. Both, VT and *Smart Destinations*, provide additional information to the visitor via technology and both, VT and *Smart experience*, use different technologies to enhance the experience by immersing the visitor into activities within the destinations.

1.4 Thesis Structure

The definition of VT was already presented in in *Section* 1.3. This was derived from the definitions of AR, VR, virtual experience and other terms in the area of VT.

In *Chapter* 2, an overview of different VT applications is provided. Therefore, a literature review is conducted and the found applications are categorized in three groups: *Nature and Wildlife*, *Cities and Sights* and *Cultural Heritage*. In the end of this chapter, typical characteristics of the applications are described and the applications are assigned to them in form of a table. This is analyzed to find out how applications combine different options within and across the characteristics and for understanding the current trends and developments in VT.

In *Chapter* 3, we design a user study to evaluate the interaction and different navigation types of two VT applications. Our user study is based on the structure and questions from other user studies in the area of VT. After conducting our user study, the responses are analyzed by visualizing the data in Likert scales and inspecting the correlations between the applications and navigation options. Then, the findings are interpreted and discussed.

[18] https://www.featvre.com/de/home
[19] https://www.reisepassnummer.de/2019/doha.html

Based on the findings, improvements for the tested navigation types are worked out and are visualized in mockups for each navigation type in *Chapter* 4. Finally, general guidelines for implement successful navigation types, which enhance the users' interaction are provided.

Chapter 5 completes the thesis by summarizing the key findings and giving an outlook for possible future work.

All relevant data, which are used and elaborated in this thesis can be found in the Git repository[20]. Additionally, all links throughout the thesis were checked on the 12.01.2021 and are still accessible.

[20] https://github.com/ga65duy/Masterthesis-Virtual-Tourism-Applications

2 Overview of Virtual Tourism Applications and Approaches

Having defined the term Virtual Tourism (VT), the goal of this chapter is to provide an overview of VT applications by an exemplary but systematic literature review of existing applications and publications. Each application is described and categorized according to its use case and used technology. All characteristics and described applications are then summarized in a table, to examine which characteristics are used the most and how they are combined in order to understand what the current trends and developments in VT are.

2.1 Literature Review Methodology

There are several procedures how to carry out an literature review. To understand the used procedure in this thesis, it is described in the following.

Existing VT applications and literature can be found on websites or scientific publications. Websites mostly focus on applications for remote exploration whereas publications also showcase other use cases of virtual technology in tourism. Further, the publications usually explain their considerations and the implementation of their application. On most websites, no further implementation details are described.
To find websites containing VT applications, different key words were searched in *Google*. These are: *VT applications*, *Virtual traveling applications*, *Virtual Experience applications*, *AR in tourism*, *VR in tourism* and *3D models in tourism*. Each website among the search results was checked whether it is or describes a VT application. When search results report on several VT applications, i.e. newspaper articles or blogs about VT, all presented applications were analyzed.
Scientific publications were found by using *Google Scholar* with the same keyword as above. In addition, the following key words were searched: *VT*, *Digital tourism*, *Smart tourism*, *e-Tourism*, *Digital traveling*, *Virtual experience*, *Smart traveling* and other search terms that can be derived from the above. For each paper the abstract, description and conclusion was read to decide if it fits to the topic. Once it was

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classified as important, it was summarized and its reference papers were recursively inspected with the same approach.

2.2 Categories of Virtual Tourism

In the next sections, several examples of Virtual Tourism (VT) applications and approaches, which were found on websites or in academic papers are listed and explained in detail. These are only explanatory as the vast number of VT applications makes it infeasible to generate a complete list. The specific examples were chosen to indicate the variety of VT use cases and the technological approaches. The interested reader is advised to read Guttentag, 2010. They list further use cases of VT.

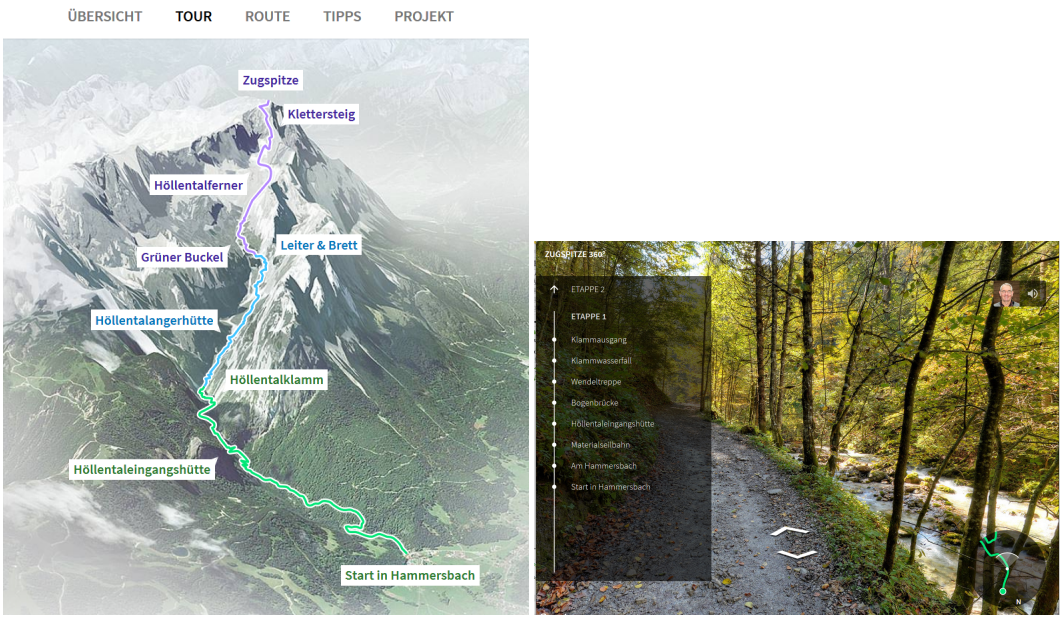
2.2.1 Nature and Wildlife

Wildlife and nature observation websites show that VT has a great potential to provide unique experiences. They use different technologies to replace traditional tours or amend them with additional perspectives and information.

Live streams allow to view animals in their natural habitat by cameras at remote locations at any time of the day. The cameras are specifically placed at hotspots and enable perspectives that are closer to nature than visiting a zoo or taking part in a safari (SZ, 2020). The website *Explore*[1] aggregates live streams across the world. Users can browse through different categories such as "African Wildlife" or "The bears of Alaska" and view the region they like. Other websites, such as the *Georgia Aquarium*[2] and *Wildearth*[3] show specific live streams of an aquarium in Georgia and live safaris in Africa at sunrise and sunset, respectively.

Another type of video technology used to transport wildlife and nature home are 360° videos. In these videos, the viewer can pan and turn the camera around while the video is playing. This adds interactivity and immersion to the videos and allows the viewer to see the full surroundings. 360° videos can be accessed and shared though different video portals such as *YouTube*. For example, the YouTube channel *Destination British Columbia*[4] has uploaded 360° videos that show different sights of

[1] https://explore.org/livecams
[2] https://www.georgiaaquarium.org/webcam/ocean-voyager
[3] https://wildearth.tv/safarilive
[4] https://www.youtube.com/channel/UCpS9F8iOFksvPuYByurAvBQ



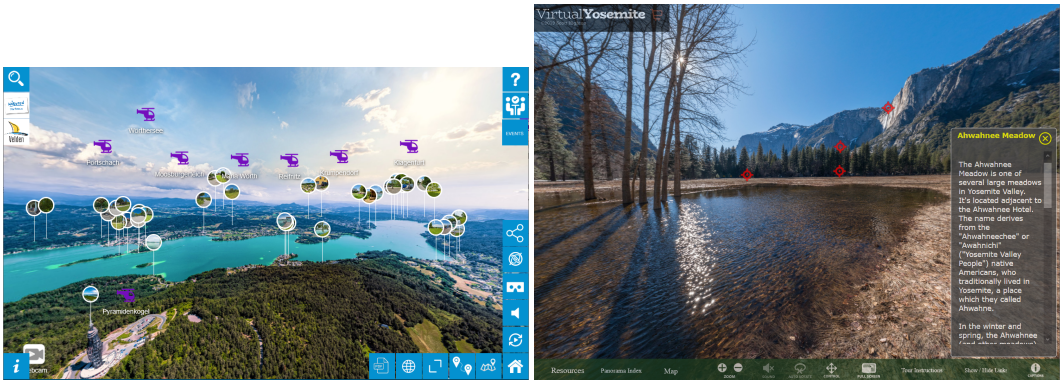
(a) Overview of the route. **(b)** Section of the path.

Fig. 2.1.: Screen shots from the application *Zugspitze360*. *Source: zugspitze360.com*

British Columbia. While playing the video, the user can change the point of view and listen to the guide.

In addition to 360° videos, websites also use 360° panoramic photographs. On *Zugspitze360*[5] users can hike from the valley to the summit of the *Zugspitze* by clicking through 360° photos as in *Google StreetView*. The initial start screen can be seen in *Figure* 2.1a. The user starts at a map of the *Zugspitze* that shows the route and places where the user can begin the journey. By clicking on one of the places, the user jumps into that location and can turn the camera to change the point of view or go back or ahead by clicking on arrows in the photo (*Figure* 2.1b). At certain spots, an audio guide tells stories about items that can be seen on the way up the summit. Based on 360° photographs, interactive maps can be built, that give the user an overview, and help the user to navigate to specific locations easily. These locations are marked with different icons. The website *Wörthersee*[6] marks the surrounding attractions of the *Wörthersee* as pins with a preview picture and helicopter icons, which show the attractions from the bird's eye view (*Figure* 2.2a). Clicking the icons, changes the location and in this case also the perspective. When the application is used on the phone it is possible to switch to VR mode. This can be used with or without VR glasses and enables to change the viewing direction with head movements.

[5] https://zugspitze360.com
[6] https://woerthersee.360-tour.at



(a) Wöerthersee
Source: woerthersee.360-tour.at

(b) Virtual Yosemite
Source: virtualyosemite.org/virtual-tour

Fig. 2.2.: Interactive Maps.

Similarly to the *Wörthersee* webpage, *Virtual Yosemite*[7] provides 360° photographs around the Yosemite national park. These photographs can be rotate automatically instead of changing the point of view manually by the user. To come from one location to an other, red target icons are used (*Figure* 2.2b) or the overview map can help to change between locations that are far apart. In addition, the user can listen to the sound of nature at each spot and receive further information, which are visualized in a text box.

Other websites such as *The Hidden Worlds of The National Parks*[8] use infinite 360° videos that include the sound of animals, nature and a mutable guide. At some spots additional YouTube videos can be played, which are marked with play icons. In the *Kenai Fjords* national park, the user takes the perspective of a surfer on a board. By clicking in the water, the user can navigate along the coast. At a certain spot the YouTube video "Watch the whale breach" can be played. The website also offers time lines where the scenery can be seen in different points of time. For example the viewer can compare the glaciers recession from 2004 until now.

The company *nDreams*[9] offers different VR experiences and games. This includes virtual simulations of beaches, alpine scenery, and northern lights that can be downloaded to any VR headset and used at home. The simulations are interactive so that the user can freely move in any direction, interact with items, and listen to sounds of nature. Apart from VR experiences usable at home the company offers other experiences at specific locations. For example, the user can put on a VR headset and walk onto a real and moving hot air balloon basket. While the user watches a flight

[7] https://www.virtualyosemite.org/virtual-tour
[8] https://artsandculture.withgoogle.com/en-us/national-parks-service/parks
[9] https://www.ndreams.com/titles/perfect-balloon-flight

over nature and alpine scenery, the basket is moving in concordance to provide a richer experience.

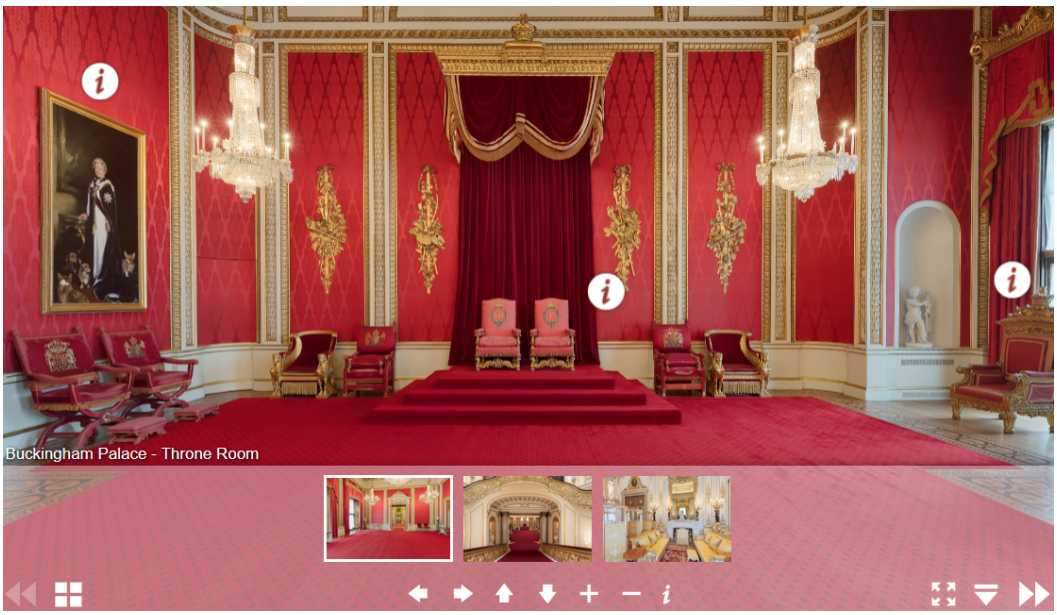


Fig. 2.3.: Buckingham palace. *Source: royal.uk/virtual-tours-buckingham-palace*

2.2.2 Cities and Sights

New York travel tour[10] provides a website, which is split in two parts: A three hour long *YouTube* video on the left side and a *Google Maps* view with marked locations on the right. The video shows a walk around New York City. By clicking on the markers in the map, the user jumps to the exact minute where the selected location is shown in the video. A top bar also allows searching for locations or sights in the city. These are shown as a drop-down list.

The website *Buckingham Palace*[11] offers a virtual tour through three rooms: the throne room, the white drawing room and the grand staircase. Each room is presented as a 360° photo. The bottom quarter of the image is overlayed with a transparent navigation bar. In the bar, users can navigate the camera in the image and jump to one of the other rooms. Within the pictures, clickable information icons are placed above exhibited icons that give a short explanation of the object. In addition, a link is provided that redirects to a web page with a more detailed description. (*Figure* 2.3)

[10] https://www.new-york-travel-tour.com/de/video-map/
[11] https://www.royal.uk/virtual-tours-buckingham-palace

Fig. 2.4.: Statue of Liberty: Website. *Source: nps.gov/hdp/exhibits/stli/stli_tour.html*

The same setup of 360° photos and the navigation bar is used on the website *The China guide*[12] to offer different tours of Chinese cities and sights. Only the tour which shows the *Great Wall* is for free. In order to access the other tours, a fee of 5€ has to be paid. The *Great Wall* tour is only taking place on top of the wall and the user can switch photos and walk down the wall by clicking arrow icons. In comparison with the *Buckingham Palace* application, it does not include any information for the user. The website of the *Catacombs of Paris*[13] only shows the information boards that can also be viewed on-site. These are included in the 360° photos and can be read when zooming in to the photo. The setup is the same as on the websites from *Buckingham palace* and *The China Guide*. When the user begins his virtual tour, he starts in the middle of the catacombs and not from the entrance.

The *Statue of Liberty*[14] website also uses 360° panoramic photographs taken from the *Liberty Island*. The photographs show the sights on the island from the interior and exterior perspective. For example, the statue can also be inspected from the inside. An overview map on the left side of the screen helps the user to change the perspective and navigate to the spots via clicking the location icons. The location can also be changed using the white star icons around the statue in the photograph. Above the map, a text box with facts about the place is displayed. On the right side, the categories "Interior", "Exterior" and "Museums" are listed. Here the user can choose exact locations, which are visualized with the location name and a photo. In the navigation bar on the bottom, the user can select additional features. The most

[12] https://www.thechinaguide.com/de/destination/great-wall-of-china
[13] https://www.catacombes.paris.fr/visite-virtuelle
[14] https://www.nps.gov/hdp/exhibits/stli/stli_tour.html

Fig. 2.5.: Statue of Liberty: Mobile Application.
Source: apps.apple.com/de/app/statue-of-liberty/id1457506359

.

interesting ones are that historic photos of the current location can be seen, and 3D Models of items can be viewed and edited by a model inspector. (*Figure* 2.4)

Not only the website shows the statue, but also the mobile application *Statue of Liberty*[15] that uses AR to present it in the user's surroundings. When the user starts the application, he has to scan his room with the mobile camera. Then the statue is projected into his room and he can walk around the statue and inspect it from different angles. In *Figure* 2.5 it is evident that different views of the statue are possible: The user can display the interior of the statue by clicking "X-ray", select a specific year with "Time Machine" or show the statue today. "Facts" provides the user with information about a certain part of a statue.

Apart from visiting cities or sights from home, virtual tourism offers are also provided at tourist destinations. In Paris, *FlyView*[16] gives the tourist the opportunity to virtually fly over Paris in a jetpack and experience the sights from a different perspective with the help of VR glasses and 360° films. For this experience, the provider uses real life footage, that was filmed by a drone.
Similarly, *TimeRide*[17] offers the tourists to get to know the Bavarian history in a flying peacock cart. The shown history reaches from the first human settlers to the fairytale king Ludwig II.
In Helsinki, tourists can get to know its scenery and popular sights at the *Flying cinema*[18]. To make the experience as real as possible, the user can feel wind, mist and snow, combined with motion.

[15] https://apps.apple.com/de/app/statue-of-liberty/id1457506359
[16] https://bit.ly/3sfrhkx
[17] https://timeride.de/muenchen
[18] https://flyingcinematour.com

2.2.3 Cultural Heritage

An important area for Virtual Tourism (VT) applications are museums, historic sights and other places conserving cultural heritage. Although, historic excavation sights are popular tourist destinations, the experiences for the tourists are limited: Historical buildings are not physically intact and it is hard to imagine how the people have lived. VT applications can enhance the historic experience by replicating the original structure or simulating interactions with the historic population. Other VT applications attempt to make museum artefacts and tours available remotely. This can help tourists to decide whether they should visit a museum and may also reduce the overall number of tourists. The latter VT applications are introduced in the fist part of this section. VT applications to enhance the tourist experience at touristic sights are presented in the second part. As stated in the beginning of the chapter, the following examples are not a complete overview of all applications. Gavalas et al., 2020 and (Noh et al., 2009) list further papers and application, that deal with VT in Cultural Heritage.

Museums

Virtual museums can be reconstructions of already existing museums, providing interactive 360° tours based on 360° photos or videos. These can be watched by the user from home:
The Petite Gallery[19] in the *Louvre* museum offers five virtual tours, that are called saison 1 to 5. These are 360° views in form of photos and videos. Each saison consists of rooms showing different artefacts. In saison 1 to 3, a small overview map in the left corner is used to change between the rooms. These are marked with red dots. The rooms can also be changed in the room with an arrow icon. Additionally, text and info icons are used to show the user more information. In saison 5 (saison 4 is not working anymore), rooms of the museum can be selected in a bar at the bottom, which shows the preview of all rooms. These can also be changed by clicking on the mouse icons in the current room. In the rooms, the user can receive more information on specific artefacts by clicking on the question mark icons. When clicking on a magnifying glass, the view is zoomed and centered on the chosen artefact.
The *Historical National Museum*[20] is narrating the history of modern Greece. Here, the virtual tour also includes icons showing additional information and the rooms

[19] https://petitegalerie.louvre.fr/visite-virtuelle
[20] http://www.nhmuseum.gr/multimedia/panoramas/hydra_en.html?s=pano70

can be changed in two different ways. First, an overview map in the corner allows to chose the rooms, which are marked with a red dot, and also the floor can be changed. Second, the rooms can be switched by clicking on the preview pictures of the rooms in the bar on the bottom.
A large provider of virtual museums using 360° views, video tours, presentations and audio content is *Google Arts & Culture*. In the year of 2015 the website offered over 450.000 artefacts. An example is the *Anne Frank house*[21], that allows the user to walk through the house the same way like in *Google Street View* and look at a presentation that includes pictures and information as text. The *Archaeological Museum of Thebs*[22] also provides a 360° tour through its galleries and additionally, a virtual tour video on Youtube, that walks the user through the museum. Apart from that, the website offers 3D models of exhibited items, that can be turned around and be edited by a model inspector. Furthermore, historic games were designed for children. These games demonstrate how people dressed in previous centuries, which writing systems were used, and how the antiquities are conserved.

To make the digital artefacts more interactive, museums create 3D models, that allow the user to move and inspect the items in detail: *The Virtual Museum of Iraq*[23], presented in the paper from Cultraro et al., 2007, is a website dedicated to the original museum of Iraq, that was destroyed during war in 2003. When the user first visits the site, he is presented an introductory video that shows how the museum in Baghdad was built. Afterwards, the user is shown a screen with a hall and eight doors. These doors are chronologically ordered and present a specific time period of Iraq‘s history. When clicking on one of the doors, a room opens that includes clickable historic 3D artefacts from that time period. Each artefact shows a description, a presentation from different perspectives and a short video placing the artefact in the historic period.
Noordin et al., 2015 describes the development of a 3D walkthrough desktop application, which walks the user through the Portuguese‘s ship *Flor de la mar*, in the *Malacca Maritime Museum*. The user can experience the ship from the outside by rotating the whole ship in several directions. When the user virtually walks in the ship, he can interact with 3D objects, that are placed in the ship. For that experience, AR and VR technologies are used to imagine the ship‘s design.
The *Museum of Pure Form* is presented by Loscos et al., 2004. It visualizes virtual 3D models of sculptures taken from the museums *Centro Gallego de Arte Contemporanea*, *Santiago de Compostela* in Spain, *The National Museum* in Sweden, *The Petrie Museum*

[21] https://www.annefrank.org/en/museum/web-and-digital/frank-family-home-360-degrees
[22] https://www.mthv.gr/en/virtual-museum
[23] http://www.virtualmuseumiraq.cnr.it/homeENG.htm

in UK, and the Museum of the *Opera del Duomo*in Italy. These sculptures can be virtually touched by the user utilizing a haptic device, which is placed on a special construction. This is attached on the arm of the user. When the sculpture is touched, the device provides haptic feedback on the by applying force on the fingers of the user.

Virtual museums are not only reconstructions of physical museums. It is possible, that they only exists in the virtual world:
The *Multimedia Museum of Anatomy* is described in the paper by Kiourexidou et al., 2019 and features anatomical maps, explanation of bones and the history of anatomy. It includes a virtual tour using 360° view and 3D models. During the tour a narrator helps the user to explore the museum.
The *Makronissos Digital Museum*[24] is an digital archive about the history of the Greek island Makronissos. The information is divided in different categories, such as time line, people or violence. All content is presented with photographs and explanatory text. The user can individually chose different categories and inform himself about the island.

Some museums offer supportive systems on-site. These use AR to guide the visitor through the real museum and provide virtual features such as reconstructions or historic avatars:
Keil et al., 2013 presents a tablet application to visualize sights in an interactive manner in the *Acropolis Museum*. The visitor gets a tablet and his position and behavior influences the narrative and the AR visualizations. When the user aligns his tablet to the item of interest, different AR visualizations are shown. These might be virtual reconstructions of an object, its placement in the current location, visual highlighting of details and recreation of mythological appearances. Additionally, the visitor can listen to stories that are made for two type of visitors: children and adults. These stories are told in first person, to bring the statues to life and in third person to address the user by an archaeologist.
Hammady et al., 2019 present a museum guidance system called *MuseumEye* to enhance customer experience and reduce the number of human tour guides. This guiding application was evaluated in the *Egyptian Museum* in Cairo. The guide is an AR system that projects interactive 3D artifacts, animated characters, sound effects and narrations via a Microsoft HoloLens in the museum. Both the visitor and the guide who is represented as an acient character (*Figure* 2.6) can interact with each other. The visitor interacts by hand gestures and air tapping to move between scenes and reveal items. The guide interacts with acoustic and visual clues that can

[24] https://www.makronissos.org

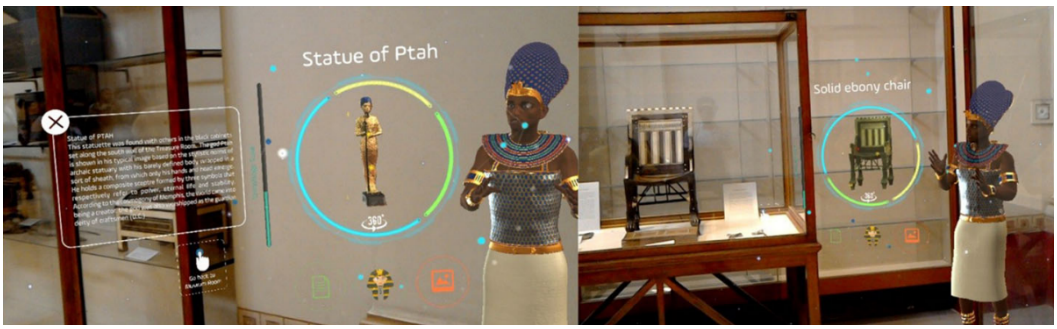


Fig. 2.6.: Antique's UI panel with the virtual guide. *Source: Hammady et al., 2019*.

be followed by the user. For deaf people, subtitles are provided. Furthermore, an interactive game can be played with other visitors. This way the visitors discover further information and social interaction with other players are enabled.

To imagine how an exhibition or museum can be designed both online and on site, applications can be used to create a virtual museum:
Mallia et al., 2019 present an AR mobile application for generating virtual museums. To create these museums the repositories Google Images, Wikimedia Commons and Europeana are used to enter the artist's name or the collection of works of arts. When the images and information are downloaded, the virtual museum is created by using 3D models and the artefacts are placed in virtual rooms (*Figure* 2.7). These have a fixed size of artefacts. After the virtual museum is created, the rooms are labeled and an overview list with artworks in the rooms is provided. This way the user can choose which rooms he wants to see.
The *Virtual Exhibition Builder* is an application that allows museums to set up virtual exhibitions. It is aimed at museum curators and non technical users. The users can visualize their artefacts as 3D models. In addition, they can set up dividing walls and navigation aids to complete the virtual exhibition (Gomes et al., 2011a) (Gomes et al., 2011b).

Sights

Cultural heritage also includes historical places and cities where applications can be used on-site to reconstruct buildings or to project photos and objects utilizing AR:
Archeoguide is an application that is used at the historic Olympia site in Greece. Before the user starts to use the application, he needs to answer several questions regarding his background, interests and available time. His answers are used to generate a personalized tour and offer a personal guide. When the user starts the

Fig. 2.7.: Virtual Museum including paintings mapped as textures onto pre-defined quads. *Source: Mallia et al., 2019*.

tour, his position and orientation is tracked to provide audio commentary and to show him 3D reconstructions of monuments and artifacts in form of a video or an image through an AR interface. The interface is running on a laptop to which a head mounted display is connected to visualize the augmented sights. On the Olympic grounds the sights are visualized when the user stands in front of them (*Figure 2.8*) and inside the Olympic stadium the user is able to watch the historic Greeks, who are animated with high realism and historical accuracy, competing in ancient Olympic games (Vlahakis et al., 2001) (Stricker et al., 2001).

A similar application is presented by Marto et al., 2019, who present the mobile prototype *DinofelisAR*. It uses AR to virtually reconstruct the Roman ruins of Conimbriga. The reconstructions and information are placed in front of the user based on his position and orientation.

The *Historical Tour Guide* by Haugstvedt and Krogstie, 2012 is also an AR mobile application. It shows historical photographs from specific decades over the present day scene in Trondheim. The user can access these photos by clicking on point of interests, choose a photo directly from a list or search on a map. In addition to the photo, a description of the motive, the source and the name of the photographer is shown.

(a) Original Image. **(b)** Augmented Image.

Fig. 2.8.: Archeoguide. *Source: Vlahakis et al., 2001*.

Sights can also be visited from home on different websites:
Ivkovic et al., 2018 present the *Bridges of Sarajevo*[25] that allows the user to explore the seven bridges of the city. In the first step, the bridges can be selected from a map. Once a bridge is selected, a 360° video is played. It includes stories, which are narrated from a guide. After visiting a bridge, a puzzle piece is collected. As soon as all bridges were visited the puzzle is complete and a final video from all bridges be watched.
Chalmers, 2008 describes how cultural heritage sites can be digitalized and virtually reconstructed in Bosnia and Herzegovina. The paper explains multiple methods and approaches, how to build 3D models (e.g. through video or photography). These approaches are applied on the website *Virtual Sarajevo*. It contains a virtual reconstruction created from panoramic photos, video walkthroughs of the streets, a virtual model of Baščaršija and stories about objects and events.
Maiellaro et al., 2019 developed the website *Balsignano modugno*[26]. This contains virtual tours, 3D models, 360° panoramas, news, videos, texts and sounds. The content of the archive shall increase the user's desire to visit the place in person.
Google Maps can show the user different places via *Google Street View* that uses the 360° format. For example, the *Colosseum*[27] can be inspected and walked through by clicking on the arrow symbols. Google can show the visitor the *Colosseum* in various years from 2010 until 2019.
The *museoTurino*[28] integrates *Google Maps* on its website and highlights locations in the surrounding of Turin. These locations can be filtered by different categories. For example: Culture or Architecture. When clicking on a location, an image and a short

[25] http://h.etf.unsa.ba/bridges-of-Sarajevo
[26] http://www.casaledibalsignano.it/index.php/tour-virtuali
[27] https://bit.ly/3nDtrXz
[28] http://www.museotorino.it/resources/navigator/index.html

description is shown. In the description, places, people, events or travel routes that are associated to the chosen location are explained. The website allows the user to choose a specific year. After selecting a year the map shows only locations, which were available at this time. It is also possible to move across the contemporary city, as Google Maps is integrated.

An other possibility to visit sights from home in a more immersive way is to use VR glasses:
You Visit [29] offers a tour of *Machu Picchu* by using 360° photographs of various spots. These spots can be selected by a preview picture on the left. While the photographs are rotating, a guide is telling stories and gives some facts about the spot. The information of the guide can also be displayed as text. When the application is run on a phone, a VR mode can be activated and the user can view the scenery with VR glasses.
Selmanovic et al., 2018 present an 360° video with a voice-over narration of the Old Bridge in Mostar. The stories are about the history, the architecture and reconstruction of the bridge. Apart from that, an interview with a famous cliff diver is provided, which gives information about the cliff diving tradition, the competition and type of jumps. When the user watched the videos and completed a quiz, that asks questions about the videos, he can virtually jump of the bridge.

2.3 Summary of presented Applications

In the previous sections, the VT applications were categorized according to their use cases in *Nature and Wildlife*, *Cities and Sights* and *Cultural Heritage*. For a quick overview, all presented applications are summarized in a table, which can be found in the Excel document[30]. In order to fit the table on an A4 paper, it is split in the three categories *Nature and Wildlife* (*Table* 2.1), *Cities and Sights* (*Table* 2.2) and *Cultural Heritage*, which is divided in museums (*Table* 2.3) and sights (*Table* 2.4). In the following sections, the characteristics of the applications are described and analyzed.

[29] https://www.youvisit.com/tour/machupicchu
[30] https://bit.ly/3q9SbrT

2.3.1 Characteristics

In the table, each application is categorized according to the five characteristics *technology*, *place*, *platform*, *interaction* and *additional features*. Each characteristic has multiple options and one application can offer more than one option. The characteristics and their options are defined as:

Technology

Webcam The user is able to watch a live video stream from a chosen location.

360° Photos The applications offers one or more 360° photos were the user can pan the view to all directions. This includes virtual tours where the user clicks from one 360° photo to another.

360° Videos While watching the video the user can pan the view to all directions. The user can not influence what is being shown just the perspective.

3D Objects The application includes rendered 3D objects.

Virtual Environment (VE) The user is seeing an entirely computer generated environment.

Place

On-site The user has to be on-site to use the application or its functionality (e.g. reconstructions).

Remote The user can use the application from anywhere.

Plattform

Website The application is available on a website.

Mobile App The application has to be installed on mobile devices. This includes AR and VR applications that are designed to be used on phones with a special case (e.g. Google Cardboard).

Installation The application requires the user to be at a specific location where the required environment is installed.

HMD AR The application is run on a dedicated AR Head mounted display (HMD) (e.g. Microsoft HoloLens) or a phone.

HMD VR The application is run on a dedicated VR HMD (e.g. HTC Vive) or a phone.

Interaction

Selectable Items The user can click on items to move around the scene or perform other actions on objects. For example, receive more information or view them from other perspectives.

Interactable Objects The user can inspect objects freely by moving or rotating them.

Head Movement The application can track the head movements of the user and translate them to the scene.

Hand Gestures The application can track the hand movements of the user and trigger events for specified gestures.

Haptic Feedback The user receives feedback from an attached haptic device. For example, a pressure on the fingers when interacting with objects.

Additional Features

Text The application offers additional textual information to objects of interest.

Audio The application offers audio output. For example, the sounds of the showed scene, music, or additional presented information is read to the user by a real or synthesized voice.

Games The application includes games or game elements such as tasks and quests to enhance the VT experience. Applications that offer separate games in addition to a VT experience are also considered here.

(Virtual) Guide The application includes a guide that the user can interact with or is responsible for narrating the story.

Digital Archive The application provides a multi-modal overview about a historic place or event. It contains documentation in several forms, such as textual information, historical photos, and videos, that are categorized.

Map The application provides an overview map where the user can see and select their position during the tour.

2.3.2 Analysis

This section analyzes how applications combine different options within and across the characteristics. As each application can fulfill multiple options of a characteristic, the sum can exceed 100%. Performing this analysis, the results enable us to understand the current trends and developments in VT. As stated before, the presented applications are a small selection of VT applications. Therefore, the results might not be necessarily representative for VT as a whole.

Inspecting the characteristic *technology*, it is evident, that most of the applications use 360° photos with 41% (16 of 39). These are followed by 3D models with 28% (11 of 39) and 360° videos with 21% (8 of 39). Webcams and virtual environment build the minority with 10% (4 of 39) each. The application *new-york-travel-tour.com* is the only one, which uses a video without 360° view (*Table* 2.2).

Most of the applications can be used remotely with 74% (29 of 39). These are 90% (26 of 29) websites and a mobile application and installation with 3% (1 of 29) each. 26% (10 of 39) can be only used on-site. These are mostly installations with 80% (8 of 10). One of this installation is a 4D cinema, called the *Flying Cinema* (*Table* 2.2), whereas the others are AR and VR applications. The remaining 20% (2 of 10) are mobile applications, where the user needs to be on scene to be able to see reconstructions or additional information, that are projected into the real environment by using AR.

In total, 18% (7 of 39) of all application use AR. Thereof, 86% (6 of 7) are used on-site and 14% (1 of 7) can be used from home. These 14% are represented by the *Statue of liberty app*, which projects the statue in any real environment in which the user is located (*Table* 2.2). Of the applications, that uses AR, 57% (4 of 7) also include 3D models.
A higher immersion is provided by VR, which is represented by 21% (8 of 39) of the applications. This can be an additional feature provided on a website with 38% (3 of 8), that can also be viewed with a HMD. In VR, virtual environments with 38% (3 of 8) or 3D models with 13% (1 of 8) can be embedded. Apart from that, real environments in the format of 360° photos with 50% (4 of 8) or videos with 25% (2 of 8), can be used, too. An application that combines the most technologies is the *Malacca Maritime Museum* (*Table* 2.3). Here VR, AR, 360° photos and 3D models were used.

An important component of VT applications is *interaction*. This includes *selectable items*, that are used to 67% (26 of 39) of the applications. They are utilized to reveal additional information in form of text with 46% (12 of 26), photos with 23% (6 of

26), or to switch between locations 73% (19 of 26). For the purpose of navigation, they are applied mainly on websites and more than one navigation type can be offered per website. Our applications count four navigation types as its maximum. Navigation is provided by maps with 35% (9 of 26) and items with 73% (19 of 26). These items can be visualized in different forms: Mostly lists with 53% (10 of 19) are used, that contain preview pictures with a description (26%) (5 of 19), only pictures (11%)(2 of 19) or only the name of the location (16%)(3 of 19).
Arrow icons are used to 47% (9 of 19). These can be fixed in a scene (37%)(7 of 19) or they appear anywhere the user moves the cursor (11%)(2 of 19). These are typical navigation icons of *Google Street View*.
Some applications use individual icons with 37% (7 of 19), that are located on a special place in the scene. These can be icons showing a target, mouse, pin or blinking star.

Another type of interaction are *interactable objects* with 18% (7 of 39) , which are mostly displayed as 3D models with 86% (6 of 7). The *Museum of Pure Form* even provides the possibility to feel the 3D object by giving the user haptic feedback through a device. The application *MuseumEye* (*Table* 2.3) uses avatars (14%) (1 of 7), that can interact with the user by narration and hand gestures and the other way round. The user also uses hand gestures (3%)(1 of 39) to move between scenes and reveal information. Other application use head movements (13%)(5 of 39), that are linked to AR or VR.

The characteristic *additional features* includes text, photos, maps, audio, virtual guides, digital archives and games. The first three were already treated in the section with *interaction* and *selectable items*. Furthermore, 49% (19 of 39) of the applications use audio, including sound of nature or music. 33% (13 of 39) use a guide, to narrate stories and guide the user through the scenery.
23% (9 of 39) provide a *digital archive* containing documentations in several forms, such as textual information, historical photos, and videos, which are categorized. Only 5% (2 of 39) embedded games in their application.

It can be concluded, that most of the considered applications are websites using 360° photos and 3D models. The websites are utilizing different kinds of navigation and provide the user with various information.

Application	Technology					Place			Plattform			
	Webcam	360° Photo	360° Video	3D Model	VE	On-site	Remote	Website	Mobile App	Installation	AR-HMD	VR-HMD
explore.org	X						X	X				
georgiaaquarium.org	X						X	X				
wildearth.tv	X						X	X				
Destination British Columbia: Youtube			X				X	X				
zugspitze360.com		X					X	X				
woerthersee.360-tour.at	X	X					X	X				X
virtualyosemite.org		X					X	X				
Google Arts & Culture: national-parks-service			X				X	X				
ndreams.com					X		X			X		X

Application	Interaction						Additonal Features					
	Selectable Items	Interactable Objects	Head Movement	Hand Gesture	Haptic Feedback	Text	Audio	Photos	Games	(Virtual) Guide	Digital Archive	Map
explore.org							X				X	
georgiaaquarium.org							X				X	
wildearth.tv							X			X		
Destination British Columbia: Youtube							X			X	X	
zugspitze360.com	X						X			X		
woerthersee.360-tour.at	X		X				X					X
virtualyosemite.org	X					X	X					X
Google Arts & Culture: national-parks-service	X						X			X		
ndreams.com			X				X					

Tab. 2.1.: Overview of the category Nature and Wildlife.

Application	Technology					Place			Plattform			
	Webcam	360° Photo	360° Video	3D Model	VE	On-site	Remote	Website	Mobile App	Installation	AR-HMD	VR-HMD
new-york-travel-tour.com			video				X	X				
royal.uk		X					X	X				
thechinaguide.com		X					X	X				X
catacombes.paris.fr		X					X	X				
nps.gov		X		X			X	X				
Statue of liberty app				X			X		X		X	
FlyView			X			X				X		X
Timeride					X	X				X		X
Flying cinema						X				4D		

Application	Interaction						Additonal Features					
	Selectable Items	Interactable Objects	Head Movement	Hand Gesture	Haptic Feedback	Text	Audio	Photos	Games	(Virtual) Guide	Digital Archive	Map
new-york-travel-tour.com	X						X					X
royal.uk	X					X					X	
thechinaguide.com	X		X							X		
catacombes.paris.fr	X											
nps.gov	X	X				X		X				X
Statue of liberty app	X	X				X	X					
FlyView			X				X					
Timeride							X			X		
Flying cinema							X					

Tab. 2.2.: Overview of the category Cities and Sights.

Application	Technology					Place			Plattform			
	Webcam	360° Photo	360° Video	3D Model	VE	On-site	Remote	Website	Mobile App	Installation	AR-HMD	VR-HMD
Petite Gallery		X	X				X	X				
Historical National Museum		X	X				X	X				
Anne Frank house		X					X	X				
Archaeological Museum of Thebs		X		X			X	X				
Virtual Museum of Iraq				X	X		X	X				
Malacca Maritime Museum		X		X		X				X	X	X
Museum of Pure Form				X		X				X		
Multimedia Museum of Anatomy		X		X			X	X				
Makronissos Digital Museum							X	X				
Keil et al., 2013						X			X		X	
MuseumEye						X				X	X	

Application	Interaction					Additonal Features						
	Selectable Items	Interactable Objects	Head Movement	Hand Gesture	Haptic Feedback	Text	Audio	Photos	Games	(Virtual) Guide	Digital Archive	Map
Petite Gallery	X					X						X
Historical National Museum	X					X						X
Anne Frank house	X											
Archaeological Museum of Thebs	X	X							X		X	
Virtual Museum of Iraq	X	X				X	X	X			X	
Malacca Maritime Museum	X	X										
Museum of Pure Form		X			X							
Multimedia Museum of Anatomy										X		
Makronissos Digital Museum						X		X			X	
Keil et al., 2013	X						X					
MuseumEye	X	X	X	X		X	X			X		

Tab. 2.3.: Overview of the category Cultural Heritage: Museums.

Application	Technology					Place			Plattform			
	Webcam	360° Photo	360° Video	3D Model	VE	On-site	Remote	Website	Mobile App	Installation	AR-HMD	VR-HMD
Archeoguide				X		X				X	X	
DinofelisAR				X		X				X	X	
Historical Tour Guide						X			X		X	
Bridges of Sarajevo			X				X	X				
Virtual Sarajevo				X			X	X				
Balsignano modugno		X		X			X	X				
Colosseum		X					X	X				
museoTurino							X	X				
Machu Picchu		X					X	X				X
Selmanovic et al., 2018			X		X		X					X

Application	Interaction					Additonal Features						
	Selectable Items	Interactable Objects	Head Movement	Hand Gesture	Haptic Feedback	Text	Audio	Photos	Games	(Virtual) Guide	Digital Archive	Map
Archeoguide	X									X		
DinofelisAR										X		
Historical Tour Guide	X					X		X				X
Bridges of Sarajevo	X									X		X
Virtual Sarajevo						X	X	X				
Balsignano modugno	X					X	X	X			X	
Colosseum	X											
museoTurino	X					X		X			X	X
Machu Picchu	X					X	X			X		
Selmanovic et al., 2018	X							X	X	X		

Tab. 2.4.: Overview of the category Cultural Heritage: Sights.

3 User Study on Virtual Tourism Applications

Interaction and navigation play an important role to enhance the virtual experience and to ensure the quality of Virtual Tourism (VT) applications. For this purpose, an user study is conducted to investigate how interaction elements for navigation should be designed, so that they are easy to use, easy to find, and can support different usage scenarios. For the examination, two VT applications with different navigation options are used. Before the user study is created, existing user studies are inspected, whereby special attention is paid to the structure and asked questions. After conducting the user study, the results are analyzed and the findings are discussed.

3.1 Overview of User Studies in Virtual Tourism

In the following, conducted studies and their results in the area of VT are summarized. Thereof, a short description about the surveyed application is given. The focus lies on the structure and in particular the asked questions, which are summed up in tables.

Noordin et al., 2015 compare two applications: The Flor de La Mar (FdLM) virtual tour and the FdLM 3D walkthrough. The FdLM virtual tour represents a virtual museum using a slide show with text information. The FdLM 3D walkthrough offers an virtual environment with 3D objects to discover the ship. For the evaluation they set up a questionnaire with ten questions for the previous tour and ten questions for the 3D walkthrough. These questions are split in the categories interface, virtual reality, interactivity and conclusion. The questions can be seen in *Table* 3.1. Each question was rated on a 5-point Likert scale, with a 1 indicating *strongly disagree* and a 5 indicating *strongly agree* based on the paper from Chertoff and Goldiez, 2010. The questionnaire was answered by 20 people, who have a degree in computer science or similar field of studies. Then the answers were evaluated by using the mean. The study concluded, that the FdLM 3D Walkthrough serves a better interface, interaction and virtual reality element compare to the existing FdLM virtual tour.

Category	Question
Interface	The virtual tour reflects a detail interior design of the FdLM Ship. The graphic used to represent FdLM is in high definition (HD). The slide shows give a good graphic representation of FdLM. The overall interfaces meet my expectation of how a virtual reality application should look like.
Virtual Reality	I am able to feel the presence of object inside the FdLM from the virtual museum. The virtual museum has a high quality of immersion. I am able to imagine how FdLM looks like in real life. The overall virtual reality elements meet my expectation of how a virtual application should look like.
Interactivity	I am able to interact well with the multimedia elements from the virtual museum. (ex: click through links and photos etc).
Conclusion	The existing virtual museum is in need of improvement especially in term of multimedia elements.

Tab. 3.1.: Questionnaire from Noordin et al., 2015.

Mallia et al., 2019 evaluated two mobile AR applications, that represent a 3D model of a church. The applications were built with different technologies: *ARCore* and *Project Tango*. The user study starts with exploring the 3D model of the church. Afterwards, 38 participants filled out a questionnaire with 21 questions, which is based on the 7-point Likert scale. It ranges from 1: *strongly disagree* to 7: *strongly agree*. The questions in *Table* 3.2 are categorized in personal skills, that reveal the familiarity of the participants with AR; comprehensibility and manipulability, that assesses how difficult or physical demanding it was to interact with the applications; enjoyment; and empirical, that reflects if an AR application can help to learn something about cultural heritage and if any differences between the two devices were noticed. The results of the study showed, that AR increases the enjoyment of learning in cultural heritage and improves the users' experience. Between the technologies *ARCore* and *Project Tango* no significant differences was found. The outcome of the study was summarized with box plots for the different question categories. Marto et al., 2019 tested which effect AR has on the user's cultural enrichment in cultural heritage and if this technology is accepted by the user. The user study started with tasks the user has to do with the application. Then, 90 participants answered the questions on a five point scale (strongly agree, agree, undecided, disagree, strongly disagree). The questionnaire surveyed on three areas: The satisfaction, ease of use and the desire to use. However, the actual questions were not published. The results were derived by the percentage of participants' agreement. The study found out that AR technology has great potential to engage people and is easy to use.

Category	Question
Personal skills	Have you experienced Augmented Reality (AR) applications before this test? How often do you use mobile devices?
Comprehensibility	I think that interacting with this application requires a lot of mental effort. I thought the amount of information displayed on screen was appropriate. I thought that the information displayed on screen was difficult to read. I felt that the information display was responding fast enough. I thought that the information displayed on screen was confusing. I thought the words and symbols on screen were easy to read. I felt that the display was flickering too much. I thought that the information displayed on screen was consistent.
Manipulability	I think that interacting with this AR application requires a lot of body muscle effort I felt that using the AR application was comfortable for my arms and hands. I found the device difficult to hold while operating the AR application. I felt that my arm or hand became tired after using the AR application. I think the AR application is easy to control. I felt that I was losing grip and dropping the device at some point. I think the operation of this AR application is simple and uncomplicated.
Enjoyment	I enjoyed using the AR application I found the AR application unpleasant. I found the AR application exciting. I found the AR application boring.
Empirical	By using the AR application, I learn more about heritage Rate the overall experience you had during the experiment? After using the AR application on two different devices, did you notice any significant differences?

Tab. 3.2.: Questionnaire from Mallia et al., 2019: Exploring Cultural Heritage Using Augmented Reality Through Google's Project Tango and ARCore

Argyriou et al., 2020 designed a study, that evaluates the effectiveness and user acceptance of the design techniques for 360° immersive video applications. In total 38 participants took place on a VR tour with a HMD. During the virtual tour the participants had to complete different tasks while the examiner took notes and the tour was recorded. Then, the participants answered questions about prior experiences, their individual data such as age and background and the questionnaire

with 20 questions (*Table* 3.3) based on a 5 point Likert scale. The questions were categorized in immersion, engagement, motion and navigation. The survey ended with a face to face interview about the overall experience. To interpret the answers, Analysis of variance (ANOVA) tests were used and the results were visualized with bar plots. The face to face interviews were summarized. The results of the study showed, that the virtual tour led to a high engagement and the immersion and motion techniques were satisfying. The navigation support was more efficient comparing with the absence.

Category	**Question**
Immersion	I did not feel distracted by any physical environment, sounds or people during the virtual tour. I feel like i actually visited the place. I felt like i lost track of time. The virtual tour felt real.
Engagement	I felt like i was totaly involved in the virtual environment experience. I would like to spend more time when visiting area, i would like to spend more time in the virtual tour. I wa focused throughout my experience. I really enjoyed the virtual tour. The virtual tour was interesting. The virtual tour was engaging.
Motion	I preferred the walking simulation than the teleportation. The teleportation was smooth and comfortable. I prefer to have no assistance to where to look and explore the environment at my own place. I was motivated to look in the direction that the vector was pointing or human was pointing.
Navigation	I prefer to have no assistance of where to look and explore the environment at my own place. I prefer to change my view motivated by the human actor to vectors. I was motivated to look in the directions the vectors were pointing at. I was motivated to look in the directions the human actor was looking.

Tab. 3.3.: Questionnaire from Argyriou et al., 2020.

Haugstvedt and Krogstie, 2012 presents a mobile AR application that shows historical photographs and information about a historical street. In a web survey with 200 people and a street survey with 42 people, he examines the acceptance of the application by applying an technology acceptance model (TAM). The questionnaire in *Table* 3.4 consists of five categories: Perceived usefulness, ease of use, enjoyment, behavioral intention and individual variables. The individual variables represent the user's age, gender, historical interest and if he uses a smart phone or a tablet. The questionnaire used a two point Likert scale for the perceived ease of use and the behavioral intention. A seven point Likert scale was used for perceived enjoyment. Before the survey was evaluated, hypothesis about the relationships between the four categories were made. These were proved by using the partial least squares regression. Additionally, for each category a statistical summary including the min/max value, mean, median and standard deviation were calculated. The results show, that the perceived usefulness and enjoyment has a direct impact on the intention to use mobile AR applications with historical information.

Category	**Question**
Usefulness	By using the app, I can more quickly and easily find historical pictures and information. By using the app, I learn more about history in Trondheim. By using the app, I can quickly find historical pictures and information from places nearby. By using the app, I am more likely to find historical pictures and information that interests me.
Ease of use	Interaction with the app is clear and understandable. Interaction with the app does not require a lot of mental effort. I find it easy to get the app to do what I want it to do.
Enjoyment	disgusting or enjoyable; dull or exciting, unpleasant or pleasant, boring or interesting
Intention to use	I intend to use the app on a smart-phone. I predict that I will use the app on a smart-phone. I intend to use the app on a tablet. I predict that I will use the app on a tablet. I intend to use the app in a city I visit as a tourist. I predict that I will use the app in a city I visit as a tourist. I intend to use the app in my hometown. I predict that I will use the app in my hometown.

Tab. 3.4.: Questionnaire from Haugstvedt and Krogstie, 2012.

Park et al., 2018 analyzed the effects of a VR tour and a video based VR tour on attitude and behavior change relative to a tourism destination. For this purpose 30 students answered a question catalog (*Table* 3.5) on a five point Likert scale with following categories: VR presence, VR enjoyment, post VR attitude change and visit intention. Additionally, general data of the participants such as gender, age, education and prior experience with VR were collected. For the data analysis of the categories *SPSS 17.0* for Windows was used. The general characteristics were analyzed by frequency analysis. To identify effects of video-based VR experience within a group, a paired t-test was used. Additionally, to determine the correlation between the elements in the questionnaire, they used Pearson correlation analysis. The survey proved, that video based virtual experience is more effective in improving visitors' positive attitude and visit intention than the basic virtual tour.

Category	**Question**
Presence	I felt like I was actually there in the VR environment. It seemed as though I actually took part in the action of the VR (sightseeing). It was as though my true location had shifted into the VR environment. I felt as though I was physically present in the VR environment. The objects in VR gave me the feeling that I could do things with them. I had the impression that I could be active in the VR environment. I felt such as I could move around among the objects in VR. It seemed to me that I could do whatever I wanted in the VR environment.
Enjoyment	It was fun. It was pleasant. It was enjoyable. It was exciting.
Attitude change	After the VR experience, my liking toward [Destination] is. After the VR experience, my preference toward [Destination] is. After the VR experience, my interest in visiting [Destination] is.
Visit intention	I expect to visit [Destination] in the future. It is likely that I visit [Destination] in the future. I can see myself visiting [Destination] in the future.

Tab. 3.5.: Questionnaire from Park et al., 2018.

Boukhris et al., 2017 compare the 3D texture model with a series of 360° pictures from the *Grotte de Commarque*. Both techniques are used with a HMD. The focus of the survey is on the sense of presence during the visit. 23 participants filled out the same questionnaire twice. Once, after using the 3D texture model and once, after using the 360° pictures. The questionnaire contains the full *IPQ* questionnaire[1] and questions regarding perceived fun, navigation easiness and learning. In *Table* 3.6 the actual questions are listed. Apart from theses questions, general information about the user were collected. These include the age, gender and level of familiarity with AR. To evaluate the different categories ANOVA was used and the results were visualized in a bar plot. The analysis of the data showed, that the 3D texture model conveys more fun and presence and no significant differences in the navigation were found.

Category	**Question**
IPQ	In the computer generated world I had a sense of being there. Somehow I felt that the virtual world surrounded me. I felt like I was just perceiving pictures. I did not feel present in the virtual space. I had a sense of acting in the virtual space, rather than operating something from outside. I felt present in the virtual space. How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)? I was not aware of my real environment. I still paid attention to the real environment. I was completely captivated by the virtual world. How real did the virtual world seem to you? How much did your experience in the virtual environment seem consistent with your real world experience? How real did the virtual world seem to you? The virtual world seemed more realistic than the real world.
Fun	I had fun during the virtual visit of the cave. This virtual visit is amusing. I would like to continue to visit this cave in the virtual environment.
Navigation	It was easy to navigate in the cave. My movements in the cave were natural.
Learning	If the pedagogical content is developed, (stories, explanatory videos) this simulation can be a good pedagogical experience. I think i have a good mental representation of the spatial organization of the cave.

Tab. 3.6.: Questionnaire from Boukhris et al., 2017.

[1] http://www.igroup.org/pq/ipq/download.php

3.2 User Study Design

The following section describes the structure of our user study and the chosen applications. The focus of the survey lies on the interaction and different navigation types, which are explained when introducing the single applications. As some statements in the questionnaire are adopted or inspired by the findings from *Section* 3.1, these have a reference, which is written in brackets. These statements were selected, because they are useful to analyze the user' opinion regarding the interaction in the applications and their navigation types. The original user study can be viewed in the *Appendix* A or in the Git repository[2].

The main part of our study considers the interaction and navigation types of two applications. To compare different types of navigations the web pages showing the *Statue of Liberty*[3] and *Zugspitze360*[4] were chosen. These applications were chosen, as each provides multiple possibilities to navigate and they are different across the board. Additionally, the applications integrate different information formats like text, photos or an audio guide. The *Statue of Liberty* applications provides three different navigation types:

- A navigation bar includes pictures and text, where the user can choose from interior, exterior or museums.
- An interactive map allows to switch locations by selecting one of the clickable location icons in the map.
- Blinking icons appear in the current scene and move the user to the next place, which is located in the icons direction.

Zugspitze360 provides two different navigation options:

- A list with textual description, which is expanded when the user hovers over a line with points, that symbolize the path. This way, the user can choose a station he wants to go to.
- Arrows, pointing forth and back are placed in the current scenes. These allow the user to move only from one place to the next one without the possibility to skip a location.

[2] https://bit.ly/2XyVBZh
[3] https://www.nps.gov/hdp/exhibits/stli/stli_tour.html
[4] https://zugspitze360.com

When the participant starts the survey, he is asked first for his gender, age and if he has used VT applications before. The last question was inspired by Mallia et al., 2019 from the category *personal skills* in *Table* 3.2.

Second, he opens the applications and gets familiar with their functionalities and navigation types. Then, the following statements are made to evaluate the application as a whole. These are answered on a five point Likert scale throughout the whole user study.

- The interaction with the app is clear and understandable.
  (Haugstvedt and Krogstie, 2012 from category *ease of use* in *Table* 3.4)
- The amount of information displayed on screen was appropriate.
  (Mallia et al., 2019 from category *comprehensibility* in *Table* 3.2)
- The information displayed on screen is confusing.
  (Mallia et al., 2019 from category *comprehensibility Table* 3.2)

Third, the user is asked to answer which navigation type is the first he discovered and for each navigation type, which was shown as a screen shot, he answers the following statements:

- I found the navigation type quickly.
  (Haugstvedt and Krogstie, 2012 from category *usefulness* in *Table* 3.4)
- It was easy to navigate to a place.
  (Boukhris et al., 2017 from category *navigation* in *Table* 3.6)
- The navigation type is useful to switch places.
- I kept the orientation when switching the places.

In the end, the participant has to choose a navigation type he liked the most and the least from all options. *None* could be ticked either. This question leans on Argyriou et al., 2020 from the category *motion* in *Table* 3.3. Afterwards, he had to justify why he liked it the most/the least and could choose between the following statements:

- I could (not) quickly find a certain place.
- I could (not) quickly discover all offered places.
- I could (not) imagine to walk through the places.
- It was (not) the most intuitive.
- Other: (The participant can give his own answer)

The last question is an open question, which asks for suggestions to improve the navigation.

3.3 Methodology

To analyze the interaction and the navigation types in the two applications, a quantitative survey with 118 participants was conducted. The raw data and all R scripts used for the evaluation can be found on the Git repository[5].
The survey was shared online in several Facebook groups and on Pollpool[6]. Additionally, the survey was sent to fellow students and friends. The survey was online for 24 days from 20.October 2020 to 13.November 2020.

Overall, we received high quality responses, solely, the responses of 1 participant had to be discarded. This participant was not able to find any of the studied navigation types, presumably because he completed the survey on a mobile device. During the preparation of the study, we found that the interaction and navigation types differ significantly between PCs and mobile devices. Therefore, we requested that the participants use their PC to conduct the study. Based on the feedback and responses we concluded that only one participant misread the instructions and thus we received 117 valid responses.

The survey contained single and multiple choice questions on nominal and ordinal scales as well as open text questions. Every kind of question is evaluated and presented according to its type and scale. The nominal personal attributes *gender*, *age*, *previous VT experience* as well as the nominal application specific questions which navigation was first discovered and liked the most or least are shown in percent.

The open questions, why a navigation type is liked the most or least and suggestions for improving the navigation, are categorized based on their content. The prevalence of each category is shown in percent.

The ordinal scales, representing the 5-point Likert scale, are visualized in a centered stacked bar chart. This shows the distribution for each statement in one bar. Each bar is divided into segments, which are colored according to the different response categories. The color ordering is the same throughout all bars and the neutral position, in our case represented by 3, is used to align the answers showing the

[5] https://bit.ly/3iag9QZ
[6] https://www.poll-pool.com/?locale=en

agreement or disagreement in the bar. The length of the colored segments is proportional to the number of respondents, who chose a specific category. Additionally, the percentage is written on the colored segments. (Petrillo et al., 2011)

For the evaluation, we analyze the results of the ordinal statements from the application and navigation perspective. Each perspective contains two views: The view within an application or navigation type and the view based on the single statements to compare the applications or navigation types with each other.
The application perspective, within an application view, includes the statements *clear information*, *appropriate information*, *confusing information* and *right number of navigations* on the vertical axis and is summarized in one chart. In all plots, the horizontal axis shows the rating from 1 to 5. Thereof, 1 represents strongly disagree and 5 strongly agree. *Figure* 3.2a shows this for the *Statue of Liberty* and *Zugspitze360*.
Within the single statement view, for the application perspective, each question of the *Statue of Liberty* is compared with *Zugspitze360*. The vertical axis is labeled with the name of the application and the heading shows the statement, which is analyzed in *Figure* 3.2b. The evaluation is described in *Section* 3.4.1.
In the navigation perspective, we analyze all answers for a specific navigation type. Each navigation type is shown as one stacked bar plot and the vertical axis is labeled with *found navigation quickly*,*easy navigation*, *useful navigation* and *kept orientation*. *Figure* 3.3a shows the surveyed navigation options i.e. the navigation bar, map, blinking icon, arrows and list.
In the single statement view, the vertical axis is labeled with the navigation options and the heading shows the statement in *Figure* 3.3b. The evaluation of this perspective is done in *Section* 3.4.2.

To draw conclusions, if the ordinal data within an application have any connection, Spearman's rank order correlation is calculated for every combination. The correlation coefficient rho measures the correlation between two variables X and Y and can assume values between -1 and 1. 1 represents a total positive linear correlation, 0 no correlation and -1 a total negative correlation (Adhianto et al., 2010). Cohen, 1988 defines the correlation coefficient beginning at 0.1 as weak, at 0.3 as moderate and at 0.5 as strong. After we calculated all correlations coefficients for our data, we analyzed all correlations and documented the most interesting findings in *Section* 3.4.3.

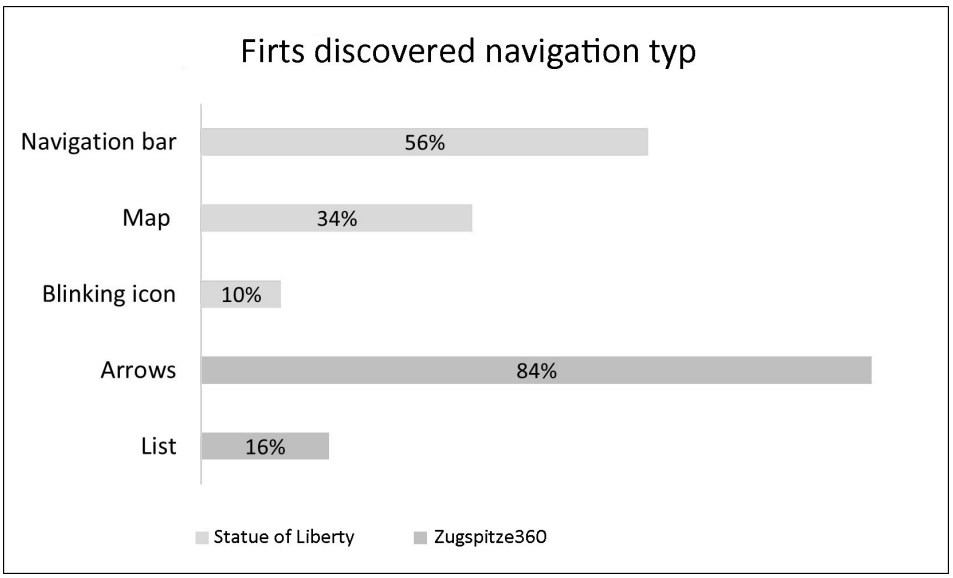


Fig. 3.1.: First discovered navigation type for *Statue of Liberty* and *Zugspitze360*.

3.4 Evaluation

From 117 respondents, 57% were female and 43% were male. 8% were in the age between 0-20, 62% between 21-30, 17% between 31-41 and 13% 40 or above. 70% of the participants are using VT applications for the first time in this survey, whereas 30% already used VT before.

3.4.1 Application Perspective

First discovered Navigation Type

The participants were asked which navigation type was the first one they discovered for the *Statue of Liberty* application and *Zugspitze360*. In *Figure* 3.1 the responses are visualized in a bar chart. This shows, that in the *Statue of Liberty* the navigation bar was discovered first with 56%, followed by map with 34% and the blinking icon with 10%. In *Zugspitze360*, the arrows were discovered first by 84% and list by 18%.

Within the Application View

Figure 3.2a shows the general statements about the applications *Statue of Liberty* and *Zugspitze360* in two centered stacked bar charts. These describe how the interaction

was rated, whether the information is appropriate or confusing and whether the application has the right number of navigation options.

The first bar of the *Statue of Liberty* application, indicates, that most of the survey participants rated the interaction with a 4 or 5 with 43% and 44%. This implies that the interaction for them is clear and understandable. 11% have a neutral position about this statement and only 2% disagree that the interaction is clear and rated with a 2.
Whether the amount of displayed information is appropriate, is scattered between the values 5 and 2. Most of the participants (50%) rated with a neutral position, which in this case means that the amount of information was just right. 46% think that too much information is on screen by ticking the answer 4 or 5 and only 4% think that to little information is provided by ticking the answer 2.
The bar showing the statement about the right number of navigation types has a similar constellation of answers as the bar showing the appropriate information. Most of the participants (48%) rated with a 3. This indicates in this case that the number of navigation options is just right. 4% judge it with 1 and 9% with 2, which means that not enough options are provided and the remaining 39% answer with a 4 (24%) and 5 (15%), which represents that there are too much navigation options.
On the statement whether the displayed information is confusing, the ratings are scattered over all possibilities from 1 to 5. 32% each disagree or strongly disagree and 20% hold a neutral position. Only 12% or 4% rated with agreement or strong agreement.

The interaction in *Zugspitze360* is judged with a 4 by 32% and a 5 by 48%. Only 11% have a neutral position and 9% answered with a 2. Nobody rated with a 1.
Whether an appropriate amount of information is displayed is confirmed by 38% which is represented by the rating of 3. 23% and 24% think that too much information is provided and only 12% and 3% think that too little information is provided in the application.
The statement about confusing information is mostly denied by 38% rating with 1 and 32% rating with 2. 13% are neutral about this statement and 13% confirmed it with a 4 and 4% with 5.
35% judge the number of navigation options with 3, which indicates, that the application uses the right number of navigation options. 10% think that there are not enough options and 32% and 23% think that there are to many possibilities to navigate.

Statement View

Figure 3.2b visualizes each statement for the applications in a single plot. This makes it easy to compare the two applications according to the statement.

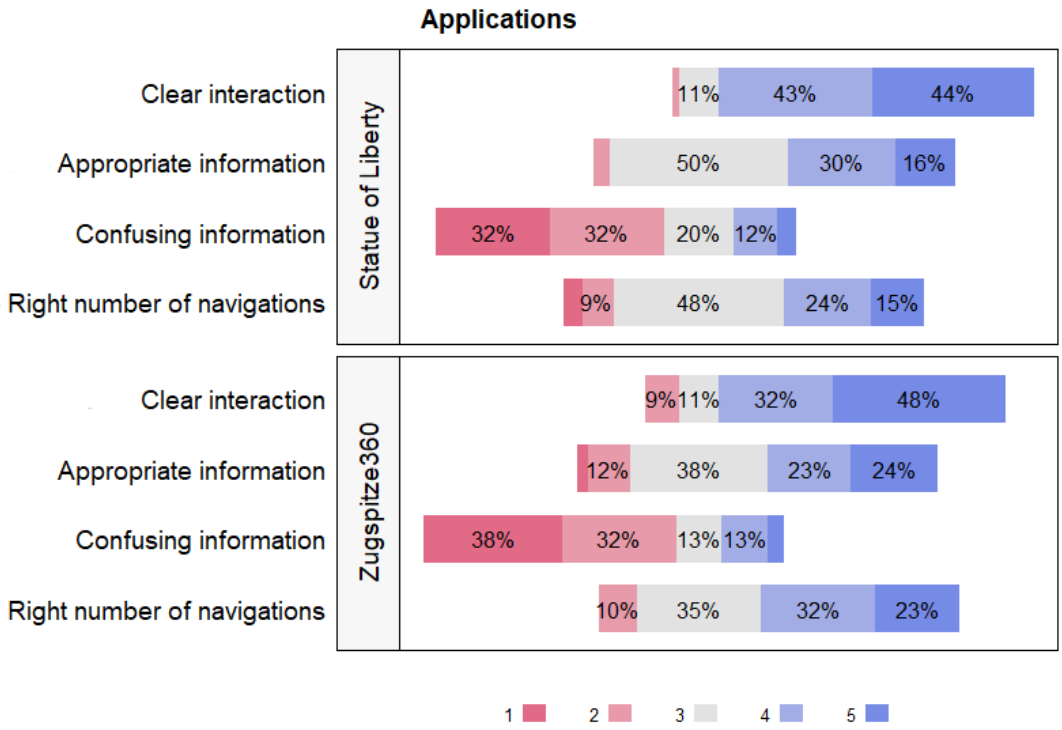
Whether the interaction is clear and understandable is rated by 11 % with a 3 for both applications. The *Statue of Liberty* has more responses for 4 and 5 with 87%, whereas *Zugspitze360* has 80%. 2% rated with a 2 at *Statue of Liberty* and 9% at *Zugspitze360*.

At *Statue of Liberty* it is noticeable, that 50% think that the amount of displayed information is appropriate. Only 4% answered that there is little information displayed. 30% and 16% think that there is much or too much information on screen.
Compared to *Zugspitze360* 38% judge the amount as appropriate. 3% and 12% answered that there is too little or little information provided. 23% and 24% judge the amount of information as much or too much.

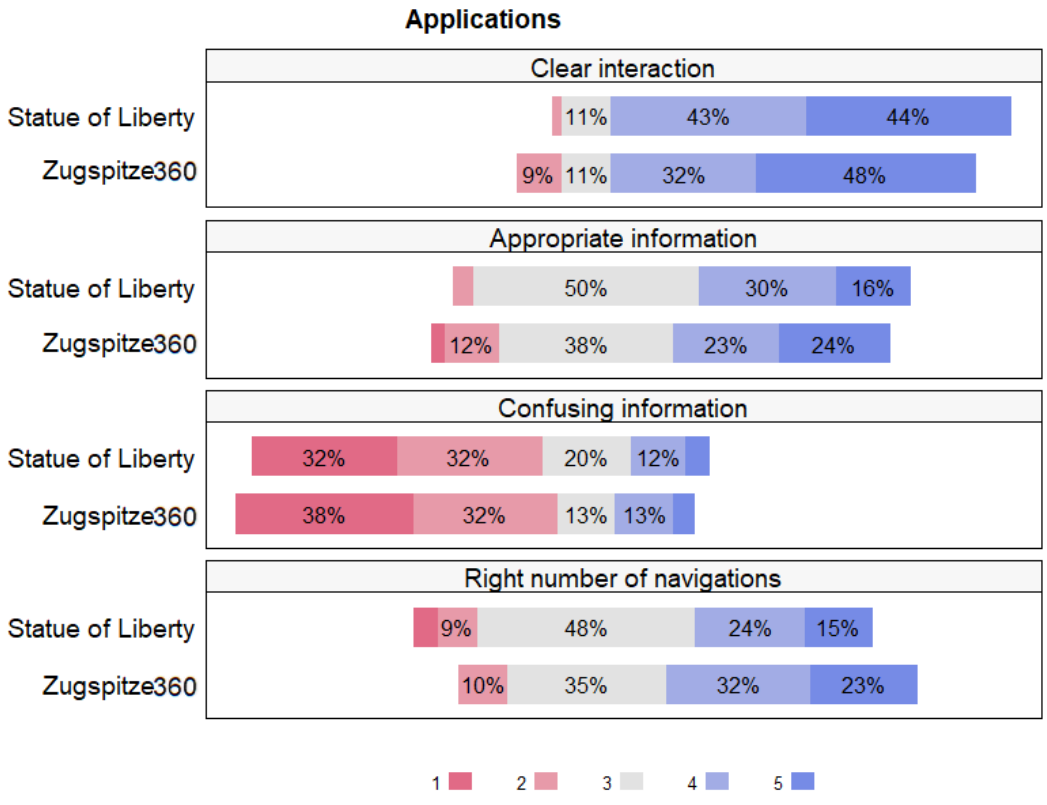
The responses whether the information on screen is confusing have in both cases the tendency to refuse. The *Statue of liberty* was rated with a 1 and 2 by 32% each. 20% answered with a 3. 12% and 4% rated by 4 and 5.
The statement for *Zugspitze360* was judged with 38% and 32% with a 1 and 2. 13% have a neutral position, whereas 13% and 4% answered with 4 and 5.

Whether the number of navigation options is right for *Statue of Liberty* was mostly confirmed by 48% answering with 3. 4% and 9% judge the number as too little or little, whereas 24% and 15% think that much or too much options were provided.
The participants mostly think that the number of options for *Zugspizte360* was much or too much by 32% and 23%. 10% answered with too little options and 35% are satisfied with the number of options.

In summary, the users are mostly satisfied with the interaction in both applications with more than 80%. The distribution of the responses, whether the information is confusing (with about 60% declining the statement for both) and the right number of navigation types (with 45% agreeing with the statement), is for both applications similar.



(a)



(b)

Fig. 3.2.: Likert scale based on the application view.

3.4.2 Navigation View

Within the Application View

In this section, the navigation types navigation bar, map, blinking icon, arrows and list are evaluated based on the navigation perspective in *Figure* 3.3a.

The navigation bar, map and blinking icon belong to the *Statue of Liberty* application, whereas arrows and list belong to *Zugspitze360*. Each navigation type is rated according the statements whether the navigation was found quickly, the navigation was easy or useful and whether the user kept orientation while switching places.

The navigation bar was found quickly is rated by 38% with a 4 and 33% with a 5. 17% are neutral and took 3 as answer. Only 9% rated with a 2 and 3% with a 1.
The responses for the easiness of the navigation slightly differs from the statement before. Here, the responses tend to strongly agree with 40% and the neutral and declining position is held by 13% and 9%.
Whether the navigation bar is useful for switching places is strongly confirmed by 47% and confirmed by 32%. Only 4% decline the statement and 17% keep a neutral position.
The orientation could be kept by 33% who agree and 20% who strongly agree. 32% judge the orientation as neutral, whereas 5% and 10% rated with a 1 and 2.

Whether the map could be found quickly was judged by 33% and 43% with a 4 and 5. 12% answered with a 3. 4% and 8% rated with a 1 and 2.
Most of the participants (30% and 45%) judged map as an navigation type, which is easy to use by answering with agree or strongly agree. 3% and 5% declined the statement with 1 and 2, whereas 12% chose a neutral position.
Whether map is useful for switching places is confirmed by 26% and 48% by answering with 4 and 5. Only 1% and 4% decline this by rating with 1 and 2, whereas 21% rate with a 3.
The statement, whether the orientation could be kept while switching places was confirmed by 32% and 38% by answering 4 and 5. It was declined by 1% and 8% rating with 1 and 2, whereas 21% were undecided by answering with 3.

The blinking icon could be found quickly by 25% and 27% who rated with a 4 and 5. 9% and 19% rated with 1 and 2, whereas 21% are undecided.
The statement, whether it is easy to switch places with the blinking icon, was mostly answered with 4 and 5 by 32% and 26%. 3% and 13% rated with 1 and 2 and 26% have a neutral position.
For 28% and 26% the blinking icon was useful for switching places and for 4% and

17% not. 25% rated with a 3.
Keeping the orientation while changing places was judged by 25% and 28% with agree and strongly agree. Whereas 14% and 7% strongly disagreed or disagreed. 26% were undecided.

The navigation type arrow from *Zugspitze360* was judged to be found quickly by 31% with a 4 and by 32% with a 5. 6% and 11% decline the statement with a 1 and 2, whereas 21% are undecided.
Most of the participants (39% and 50%) agree that the arrows are an easy type of navigation by rating with 4 and 5. Only 1% and 3% rated with a 1 and 2, whereas 8% take a neutral position.
The answers for the statement whether arrows are an useful navigation, have are similar range as the statement before. Here, also 39% rated with a 4 and 44% with a 5. 10% judged the easiness with a 3 and in total 6% declined the statement.
Whether the orientation could be kept was rated by 32% and 28% with agree and strongly agree, whereas 4% and 14% answered with strongly disagree and disagree. 22% are neutral about it.

List has the highest agreement whether it was found quickly, when compared with the other navigation types with 20% and 68% answering with 4 and 5. Only 3% disagree and 9% are undecided.
The easiness of the navigation type is rated by 28% and 46% with a 4 and 5. 2% and 9% answered with 1 and 2, whereas 15% ticked 3.
For 24% and 42%, who answered with 4 and 5, the list is an useful navigation type. 3% and 15% think it is not useful by rating with 1 and 2. 16% answered with a 3.
Keeping the orientation while switching places was judged by 38% for both 4 and 5. 8% rated with a 2, whereas 16% answered with a 3.

Statement View

In *Figure* 3.3b, the navigations are directly compared to each other based on every statement. Each statement is represented as a centered stacked bar chart. Since the percentages have already been explicitly stated in the section above, we now look closer on the observations that can be seen from the graphs for the navigation types.

It is evident, that the statement whether the navigation was found quickly is mostly judged positive with a 5 for list compared to the other navigation options and only 3% disagreed with a 2. The navigation bar and map have been also judged mostly positive with about 70% each and the answers containing 1 and 2 are about 12%.

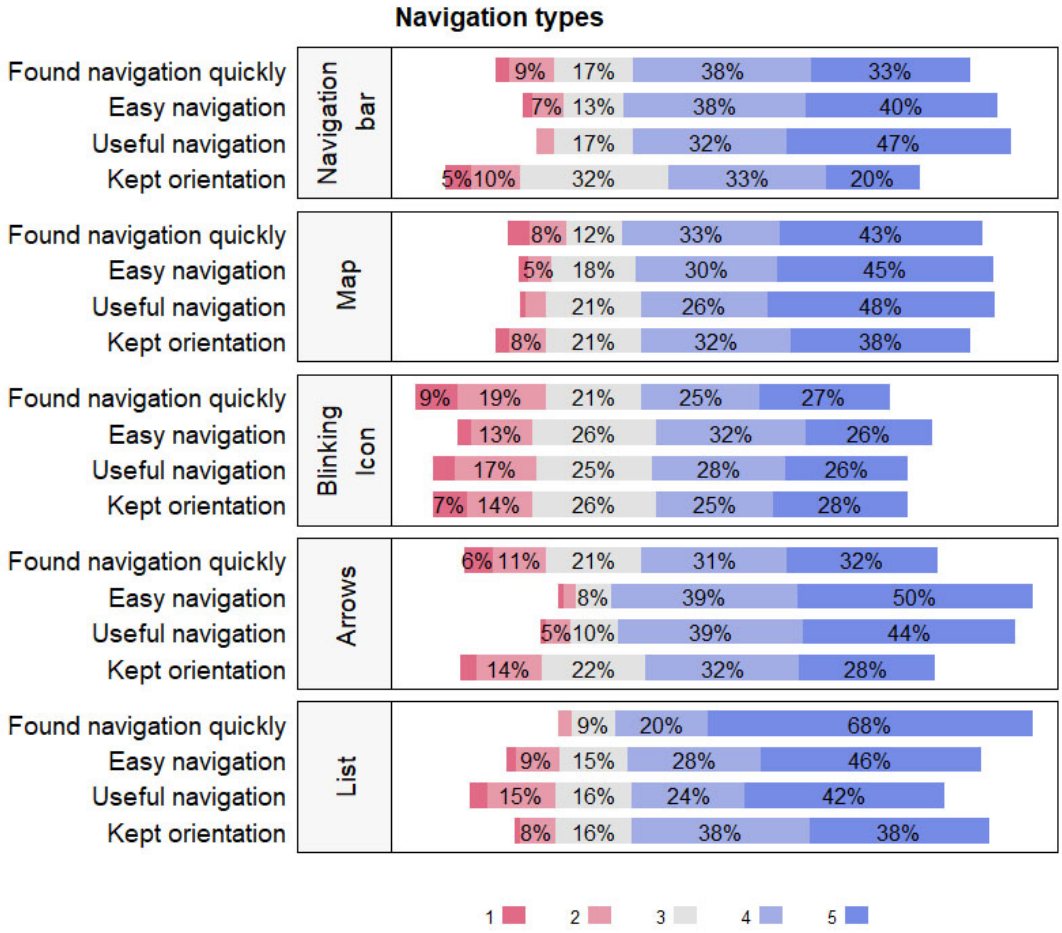
The blinking icon and arrows are compared to the other navigations positioned further on the left side, which means that more participants decline that these navigations can be found quickly.

Whether the navigations are easy to use, is for the navigation bar, map and list judged mostly positive with more than 70% rating with a 4 and 5. And only about 10% rated with 1 and 2. In comparison, arrows are closer to the right, which shows, that about 90% agree that this type is easy to use. This is confirmed by the low amount of responses for 1 and 2 with 3%. The blinking icon has the highest number of responses containing 1 and 2 with 16% and a 3 with 26%. Compared to the other navigations the blinking icon was not found as easy.

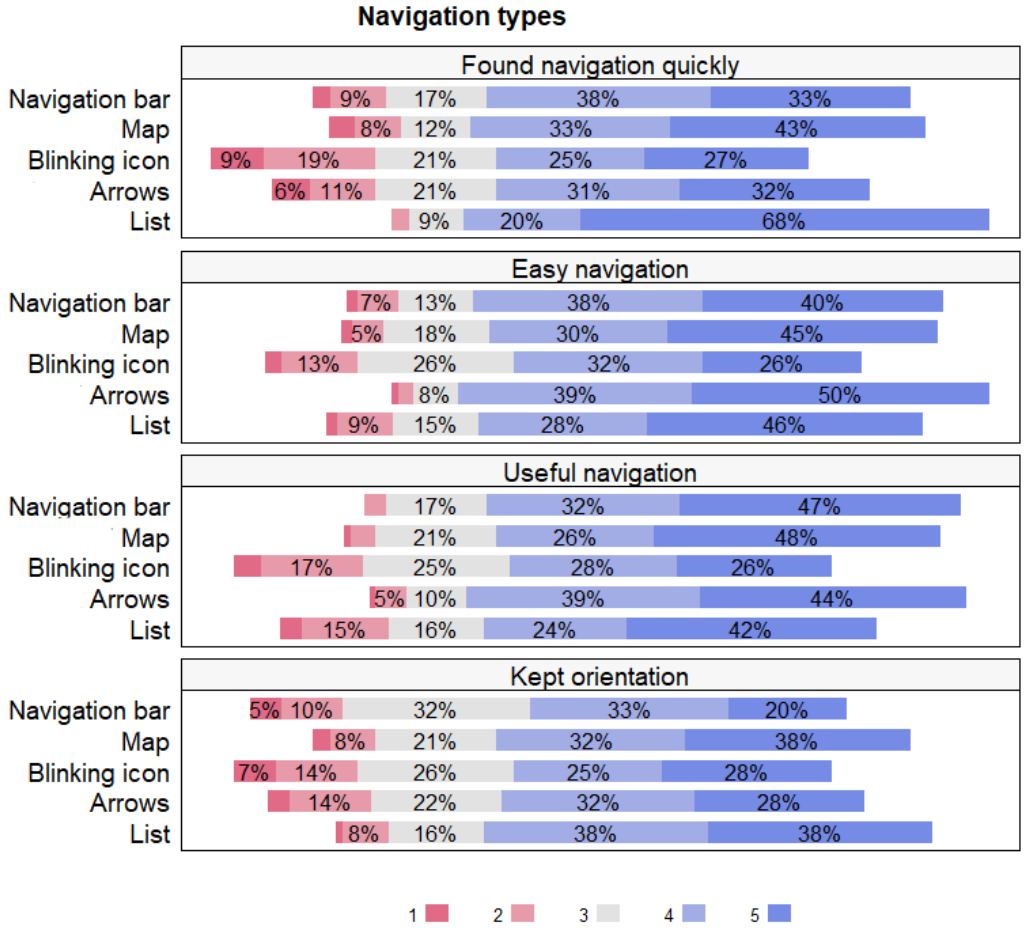
The statement whether the navigation options are useful for switching places, is similar to the navigation bar, map and arrows. Here, the tendency is at 4 and 5. The blinking icon and list are positioned more on the left, as about 20% judged the usefulness with a 1 or 2.

To keep the orientation, the map and list show the most positive responses with about 70% and only 9% rated with 1 or 2. The navigation bar, blinking icon and arrows show a similar distribution of responses. The responses tend more to 1 and 2 when compared to the others. Also more participants have a neutral position about the latter three navigation types and answered with 3.

In general, it is evident,that the navigation bar and map are positioned more on the agreeing side presented with a 4 and 5 for the statements apart from the orientation. Whereas the blinking icon has a higher percentage of responses in the disagreeing side presented by 1 and 2, compared to the other navigation types.



(a)



(b)

Fig. 3.3.: Likert scale based on the navigation view.

Most and least liked Navigation Types

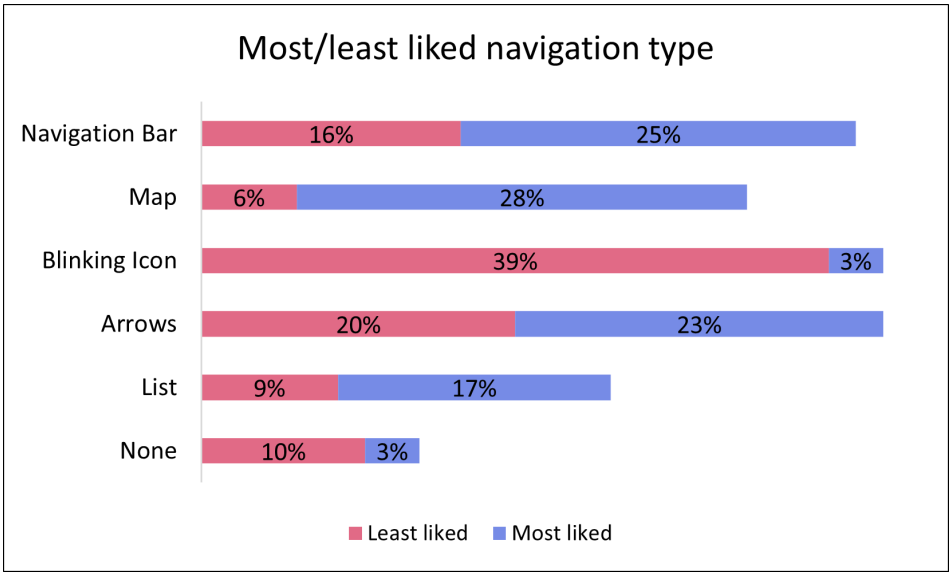
In *Figure* 3.7 the most liked navigation types are marked with blue and the least liked navigation options with red. In each bar, the percentage is given for the least and most liked navigations.
The *Table* 3.8 and 3.9 list the responses, why a specific navigation type was rated as best or worst. As the participants could select multiple options, where the possible answers were *I could quickly find a certain place*, *I could quickly discover all offered places*, *I could imagine to walk through the place*, *It was the most intuitive* for the navigation types which were rated as best and the answers *It took to much time to find a certain place*,*I could not discover all offered places easily*, *I could not imagine to walk through the place*, *It was not intuitive* for the worst option, they could also add an individual reason. The percentage was calculated with the total amount of answers per navigation type and not based on the 117 participants.
In the following we describe, why a navigation type was rated as the best or worst. Beginning with the best navigation types in descending order of percentage.

The most liked navigation type is map with 28%. This was chosen mainly, because a certain place could be found quickly (53%) and it is easy to discover all offered places (31%). Further reasons were that 11% of the participants could imagine to walk through the place and 3% judged it as intuitive.
The second most liked navigation with 25% is the navigation bar, as a certain place can be found quickly (78%). 12% chose it, because all offered places could be easily discovered and about 3% think that it was the most intuitive and one could imagine to walk through the place. One person gave a specific reason for the navigation bar: It helped him to decide if a place is worth for visiting based on the preview pictures.
The third place is represented by arrows with 23%. These helped 43% to imagine to walk through the place and for 27% it was easy to find a specific place. 18% and 11% answered that all places could be easily discovered and it was intuitive to use.
For 17% of the participants, the list is the best navigation option, as it is easy to find certain place (63%). 18% could discover all offered places and for 12% the usage of this type of navigation gave them the feeling of walking through the place. Only 6% answered, that it is most intuitive.
The last navigation type is the blinking icon with 3%. This helped 85% to discover all offered places and 14% to imagine to walk through the place.
The remaining participants (3%) said, that all navigations need improvement. Thereof, one person said, that a combination of coarse and fine navigation would work best for him. As a response was required, others selected answers which were

predefined instead of choosing other and give a meaningful reason. Therefore, we do not consider this answers.

Having just looked at the most liked navigation types, we now look at the least liked navigation types.
It is evident, that the blinking icon is the least liked navigation type with 39%. This is also reflected in the number of 3% who rated it as best. 40% of the participants needed to much time to find a certain place and 23% could not discover all places easily. For 17% the use of the blinking icon was not intuitive and 14% could not imagine to walk through the place. One person did not understand what purpose this navigation type has and another one said, that it was hard to find the navigation type.
On the second place are arrows with 20%. It took to much time to find a certain place (70%) and 9% each answered that it was difficult to discover all places and imagine to walk around. For 6% it was not an intuitive navigation type and one person said that it was not pleasant for his eyes.
The navigation bar was liked the least by 16% of the participants, as it took to much time to find a certain place (48%) and imagine to walk through the place (34%). 10% found it difficult to discover all places and for 6% it was not intuitive.
9% liked the list least, because it did not give the feeling to walk through the place (42%) and 28% wasted to much time to find a certain place. 14% each judged the list as challenging to discover all places and not intuitive.
Map was disliked from 6%, as they needed to much time to find a specific place (54%) and could not imagine to walk through the place (36%). For 9% it was not easy to find all offered places.
The remaining 10% chose none as the least liked navigation option. The reason of 25% was that they found all navigations good and 8% said, that all options have their advantage or disadvantages. 16% confirmed, that they chose none by also answering with none. The other answers are not considered, because predefined response options were chosen, which do not make sense in this context. The reason for that is, that the question required an answer, but the participants did not chose an additional reason.

To summarize, we could see, that the most liked navigation types were mostly chosen because the participants could find a certain place (map, navigation bar, list), could imagine to walk through the place (arrows) and could easily discover all places (blinking icon). The least liked navigation options were chosen on the basis of time the users needed to find a certain place (blinking icon, arrows, navigation bar, map) and they could not imagine to walk through the place (list).



Tab. 3.7.: Responses for the most/least liked navigation type.

Navigation options	Percentage
Navigation Bar	
I could imagine to walk through the place.	3,57%
I could quickly discover all offered places.	12,50%
I could quickly find a certain place.	78,57%
It was the most intuitive.	3,57%
The option allowed to change between places classified as interior, exterior and museum. Also, the thumbnail gave me a certain idea of whether the place was being worth visiting or not. Since the images of the interior of the statue of liberty were somehow distorted, I quickly decided not to bother visiting other places inside the statue. The thumbnails helped me to decide if a certain place was worth my time.	1,79%
Map	
I could imagine to walk through the place.	11,67%
I could quickly discover all offered places.	31,67%
I could quickly find a certain place.	53,33%
It was the most intuitive.	3,33%
Blinking Icon	
I could imagine to walk through the place.	14,29%
I could quickly discover all offered places.	85,71%
Arrows	
I could imagine to walk through the place.	43,18%
I could quickly discover all offered places.	18,18%
I could quickly find a certain place.	27,27%
It was the most intuitive.	11,36%
List	
I could imagine to walk through the place.	12,12%
I could quickly discover all offered places.	18,18%
I could quickly find a certain place.	63,64%
It was the most intuitive.	6,06%
None: All need improvement.	
None of these really work on their own. The perfect tool would offer an intuitively usable combination of coarse and fine navigation.	25,00%

Tab. 3.8.: Why the navigation type was liked the most.

Navigation options	Percentage
Navigation Bar	
I could not discover all offered places easily.	10,34%
I could not imagine to walk through the place.	34,48%
It took to much time to find a certain place.	48,28%
It was not intuitive.	6,90%
Map	
I could not discover all offered places easily.	9,09%
I could not imagine to walk through the place.	36,36%
It took to much time to find a certain place.	54,55%
Blinking Icon	
I could not discover all offered places easily.	23,88%
I could not imagine to walk through the place.	14,93%
I did not understand what this is for.	1,49%
It took to much time to find a certain place.	40,30%
It was not intuitive.	17,91%
The blinking icons were placed sparsely in the area to be discovered. Also, the general direction of the closest blinking icon was not indicated to the visitor. Therefore, using this method to navigate the area is frustrating. It felt more like a mediocre video game than a visit (albeit virtual) at this place. The most annoying factor was surprisingly not being unable to jump across the map (obviously, with this kind of navigation you can only jump to points visible from your current location) but having to search for the next location as if I was taking part in a poorly designed scavenger hunt.	1,49%
Arrows	
I could not discover all offered places easily.	9,68%
I could not imagine to walk through the place.	9,68%
It took to much time to find a certain place.	70,97%
It was not intuitive.	6,45%
The movement is not pleasant for the eyes	3,23%
List	
I could not discover all offered places easily.	14,29%
I could not imagine to walk through the place.	42,86%
It took to much time to find a certain place.	28,57%
It was not intuitive.	14,29%
None	
None	16,66%
All navigations are good.	24,99%
All have advantages and disadvantages	8,33%

Tab. 3.9.: Why the navigation type was liked the least.

3.4.3 Spearman's Rank Order Correlation

In the following, we perform correlation tests to find out whether there are relationships between the statements within or between navigation types. These relationships can be used to deduct conclusions.
The null hypothesis represents that there is no correlation between two statements, whereas the alternative hypotheses represents a correlation. After performing the test, the correlation coefficient ρ and the p-value are obtained. The correlation coefficient indicates the strength of the correlation. A value starting from 0.3 stands for a moderate correlation and a value from 0.5 for a strong correlation. The p-value indicates the significance level (Cohen, 1988).
For this evaluation, we only consider the ρ values starting from 0.3. All p-values in the following tables are not higher than 0,0002. This implies that the null hypothesis can be rejected at a significance level of 99% and there is a significant correlation between the tested variables.

Correlation within a Navigation Type

From *Table* 3.10 it is evident, that for each navigation type the responses to the questions whether the navigation type was found quickly, the navigation is easy to use or useful for switching places and whether the participant could keep the orientation while switching places, are moderate or strongly correlated. For example, the answers to the statement that the navigation type map is easy to use correlate with 0.68 with the answers that map was found quickly. In the table, this can be seen in the first box at the top left. As the Spearman's rank correlation is symmetrical, the correlation applies in both directions.

	Found quickly		**Kept orientation**		**Useful navigation**	
	Navigation	ρ	Navigation	ρ	Navigation	ρ
Easy navigation	Navigation bar	0,46	Navigation bar	0,39	Navigation bar	0,47
	Map	0,68	Map	0,61	Map	0,67
	Blinking icon	0,60	Blinking icon	0,58	Blinking icon	0,71
	Arrows	0,43	Arrows	0,31	Arrows	0,63
	List	0,52	List	0,61	List	0,72
Useful navigation	Navigation bar	0,40	Navigation bar	0,39		
	Map	0,50	Map	0,60		
	Blinking icon	0,49	Blinking icon	0,67		
	List	0,45	Arrows	0,39		
			List	0,51		
Kept orientation	Navigation bar	0,39				
	Map	0,46				
	Blinking icon	0,44				
	Arrows	0,33				
	List	0,44				

Tab. 3.10.: Correlation between the statements within a navigation type.

Correlation between Navigation Types

In *Table* 3.11 the navigation types are compared with each other based on the statements. Correlations could be found for the navigation bar, map, blinking icon, arrows and list. But there are differences in what statements of the navigation types correlate with each other. For example when the navigation types blinking icon and map were compared, the correlation coefficients for all possible statements were moderate or strong, e.g the ρ value for the statement that the orientation could be kept by using map or the blinking icon is 0,57.
The comparison of arrows and the navigation bar, showed only a correlation in the statement, that the navigation types are easy to use with 0,35.

	Navigation bar		**Map**		**Blinking icon**	
	Statement	ρ	Statement	ρ	Statement	ρ
List			Kept orientation	0,31	Useful navigation	0,36
					Kept orientation	0,34
Blinking icon	Useful navigation	0,33	Found quickly	0,30		
	Kept orientation	0,42	Easy navigation	0,40		
			Useful navigation	0,39		
			Kept orientation	0,57		
Arrows	Easy navigation	0,35	Easy navigation	0,37		
	Useful navigation	0,34	Useful navigation	0,32		
	Kept orientation	0,45	Kept orientation	0,32		
Map	Useful navigation	0,38				
	Kept orientation	0,35				

Tab. 3.11.: Correlation between navigation types.

Correlation between the Application and Navigation Statements

The *Tables* 3.12 and 3.13 show the correlation values for the general statements about the application *Statue of Liberty* or *Zugspitze360* with their navigation types. These correlation were calculated to find out, which impact the navigation types have on the appearance and usage of the application as a whole.

Comparing the general statements with each other, it is noticeable that an appropriate amount of information correlates with the interaction in both applications. This indicated, that the amount of appropriate information can have a positive effect on the interaction. This assertion is strengthened with the negative correlation between the statement, that the displayed information is confusing and the interaction is clear. This means that a more confusing information leads to a less clear interaction and also a clear interaction to a smaller amount of confusing information.

Additionally, both application show a correlation between the amount of appropriate information and the right number of navigation options. The correlation coefficient is for the *Statue of Liberty* moderate with a value of 0,30 and for *Zugspitze360* strong with 0,56. This shows that the number of provided navigations can have an impact on the amount of appropriate information.

In the *Table* 3.12 for the *Statue of Liberty* application, it can be seen that the statements easy navigation, useful navigation and kept orientation are correlating with clear interaction for the navigation types map and blinking icon. For the navigation bar only useful navigation and kept orientation correlate with the interaction.
For *Zugspitze360* in *Table* 3.13 it can be observed, that all possible statements about the navigation type list are correlating with the interaction. The navigation type arrow correlates in the statements easy navigation and found navigation type quickly.

		Clear interaction	**Right number of navigations**
Statue	Information appropriate	0,32	0,30
	Confusing information	-0,40	
Map	Easy navigation	0,51	
	Useful navigation	0,47	
	Kept orientation	0,46	
Navigation bar	Useful navigation	0,31	
	Kept orientation	0,40	
Blinking icon	Easy navigation	0,43	
	Useful navigation	0,39	
	Kept orientation	0,38	

Tab. 3.12.: Correlation between the general statements and the navigation types for *Statue of Liberty*.

		Clear interaction	**Right number of navigations**
Zugspitze360	Information appropriate	0,39	0,56
	Confusing information	-0,33	
Arrows	Easy navigation	0,49	
	Found quickly	0,33	
List	Easy navigation	0,42	
	Useful navigation	0,51	
	Found quickly	0,39	
	Kept orientation	0,46	

Tab. 3.13.: Correlation between the general statements and the navigation types for *Zugspitze360*.

To summarize, we could find correlations between the statements within the navigation types and across the navigation types itself. When considering the application as a whole and the navigation types, it could be seen that the navigation types have an impact on the interaction with the application.

3.4.4 Interpretation and Discussion

After the data were analyzed in the previous sections, we now consider the conclusions we could draw from the results.

From the correlation tests in *Section* 3.4.3, a relationship between an easy navigation, useful navigation and quickly found navigation could be calculated. This could imply that if the user is able to find the navigation type quickly in an application, he perceives the navigation type as easy to use and useful to switch places. To find a navigation option quickly, it should be ensured that a navigation option is well highlighted. The size and the color plays an important role. A color should be chosen, which stands out from the background. As the background changes when switching places, it would be good to use borders around the navigation indicator.
When looking at which navigation type was discovered first, navigation bar, map and arrows had the most answers. All have in common that they are always found in the same place. The navigation bar and map have a black border, which sets them apart from the content. The arrows also have borders, but we assume that the reason they were discovered as first is that by mouse movements the arrows appear automatically at the mouse position.
A negative example for an easy discoverable navigation is the blinking icon. This was discovered first by only 10%. The reason could be that it is not always visible and easily drowned in the background. Some users even interpreted the blinking icon as a loading symbol.

There is also a relationship between the orientation and whether a navigation type is easy or useful. This could mean that the participants are more likely to keep the orientation when the navigation type is easy to use and useful for switching places. An easy use leads to a better focus on the application and the navigation type itself, so that the user is not distracted by how to use it. To implement an easy navigation type, the navigation type shall be labeled, so that it is easily understandable how to use it or even provide a small tutorial, which shortly shows how the navigation type is used.

Navigation types are an important part of VT applications and influence the interaction. This can be inferred from the correlation coefficients in *Tables* 3.12 and 3.13.

Therefore, the used navigation options should be easy to find and easy to use in order to develop an application with a good interaction.
Another important aspect is to not flood the user with too much information. As a correlation between the amount of information is appropriate and the number of navigation options was found, this could imply, that too many navigations options overwhelm the user. As the correlation coefficient for *Zugspitze360*, which uses two navigation options, was strong and for *Statue of Liberty*, using three navigation types, was moderate, we assume, that a number of three navigation options in an application is suitable to ensure a clear interaction.
If the developers of an application notice that there will be more than three options, some navigation options might be combined. In the applications *Statue of Liberty* and *Zugspitze360*, for example the navigation type list and map could be summarized by placing the location's name above the location icon. This way the user keeps the orientation and gets the information where he will move. It would also be possible to add a preview picture next to the location's name, which gives the user a better understanding how the place will look like and he can decide in advance if it is worth to move there.

Different Navigation Types for specific Scenarios

Based on the results from *Table* 3.3b, which shows the responses for navigation statements, and the responses why a navigation type was liked the most or least (*Tables* 3.8 and 3.9), we could find out which navigation types should be used in different situations.

When the user wants to keep the orientation, the navigation map from *Statue of Liberty* or list from *Zugspitze360* suits the best. The map could be suited best, because it is placed in the corner and the user still has the picture of the current location in front of him. The map visualizes a small excerpt of the whole place, which includes labels, describing places or buildings, and icons which visualize where the user can move.
The list seems to be chosen, because it represents an ordered list of places, where the user has a linear movement direction, either upwards or downwards.
The navigation bar, blinking icon and arrows provide less orientation. While the navigation bar provides a sorted list grouped by the museums or the exterior and interior locations, there is no information about their position. The reason why the user loses orientation with the blinking icon, could be due to the jumps, which do not have a similar distance from one place to another. This way it is difficult for the user to trace how far he is from the place before, although he knows in which

direction he moved. The problem with the arrows might be that the images are not loading in time when the user switches the place. It takes a few seconds until the picture loads and in the meantime a blurred picture is shown, which might cause the lost of orientation.

To find a specific place mostly the navigation bar, list and map were used. The reason for the navigation bar might be, that the user can search a place by the categories external, internal or museum and additionally sees the names and preview pictures of the locations. List is similar to the navigation bar, but only shows the names of the locations. The motivation why map was chosen, might be that the user can find the specific location based on the surrounding sights or buildings, which are visualized in the map.
The arrows and blinking icon were not judged as helpful to find a specific place. This might be because the user does not exactly know where this navigation types bring him. He only knows in which direction he will move.

When a user wants to get a feeling of walking through the place, the arrows were preferred, because the distances between the places are only a few meters long and have for each transition the same length.

4 Design and Development of Virtual Tourism Applications

In this chapter, suggestions are made to enhance the navigation of the applications *Statue of Liberty* and *Zugspitze360* based on the results of the user study. The improvements are described and visualized in high fidelity mockups for every single navigation type. For a better comparison, at the end of the corresponding section, all refinements for each application are shown in a before and after comparison. The mockups and the Photoshop files can be also found in the Git repository[1]. Finally, we present advices and guidelines, which help to implement a successful navigation independently from the presented navigation types.

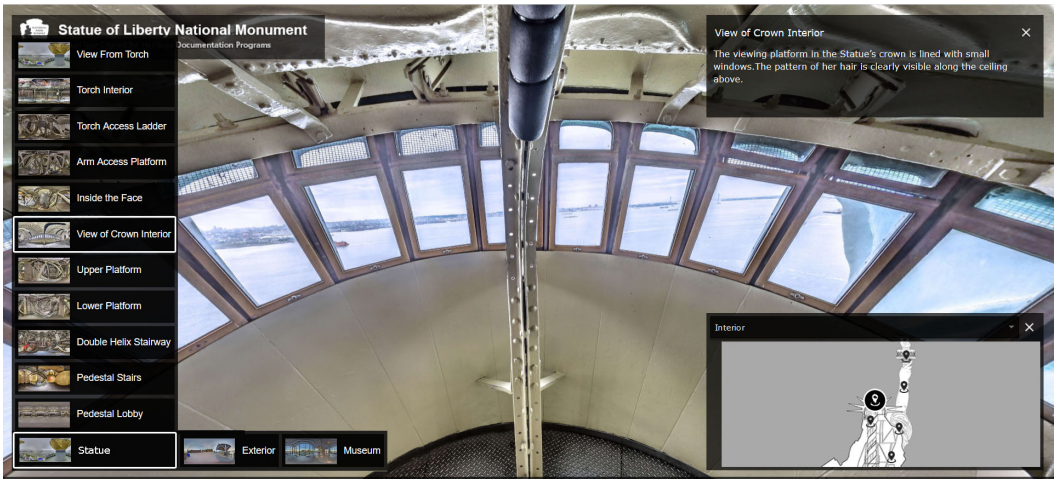
4.1 Statue of Liberty

4.1.1 Navigation Bar

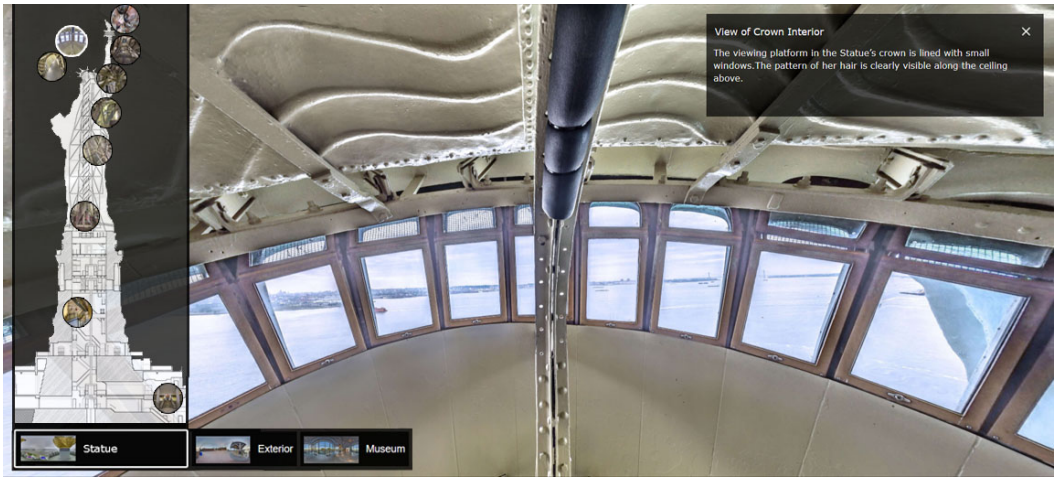
The participants, who rated the map as the best did so because a place could be easily found. Only 3% answered that the navigation bar is intuitive and from the general feedback to the survey, the users did not understand if there is a logical order behind the listing of the places in the categories interior, exterior and museums.

Therefore, the following suggestions were made in the navigation bar. First, we renamed the category *Interior* to *Statue* to make it more clear and separate it from the category museum. The name statue was chosen as the order from the list represents the ascent of the statue from the bottom to the top. Second in the detailed view of the navigation bar, the current place is highlighted with a white border. This is also done for the category itself, so that the user can easily see where he is when the detailed view is folded. The realization can be see in *Figure* 4.1a. The navigation bar and map, which can be seen on the bottom right, are working together. Meaning when the user choses a place from the navigation bar, the map is updated. In the original application, it centers on the current place, shown as a moving location icon

[1] https://github.com/ga65duy/Masterthesis-Virtual-Tourism-Applications/tree/master/Mockups



(a)



(b)

Fig. 4.1.: Improvement options of the navigation bar.

moving up and down, and shows an excerpt where the user is. As the users did not see this connection, the color of moving location icon was changed to white and it is positioned in a black circle with a white border. This change shall remind the user on the highlighting in the navigation bar and also make the current position in the map more visible. Recognizing the connection between the navigation bar and map shall also improve the orientation of the user when using the navigation bar, which was rated negatively by 15% of the survey participants.

Additionally, a second option how to improve the navigation bar is presented in *Figure* 4.1b. Here, a sketch of the statue is used instead of the detailed view including the preview picture and the name. The preview pictures are represented in circles, which have a black border to make it more visible. When a user hovers over the preview picture it becomes larger and the name of the place is shown as well. The

current position of the user is indicated by a white border around the preview picture. This way the user gets a better feeling how far he already climbed up the statue. In this version, the map on the bottom right, which can be seen in *Figure* 4.1a is hidden, as the whole statue can be already seen in the navigation bar.

These two improvement possibilities shall help the user to understand the navigation bar better and add more orientation.

4.1.2 Map

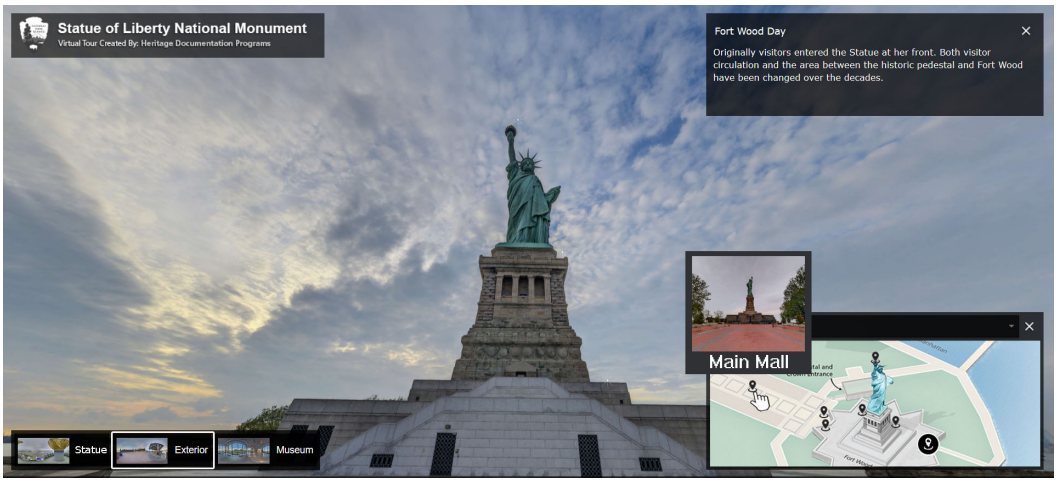


Fig. 4.2.: Improvements of map.

The user study revealed that the map is the most liked navigation type and performed the best in all categories, easiness, usefulness, orientation and whether it was found quick, in comparison to the other navigation types. Nevertheless, we want to build on the current version of the map, as the participants who liked map the least criticized that it took to much time to find a certain place (55%) and the connection between the navigation bar and map was not realized by the user, which was confirmed in the feedback.

To make the connection between map and navigation bar more clear for the users. The slowly jumping location icon, standing for the current position was replaced with a white location icon in a black circle and a white border. On the bottom left in the navigation bar, it is evident that the category where the user currently is, is also highlighted with a border. When the user expands the category exterior, the exact place will be also highlighted.
As some participants said, that it took to much time to find a certain place on the map, a preview picture and its label written in white is provided in the form of a

rectangle. It is backed with black to make the label readable when the background changes. In order to not overcrowd the map with pictures, the previews are only shown when the user hovers over a certain location icon. This addition shall help to easier find places based on the picture and label, in addition to the surroundings, which are sketched in the map. It might be especially useful for people who were not on site before as they might not know where each place is located.

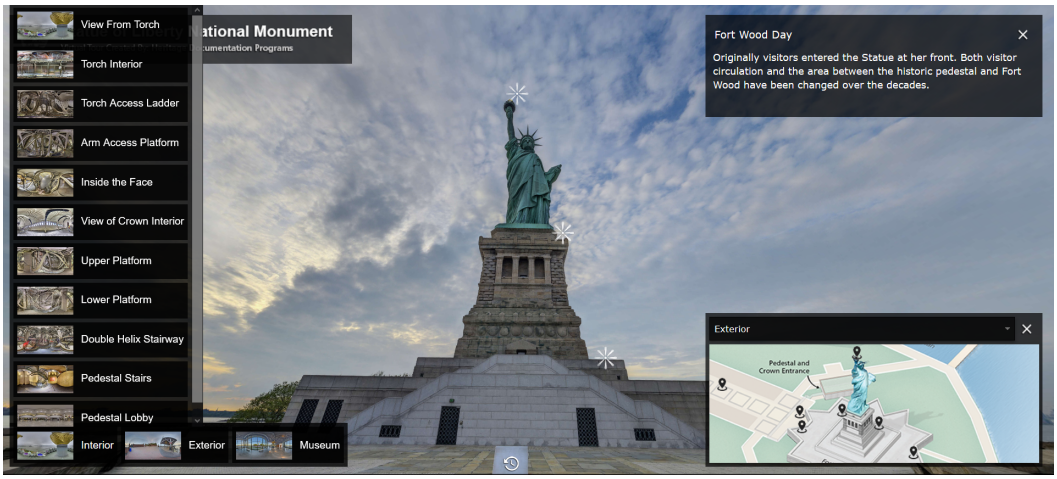
4.1.3 Blinking Icon

Fig. 4.3.: Improvements of the blinking icon.

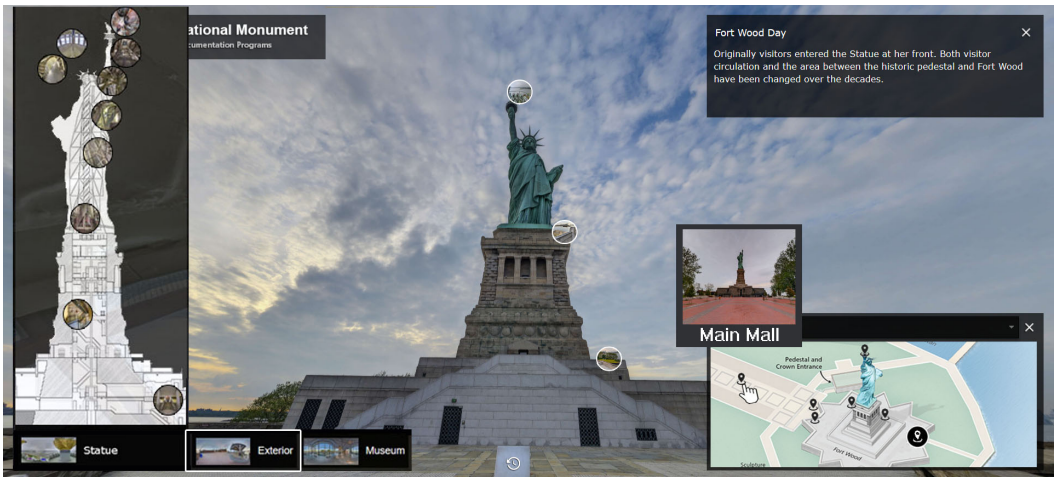
The blinking icon performed the worst compared to the other navigation types regarding the easiness, usefulness, orientation and whether it was found quick. This is also reflected in the fact that it was least liked.

To improve the blinking icon, the blinking animation is removed as the icon is hardly noticeable when the icon disappears for a second. Increasing the speed of the blinking would be a possibility, but as there can be multiple blinking icons in one place, it could be annoying for the user and distracting (Ware, 2008). Therefore, we decided to remove the blinking and replace the icon with a circle containing a preview picture to provide the user with more orientation. The preview shows the place where the user will come to when he clicks on it. To make the circle good visible, a color has to be used that is substantially different from the background. As the background colors change every time when the user moves to another place the best option is to use borders (Ware, 2008). In *Figure* 4.3b the replacement for the blinking icon can be seen, which has a white border.
The user also has the possibility to get a closer look on the previews by zooming in when he hovers over it. Additionally, the name of the place is written in white color on a black rectangle, to make the description readable independently from the background (*Figure* 4.3c). This feature shall help the user to decide whether he wants to jump to a new place before switching and get an overview which places are in the surrounding area.

In *Figure* 4.4 an overview of the application *Statue of Liberty* is shown how the navigation types navigation bar, map and blinking looked originally (*Figure* 4.4a) and how the navigation types look after the improvements (*Figure* 4.4b).



(a)



(b)

Fig. 4.4.: Comparison of the *Statue of Liberty* application before and after the improvements.

4.2 Zugspitze360

4.2.1 Arrows

Fig. 4.5.: Improvements of arrows.

The arrows were judged the worst in the category orientation and whether the navigation type is easy to find. The orientation was rated negatively by 18% and 17% could not find the arrows quickly.

To improve the arrows based on these insights, we propose to enlarged the size of the arrows to make them easier visible. Nothing has been changed in the alignment, as the arrows lie in a different plane, which makes them stand out well from the surroundings. We have also considered to add a background to the arrows and place them closer together. But as the background would overlay too much of the surroundings, we decided just to enlarge the icons, so that they are better visible. By the enlargement the borders around the arrows also become clear, which helps to separate the arrows from the background.
In the original application, when a user moves his mouse around the view, a new arrow appears, which is pointing forward. This arrow changes his size depending on the mouse's position, so in some places it is hardly visible. This can be seen in *Figure* 4.8a slightly above the white arrow pointing backwards. As the user can also use the mouse to change his point of view by clicking in the picture and dragging, we recommend to remove the gray arrow to avoid confusion. Instead, the white main arrow gets highlighted in light blue when the user wants to click it and the direction *Vorwärts* or *Rückwärts* is written above the arrow. The labels are written in German as the whole application is shown in this language. This feature shall enhance the

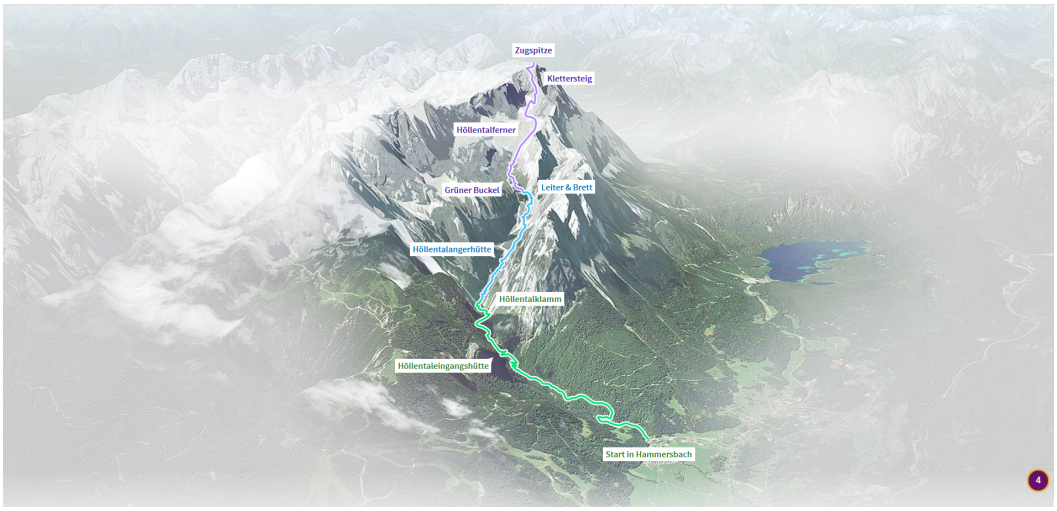


Fig. 4.6.: Sketch from *Zugspitze360*. *Source: zugspitze360.com*.

orientation as the labels and highlighting makes it better understandable where the user came from and where the new position is located. It is not always clear, which arrow represents the back or forward direction as the directions of the arrows change from position to position and there are scenarios where the arrows are positioned close to each other and one is pointing slightly left and the other one slightly right. The mockup showing the improvements for arrows is shown in *Figure* 4.5.

4.2.2 List

The user study showed, that list was rated negatively by 18% with regard to the usefulness and by 11% to the easiness. The participants, who chose the list as the worst navigation options argued that they could not imagine to walk through the place (42,86%). But the ones, who rated it as the best one said that they could find a certain place quickly (63,64%).

We assume that the easiness and usefulness of the navigation type was rated badly because it only presents an ordered list of the station's names, divided in three stages. To improve it, we replaced the list with an excerpt of the image (*Figure* 4.6), which was previously only shown when the application is started. It shows the mountain and the whole path up. We have customized the original image by coloring the path up the mountain in black with a white border and added the stations in form of black circles with a white border. The borders shall make the path and the locations more visible as the background changes from dark green to white. The current position is highlighted in green color. This shall visualize the user, how far he already climbed

and how much is still ahead of him. Each of the visualized stations can be clicked to change the location. Before clicking on a specific station, the user is provided with additional information including the name of the location and a speaker icon indicating when audio is available (*Figure* 4.7b).The visualization of the mountain itself is bordered with transparent black to separate it from the virtual tour. The overview map closes automatically when the user moves away with the mouse, this functionality was kept from the original version. If the overview is closed, a black rectangle including a gray arrow points out the navigation type (*Figure* 4.7a).
This suggestions for improvement shall make the navigation type more useful as the user can see different information such as the position, the path before and behind him and the location name with an information about the guide, when hovering over a place. The path should also reinforce the feeling of climbing up the mountain and help to find a specific location easily.

(a)

(b)

Fig. 4.7.: Improvements of list.

The users' feedback for the list and arrows was that the pictures were loading slowly and the transition from one place to another was often jarring. It could be possible that this fact has an impact on the orientation. Therefore, we propose to improve the transition by showing the current position until the next one is loaded or provide a small video, which imitates the walk to the next place and strengthens the feeling of actually being on-site.

In *Figure* 4.8 an overview of *Zugspitze360* is shown how the navigation types list and arrows looked originally (*Figure* 4.8a) and how the navigation types look after the suggested improvements (*Figure* 4.8b).

(a)

(b)

Fig. 4.8.: Comparison of *Zugspitze360* before and after the improvements.

4.3 Guidelines for successful Navigation Types

Based on the findings and feedback from the user study, general guidelines are presented to help with the implementation of the navigation types. A summary is provided in *Table* 4.1 divided in the categories *Visibility*, *Functionality* an *Navigation types*.

When a navigation type is implemented, it should be ensured that it is clearly visible. The features that influence the visibility are size, color, motion and stereoscopic depth. The strongest visibility occurs when an element differs in some feature from all other elements. Depending on the variety of the background, more features are necessary to make an object easier detectable. For example, the size can be used to make an object distinct from another. But if the object differers in size and color, it will be even more distinct (Ware, 2008).
For this purpose, a suitable size should be chosen for the navigation elements, which is not too small but also not too large, so that it does not cover to much of the virtual tour elements. Additionally, a color should be used that is substantially different from the background images of the virtual tour. As the background colors mostly change when passing from one place to another, finding a distinct color might be difficult. In these cases, borders around the elements or a neutral background behind them should be used to make them easier visible. Making use of the stereoscopic depth is also useful. For navigation elements, stereoscopic depth can be used most effectively by positioning them on top of the virtual tour elements, so that a new layer is created.
When small text, such as labels or symbols are included in the navigation type, a luminance contrast is necessary. From the International Standards Organization (ISO) a ratio from 3:1 between the luminance of the small elements and its background is recommended. This means, that the color black for the background and the color white or pastel colors for the foreground are the best options to use. These can be used also the other way around (Ware, 2008). Specific examples can be found in the *Figures* 4.4 and 4.8.

The functionality of the navigation type must be made clear and easy understandable for the user. Therefore, it is important to use commonly known symbols or designs, so that the user knows how to use it. The symbols should be kept consistent and simple. For example, location icons can be used to indicate the visitable places on a map. Another example are expandable bars where an arrow can be used to show the direction where the bar will expand.
It is also helpful to think from the perspective of the user, who is using the application

for the first time and has not visited the place before.
Another important aspect is the responsiveness (Pinkerton, 2018). A navigation element has to provide feedback to the user when he has performed an action, such as clicking on an icon, and ensure that the functionality is in accordance with the user's actions. This makes the functionality comprehensible for the user as he directly sees the changes.
In the application *Statue of Liberty* the navigation bar and map worked together. Meaning, when a place was selected in the navigation bar it was updated in map. This feature was not recognized by the users, although the updates where visible in the map. But this connection could not be seen when the location was chosen in the map. To better underline the connection between theses navigation options a highlight of the chosen position in the navigation bar is helpful. Therefore, a bright color was used to attract the user's eye (Beaird, 2010) (*Figure* 4.1a). In general, the current position in the virtual tour should be marked in the navigation types when possible. For the navigation types, which are used for simulating a walk through the place, such as the blinking icon from *Statue of Liberty* or the arrows from *Zugspitze360*, it might be difficult to realize this suggestion. Whereas, it is easy implementable for the navigation bar, map and list.

When using navigation options, such as the blinking icon or arrows, it is advisable to use the same step size when switching the places. Especially, in walking tours, such as *Zugspitze360*. This makes it more consistent and the user gets a feeling how far he moved and it adds orientation. Attention should be also paid to the loading of the images when passing to another place. Blurred and jarred images might lead to distraction and orientation loss of the user.

The users' feedback showed that the participants liked the opportunity to use different navigation types and when using the application they would not stick just to one option. After the evaluation, the number of minimum two and maximum three navigation types is considered optimal in order to not overwhelm the user, but still provide them with different options. When implementing the navigation types, it is important to implement them for different scenarios, as every user is individual, and avoid redundant functionalities.
People might use VT applications for different purposes. One person might want to get an overview of all visitable places, whereas another one would like to see just the main attractions. For this scenarios the best option would be to use a list or map, which shows all locations or main attractions in one place. Another person might want to get to know the place like in a real tour. Meaning, a navigation type which simulates to walk through the place is necessary. To realize this, symbols indicating

Visibility	Functionality	Navigation types
• Chose a suitable size • Use different colors from background • Border the navigation type • Make use of stereoscopic depth • Make use of luminance contrast for small symbols or text	• Use commonly known symbols • Ensure consistency and keep it simple • Think of the users' perspective • Responsiveness in accordance with the users' action • Underline connections between navigation types • Highlight the current user's position	• Use 2-3 options • Think of different scenarios • Avoid redundancies

Tab. 4.1.: Guidelines summary.

the direction where the visitor can go next are meaningful. For this scenario it is important to use small steps between the different stops to imitate the walk.

5 Conclusion and Future Work

5.1 Conclusion

As Virtual Tourism (VT) applications have become increasingly important, especially in the present time with the spread of COVID-19, the first part of the master's thesis defines VT and provides an overview of VT applications. In the literature, there is no generally established definition of VT. Therefore, several definitions of VT and related terms from the literature were investigated. The definition in this thesis contains three aspects: First, VT enables a remote visit of a virtual replication without traveling, which can present a real or invented world. Second, VT can be also used on-site, whereby additional virtual information is blended in the visitor's view and third, interactivity with the virtual world is an important aspect and must be available.
In the VT applications overview, 39 applications are described and divided into the categories *Nature and Wildlife*, *Cities and Sights* and *Cultural Heritage*. In the end, all applications were summarized in a table, which included the five characteristics *technology*, *place*, *platform*, *interaction* and *additional features*.

In the second part, the focus was on the navigation types, as they are an important component of VT applications. An user study was conducted to evaluate the navigation types and the interaction of two VT applications. The findings from the user study were used to suggest improvements for each navigation type. The improvements were visualized in mockups. Finally, general guidelines were presented, which are applicable independently of the presented navigation types, when realizing a virtual application from scratch. These include how to highlight a navigation type, how to best bring its functionality closer to the user, and how many navigation types should be used.

Summarizing, the master's thesis defined the term Virtual Tourism (VT), provided an overview of its applications and elaborated improvements and guidelines for the navigation types based on a conducted user study.

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5.2 Future Work

In the present thesis, a user study was conducted to evaluate the interaction and navigation types of two VT applications. Based on these findings improvements were realized in form of mockups. In future, an additional user study could be conducted to evaluate whether the presented improvements enhance the interaction and the navigation options.
As the suggested improvements were not implemented yet, the next step would be to embed the suggestions in the original applications. Therefore, an overview of different frameworks or libraries, such as A-Frame[1] or React360[2], and their functionalities would be useful in order to select the right technology for the implementation as each one has its advantages and disadvantages.
The elaborated overview, showing which technology is suited best for specific features, could be used as a checklist, which helps other developers to decide for a specific framework or library when implementing a VT application from scratch.

As the current user study is focused on the interaction and navigation on web pages, further user studies can be conducted, which concentrate on different components. An example would be to evaluate the immersion of an application, which represents an important part of VT applications. The stronger the immersion is, the better the user can imagine himself in the virtual world and the virtual experience can be enhanced. Especially, the AR and VR technologies contribute to a positive immersion (Bec et al., 2019). Therefore, one could investigate which technologies lead to a good immersion and how these are implemented to provide a good virtual experience.
In mobile applications or applications using AR or VR, the navigation mostly differs from the ones, which are used on web pages. Here, head movements, gestures or movements of the mobile device are used to change the perspective or places. This type of navigation could be also evaluated in the future.

Up to now, the users of a VT application could see all provided navigation options. In future dissertations, these navigation options could be personalized based on the users' interaction and the usage of navigation options.
Another possibility could be to add an virtual assistant to the application, so that everything can be controlled by the speech of the user. For example, if the user says "I want to see an overview of all main attractions", the application blends in an overview and maybe a short voice over, which gives some interesting information about the place. Via speech one could also enable to change places by speaking out the target or telling the application in which direction the user wants to walk. The

[1] https://aframe.io/
[2] https://github.com/facebookarchive/react-360

virtual assistant would represent a person with whom the user can communicate, get insights about the place and brings the user to his desired destination.

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User study

A

Virtual Tourism Applications
Dear participant,
thank you for taking part in the survey for my master thesis at the Technical University of Munich. In this survey, virtual tourism applications using 360° photos are evaluated based on their navigation possibilities and interaction. Virtual tourism applications allow the user to visit a place from home instead of visiting it in person. The survey takes about 10 minutes. Please conduct the study on a computer as the views may differ on a mobile device. Please fill out the questionnaire honestly and completely. Your data will be collected anonymously and will not be passed on to third parties.
If you have any questions, you can contact me at maria.potzner@tum.de Thank you very much for your participation.
Maria

Personal Infortmation
Gender: O Male O Female O Other
Age: O 0-20 O 21-30 O 31-40 O 40+
Have you used a virtual tourism application before? O Yes O No

Application: Statue of Liberty
Please open the following link https://www.nps.gov/hdp/exhibits/stli/stli_tour.html and get familiar with the application. Try out the 360° view and explore the surroundings. Take a look at the different functionalities. Especially on the different navigation options. When you got familiar with the application, come back and answer the questions in the following section.

General: Statue of Liberty
In the following, statements will be presented. Please specify your agreement to each statement.

The interaction with the app is clear and understandable.
Strongly disagree O O O O O Strongly agree

The amount of information displayed on screen was appropriate.
Strongly disagree O O O O O Strongly agree

The information displayed on screen is confusing.
Strongly disagree O O O O O Strongly agree

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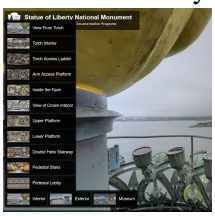
Navigation: Statue of Liberty
In the following section the focus is on naviagtion and navigation types. Please open the link https://www.nps.gov/hdp/exhibits/stli/stli_tour.html again to come back to the initial screen of the application.

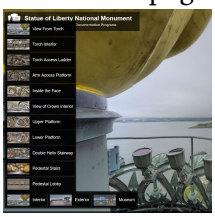
Which navigation type was the first you discovered?

O Navigation Bar 

O Map 

O Blinking icon 

Use this type of navigation to answer the following question. Hint: If you got lost, refresh the page.



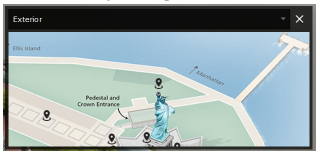
I found the navigation type quickly.
Strongly disagree O O O O O Strongly agree

It was easy to navigate to a place.
Strongly disagree O O O O O Strongly agree

The navigation type is useful to switch places.
Strongly disagree O O O O O Strongly agree

I kept the orientation when switching the places.
Strongly disagree O O O O O Strongly agree

Use the map to navigate to other locations. You can find it on the buttom right. Hint: If you got lost, refresh the page.



I found the navigation type quickly.
Strongly disagree O O O O O Strongly agree

It was easy to navigate to a place.
Strongly disagree O O O O O Strongly agree

The navigation type is useful to switch places.
Strongly disagree O O O O O Strongly agree

I kept the orientation when switching the places.
Strongly disagree O O O O O Strongly agree

Use the icon to navigate to another location. It can appear somewhere in the current scene. Hint: If you got lost, refresh the page.

I found the navigation type quickly.
Strongly disagree O O O O O Strongly agree

It was easy to navigate to a place.
Strongly disagree O O O O O Strongly agree

The navigation type is useful to switch places.
Strongly disagree O O O O O Strongly agree

I kept the orientation when switching the places.
Strongly disagree O O O O O Strongly agree

The number of navigation options was just right.
Strongly disagree O O O O O Strongly agree

Application: Zugspitze360
Please open the following link https://zugspitze360.com/tour/1 and get familiar with the application. Discover the different navigation options and the provided information. When you got familiar with this application come back and answer the following questions.

General: Zugspitze360
In the following, statements will be presented. Please specify your agreement to each statement.

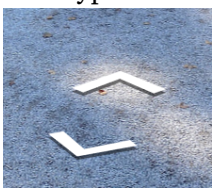
The interaction with the app is clear and understandable.
Strongly disagree O O O O O Strongly agree

The amount of information displayed on screen was appropriate.
Strongly disagree O O O O O Strongly agree

The information displayed on screen is confusing.
Strongly disagree O O O O O Strongly agree

Navigation: Zugspitze
In the following section, the focus is on navigation and navigation types. Please open the link https://zugspitze360.com/tour/1 again to come back to the initial screen of the application.

Which navigation type was the first you discovered?

O Arrows 

O List 

Use the arrows to navigate to another location. It can appear somewhere in the current scene. Hint: If you got lost open this link https://zugspitze360.com/tour/1.

I found the navigation type quickly.
Strongly disagree O O O O O Strongly agree

It was easy to navigate to a place.
Strongly disagree O O O O O Strongly agree

The navigation type is useful to switch places.
Strongly disagree O O O O O Strongly agree

I kept the orientation when switching the places.
Strongly disagree O O O O O Strongly agree

Use the list to navigate to another location. It appears on the left side. Hint: If you got lost open this link https://zugspitze360.com/tour/1.

I found the navigation type quickly.
Strongly disagree O O O O O Strongly agree

It was easy to navigate to a place.
Strongly disagree O O O O O Strongly agree

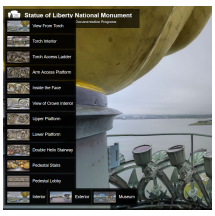
The navigation type is useful to switch places.
Strongly disagree O O O O O Strongly agree

I kept the orientation when switching the places.
Strongly disagree O O O O O Strongly agree

The number of navigation options was just right.
Strongly disagree O O O O O Strongly agree

Conclusion

Which navigation did you like the most?

O Navigation Bar 

O Map 

O Blinking icon

O Arrows

O List

O None: All need improvement

Why did you like it the most?
O I could quickly find a certain place.
O I could quickly discover all offered places.
O I could imagine to walk through the place.
O It was the most intuitive.
O Other:

Which navigation did you like the least?
O Navigation Bar
O Map
O Blinking Icon
O Arrows
O List
O None

Why did you like it the least?
It took to much time to find a certain place.
O I could not discover all offered places easily.
O I could not imagine to walk through the place.
O It was not intuitive.
O Other

Do you have suggestions to improve the navigation?