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Master Thesis

Towards a VirtualLearningSpace: Developing a VR-Space & evaluating the learning experience compared to standard 2D-approaches in the context of telling the history of a district

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DEPARTMENT FÜR INFORMATIONS-
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Contents

List of Figures

List of Abbreviations

AR Augemented Reality

GIS Geographic Information Systems

HMD Head Mounted Display

JS JavaScript

VR Vitual Reality

MR Mixed Reality

XR Extended Reality

XRDA WebXR Device API

List of Tables

Abstract

Until now, education (in history) is often limited to texts and two-dimensional visualizations. Now and then, there are attempts to incorporate Virtual Reality (VR), but the technology is mostly applied in a primitive way, e.g. to present a single historical building like a temple in 3D. However, one searches in vain for more sophisticated applications which explain for example how an area has developed over the years. This thesis aims to investigate the advantages and disadvantages that a three-dimension learning space could bring over a two-dimensional one. A web-based 2D and 3D/VR application applications are built that visualize open data on the history of a district. Subsequently, a user study is carried out, evaluated, and several aspects such as the terms of the learning experience are analyzed.

1 Introduction

In this paper, the development and application of web-based 2D and 3D/Virtual Reality (VR) applications in the field of communicating historical knowledge are investigated. Since this is a complex topic, this paper focuses on the learning experience, and the technology behind it and not actually on the historic knowledge and whether this is pedagogically valuable. The main purpose of the thesis is to first examine all aspects of relevant technological and design aspects for developing such an application, then to show a way how existing technologies can be leveraged to build such an application, and finally to evaluate the developed app.

The basic idea for the visualization that is developed is to visualize an open geo-dataset of buildings and other objects of a Viennese district to tell the story of that district. The approach involves building a map that allows a "journey through time". For example, the user should be able to easily discover which buildings were standing in the area of the district at which time and what the settlement looked like in the different eras. Virtual environments generally have proven to be useful in visualizing complex spatial data [9]. However, it is an open research field to figure out how to best exploit the potential they have, how to address cognitive and usability challenges, and how to design controls in the most suitable way [9]. This research aims to provide some answers to the challenges discussed in the literature.

This thesis is structured as follows: section 2 introduces the applied research method, lists the research questions, and names the most important research goals. Section 3 explains the main and related topics that this thesis deals with in a theoretical way and showcases some of the aspects that are important when later on building the application. The section is divided into subsections focusing on VR and related technologies, visualization theory, interface design, and open data. Section 4 is dedicated to the built application. The section first explains the use case and context of the application and then proceeds to describe the used dataset and the developed 2D and 3D applications. Section 5 showcases and discusses the research findings and section 6 summarizes the main results and provides an outlook on future research.

2 Research Methodology

2.1 Research Questions

In this thesis, the overarching research question of *How can VR be applied in the context of education in history?* is investigated. Since this is a rather broad question it is further divided into four sub-questions:

- *What are the aspects of VR and visualization theory that need to be considered when building such an application?*
- *How can the potential of web-based technology and open data be leveraged in this context?*
- *Which effects does the new application have on the learning experience of its users?* and
- *What are its advantages and disadvantages, compared to a 2D application on the same material?*

This scientific paper combines three research methods which all cover different sub-objectives of this research:

- **Semi-Structured Literature Review**

  First of all, a semi-structured literature review is performed to create an overview of the research in the field of virtual reality, learning, and visualization theory. The core aim of this part is to uncover all important aspects that have to be taken into account when designing a new VR solution. Furthermore, potential opportunities and research gaps should be discovered.

- **Proof of Concept**

  As the next step, two web-based applications - one in 2D and one in 3D - will be set up as Proof of Concept on what a digital learning space for history could look like. The goal of setting up this application is to determine, whether such applications are at all feasible in a meaningful way.

- **User Experience Study**

  Finally, applications are tested out in practice, and data about the user experience is collected and later on, analyzed with the intention of discovering, the differences between the 2D and the 3D app.

2.2 Research Methods

2.2.1 Semi-Structured Literature Review

A semi-structured literature review is conducted to build up the necessary background knowledge. The applied method loosely follows the "Systematic literature review" approach - as introduced in [10]. According to theory, a literature review can be seen as a tool to review and interpret all accessible studies which are of relevance for a specific field of research [10]. For this research, the research field of interest is VR, visualization in general, education, and other related topics such as open data.

This part of the research thesis can be regarded as secondary research since it focuses on giving an overview of the scientific work that already exists [11]. It should provide valuable insight since most papers deal with only a few aspects of VR and its related topics. Hence there exists a need to summarize and compare results. With this kind of research, one could for example discover unresolved challenges or research gaps in this area [11].

To have a wide range of choices of papers for further investigation, several digital libraries are used - Google Scholar, Science Direct, Research Gate, and Pro Quest. To guarantee a certain quality of the references, the following inclusion criteria have been defined: written in English and published in a scholarly journal, in conference proceedings, or as a book by a well-established, trustworthy publisher. In addition, emphasis was placed on papers published between 2000 and 2022. This was done to ensure a certain actuality of the papers discussed. However, some older papers dating back to 1960 were included as well, if no newer articles on the same subject existed or if they were the original source of knowledge. Since the overall amount of papers in this research field is quite large the search is limited to papers that have the search keywords (see below) in their title or abstract (that is indicated with the abbreviation NOFT).

The search queries for the research are:

- NOFT("Virtual Reality" OR "VR")
- NOFT(("Virtual Reality" OR "VR") AND "2D")
- NOFT(("Virtual Reality" OR "VR") AND "Open Data")
- "Web VR" OR "web-based Virtual Reality"
- NOFT(("Virtual Reality" OR "VR") AND ("Augmented Reality" OR "AR"))
- NOFT(("Virtual Reality" OR "VR") AND ("education"))

2.2.2 Proof of Concept

To demonstrate the feasibility of a virtual learning space on the subject of history, a sample web-based VR application is created. Subsequently, this sample project will serve as a starting point for further research on the subject.

The development of the site is realized via JavaScript (JS), CSS, and HTML. For most of the functionality and visualization, the JS library A-Frame [12] is applied. Furthermore, Python is used to prepare the data for the website accordingly and to automate part of the translation of the data in a format that can be processed by A-Frame.

Hosting of the website is done via the glitch.com platform and testing of the final application is carried out via the Oculus Quest 2. These VR goggles were chosen because they allow for a fairly full VR experience for a relatively low price, where individual pixels are hardly noticeable anymore. In addition, the device has an integrated processor and browser and can thus be operated without additional devices. Moreover, the respective Oculus controllers offer some advantages in terms of control.

2.3 User Experience Study

To find out whether the developed application has the potential to improve the learning experience, a user study will be conducted. There are a variety of ways to measure the user experience, ranging from eye tracking to camera studies to ethnographic field studies [13]. The diversity of methods can partly be explained by the fact that users' actions are not always coherent - for example, there could be a difference between what users say and what they do [13].

For this research step, the method of so-called focus groups is applied. The participants in the study are divided into groups of 2-3 persons in which both discussions and exercises take place and feedback can be given in oral or written form [14]. This method was chosen because it is especially suitable for showing the diversity of perceptions and emotional dynamics within a group setting and learning about history most of the time works in smaller groups (for example by visiting a museum or learning in a classroom setting) [15]. Moreover, the method is a kind of group interview, which is particularly suitable to obtain different perspectives [15], which corresponds as well to the aims of the research. In the case of this study, this will be achieved in the way described in the next paragraphs:

Participants

In the study, a total of about 24 people will participate, who will be divided into small groups of 2-3 people each. The people in a group should be between 16-70 years old and the cohort should be balanced between men and women, boys and girls.

Procedure

In the first step, the group is shown a classical 2-D learning object - about a historical aspect. Afterward, it is discussed. In the next step, the participants are introduced to the VR glasses and enter a virtual world where they are shown the same content, but in a completely different way. Once again, the participants discuss what they see.

The interviews are all recorded and then transcribed. During the analysis of the textual documents, a pre-trained ML algorithm will be used for sentiment analysis - to detect single positive and negative comments. The results will then be visualized and discussed.

3 Theoretical Background

This section is intended to provide the reader with an overview of the current state of research on topics that are addressed in this study or are related to them. In addition, this section highlights important challenges that are important to consider, when designing and implementing a new application.

3.1 Virtual Reality

With the help of Virtual Reality (VR) a realistic-looking virtual, synthetic 3D-environment can be created in which users can navigate, view objects from different perspectives, and interact with them [16, 17]. Besides interactivity, VR focuses on creating an immersive experience in the sense that any distractions are suppressed as far as possible and the focus is laid primarily on the virtual environment [16]. A person wearing a head-mounted display (HMD) - as shown in figure 1 - can usually not see the objects surrounding him/her in the real world as the display covers almost all of his visual field [1]. As a result, he ignores distractions such as other persons jumping around in front of him and just focuses on the virtual experience. Sometimes, a third principle of VR is named as well, namely, imagination which refers to the user's ability to think to experience non-existing worlds [18].

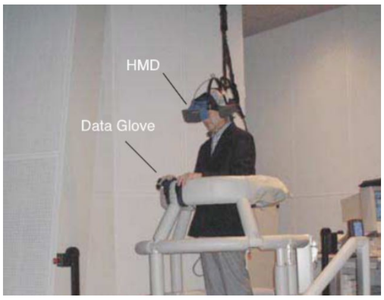

Figure 1: An example of a HMD taken from [1]

Head Mounted Displays (HMDs) ... as shown above, in figure 1, are the basis of a VR system. They are as the name already says attached to the head of the user and made out of liquid-crystal displays (LCDs) or tiny CRTs in a pair of glasses [18]. HMDs can expand the field vision on the display screen and are able to generate an "imaginary" screen that can seem to be a few meters away from the user and not directly in front of their eyes (as it actually is) [18]. This capability, or optical illusion, allows VR systems to trick users and create a sense of depth or three-dimensionality, even though the display itself is only a two-dimensional screen.

VR is a multidisciplinary research field, as it relies on concepts of mechanical and electrical engineering, informatics (distributed systems), biology (human anatomy), and several other disciplines [16]. Main research challenges could be categorized into the following four types: software, hardware, human, and data/network factors [16].

A VR system usually incorporates the following three components [16]:

- *the sensors* - that track for example the user's body movement or the bend of the fingers and instruct the computer running the simulation to create new visual or audio signals. Examples of popular sensors in this context are gyroscopic sensors which measure the angular speed of their rotation or accelerometers which measure as the name already suggest the acceleration of movement [17].

- *the effectors* - that stimulate the user's senses. Examples of effectors include the head-mounted display which is sometimes also called stereoscopic display as in [17] or speakers.

- *the reality simulators* - which connect the sensors with the effectors in such a way that for example, a body movement tracked by the sensors would trigger a change in the shown image on the display (effector). Only through reality simulators the VR experience can create the illusion of being a real experience. Reality simulators have a stack of the technology behind them, including A) software, hardware, and operating systems to provide the required interface, B) frameworks and engines to run the applications, and C) software tools to create the applications. [17].

While some of the VR solutions can combine all three components in one system - like the Meta Quest II [19] others might have different functionality split up into different devices. A typical example of this is a laptop or PC that collects the tracking data and runs the simulation and a head-mounted display (HMD) that acts as an external monitor to show the output to the user.

3.1.1 A short History of VR

The following paragraphs are intended to provide an overview of the historical events that have led to the emergence of Virtual Reality.

Heilig & The Sensorama: VR as entertainment

Although VR still sounds very modern, the idea and its implementation are certainly not new. The first development approaches can be found in the early 1950s [20].

The earliest traces of VR development probably date back to Morton Heilig, a filmmaker, who worked on the topic in the 50s and received a U.S. patent for the first virtual reality arcade [18]. Heilig's vision was to build the movie theatre of the future [18]. With his creation, Heilig first put the idea into the world that one could design a virtual space that people could sense and experience if they would be part of it. The name he gave his invention - "Sensorama" - suggests this as well [18].

Heiling's Sensorama which is shown in figure 2 consisted of a chair and a kind of box where users would put their heads in and where the screen was placed [2]. The machine was showing users a movie about a motorcycle, moving on a freeway and was intended to give viewers the feeling of driving this motorcycle [2]. It lacked any options for interactivity and was built primarily for entertainment [2]. In addition, the machine was quite hard to move. The sensorama highlights that VR started rather as a native amusement machine, similar to the old arcades, than as a serious research project, training or learning device.

Figure 2: Heiling's "Sensorama" taken from [2]

Sutherland's Sword of Damocles: interactivity & virtual-creation

Another pioneer of VR is Ivan Sutherland, whose work on the "Ultimate Display" [21] has laid an important foundation for further developments. Sutherland is one of the first researchers to recognize the potential of using computer-based visualization as a means to represent objects that could not be realized in the physical world [21]. He sees the endeavor as a "mathematical wonderland" and developed the idea of a space in which the state of all objects and entities in it is determined by the computer [21]. Sutherland, therefore, coined the idea that one could virtually create situations and objects without having to deal with the limitations of the physical world.

Sutherland is also recognized as one of the first researchers to try a so-called head-mounted display (HMD), providing a visceral idea for later developments [22, 20]. The display which is shown in figure 3 was developed in 1968 and called "The Sword of Damocles" [22, 20]. The gadget was supported by a massive and bulky massive metal structure on the ceiling from which it would hang down and enable an operator to use it [2, 20]. Since the big metal structure could have eventually fallen anytime and hurt the VR user standing under it, it received this satirical nickname.

"The Sword of Damocles" was an innovative idea, as it could track a user's position and eye movement and then adapt the displayed image accordingly to where a user was looking [2]. Hence it first demonstrated some basic interactivity and showed how to implement the idea of a virtual 3D space that could be explored and experienced. However, the "sword" highlights also some core challenges of VR technology back in the day. It was not portable, relied on a specific setup, and was quite inconvenient. When comparing the solution to a modern one such as the Meta Quest 2 [19] it is also a good reminder of how far we have come in terms of technological advancement.

Figure 3: Ian Sutherland's "Sword of Damocles" taken from [2]

Batter & Brooks - Feeling what you see

In 1972 Batter and Brooks designed a VR system that was applied to teach elementary field theory [23]. Two versions of the system were built - one with visual and haptic feedback and another with just the visual output [23]. An experiment where users had to use a knob to move in a virtual plane showed that the ones who were trained with the first kind of display performed significantly better than the ones that used the second [23]. Hence they first showed that you could combine the feel and haptic information of objects with their visuals in the context of a VR application [18]. Furthermore, this experiment was one of the first to highlight the ability of VR in training and not just for entertainment purposes.

VR for training & controlling - Fighter Jets & Space Exploration

Because of these advancements in VR development, the technology quickly became highly interesting for the US military as they saw an opportunity to replace their expensive flight simulators which back in the 70s used to be mainly analog solutions that become practically useless anytime new planes were introduced [18].

One of the pioneers of this time was Thomas Furness who worked with the US Airforce from the 60s to the mid-80s [24]. Furness developed (head-mounted) display systems for pilots that would display the necessary information for controlling a jet based on their head position and thus avoiding the issue of showing too much information at the same time [24]. His vision was to connect the sensors of pilots â€" visual, auditory, and tactile â€" with the machine that they were flying [24].

Still, in the 70s other organizations besides the US military like NASA began to perceive VR as a valuable tool for training [20]. Especially the ability to virtually experience environments and situations that are hard to recreate or to get oneself into made VR a promising innovation. This especially applies to NASA which utilized the technology to conduct training for space exploration [20].

After the 70s: the wide spread of VR technology

In the 1980s and in the decades that followed, more and more industries recognized the benefits of VR for tasks involving simulation, visualization, or control [20]. The widespread adoption of VR naturally benefited its technical development. To have a better overview of how VR can be used nowadays the next section will present several applications of VR.

The 2010s: VR as portable mass product

The 2010s was the decade when VR became genuinely well-known among the general public around the world. 2013 Oculus Rift was introduced - a highly portable, affordable VR system [25]. 2014 saw the introduction of SmartphoneVR with the Google Cardboard - a VR solution that only requires a modern smartphone, cardboard, lenses, and rubber or glue to hold it all together [25]. Although these new solutions especially the SmartphoneVR are sometimes are not of high quality and lack the possibility of creating a realistic-looking virtual space they quickly spread the word about VR, they contribute largely to the spread of the technology.

3.1.2 Applications of VR

In this section, several applications of VR will be listed and shortly explained. Since VR is a widespread technology with countless possible applications, only a handful of examples will be presented in this section. Furthermore, the topic of education will not be covered here and discussed in more depth in section 3.1.3.

Therapy/Medicine VR can be successfully applied to reduce the pain and anxiety experienced by patients undergoing medical treatment [25]. Pain-reducing interventions that incorporate VR typically aim to distract the patient from reality and can be effective in both children and adults [25]. Especially the immersive nature of VR seems to be an advantage here. However not all VR approaches in this field focus on distraction and medical treatments. Virtual reality exposure therapy (VRET), as the name suggests, aims to confront patients with their threats in a virtual space [26]. For example, a person with a phobia of spiders undergoing VRET treatment might interact with a spider in VR while touching a hairy fabric [26]. Studies have already proven that this therapy is successful in patients with a fear of heights and flying [26]. VRET may also be effective for other anxiety disorders, but further research is needed to confirm this hypothesis [26].

Entertainment/Gaming. As discussed in section 3.1.1, the entertainment field is probably the oldest application for VR. Examples of VR applications in that sense include ones that serve primarily the fun factor of the users - such as massive multiplayer online role-playing games (MMORPGs, e.g. World of Warcraft) [27]. Nevertheless, one should not underestimate the impact of the role of these systems. Gaming VR solutions contribute largely to the further technical development of VR and can sometimes even effectively support users with health concerns such as balance and postural stability [28]. VR gaming solutions have even proven effective in the area of stroke rehab [29].

Business/Retail/Communication. 3D E-Commerce has recently received more and more attention as a new form of present products online that can overcome several limitations of traditional E-commerce [30]. Although they usually cannot simulate the real-life retail environment, they contribute to enhancing the shopping experience [30]. Furthermore, they create new ways of conducting business online. The most prominent example is probably the metaverse - a whole shopping world with streets and stores that is completely online [31]. Besides the applications in retail, a range of other business use cases exist like the conducting of 3D-video calls [32].

Design/Architecture/Real Estate. When it comes to designing an object like a building VR can prove to be a valuable tool to both create and communicate a design [33]. In addition, VR offers a different design experience to designers by allowing them to interact with their creations in real-time [33]. Even when it comes to presenting real estate to potential customers, VR can be applied [34]. Applying VR in this field comes with the advantage that apartment tours can take place anytime and anywhere around the globe, saving customers a great deal of money and time [34].

3.1.3 Education & VR

The idea of using VR in education or training is by far from being a novel one. As already discussed in section 3.1.1 first examples of using VR in training go back to the 70ies, others [35]. However, back then only a few organizations have access to these technologies. Until the early 2000s, other institutions such as schools lack the financial capabilities to buy the required equipment to use VR, and the preparation of content in VR is usually considered too complex [36]. As a result, the applications for VR in education are limited to relatively primitive content such as simulating animals moving in space [36].

In the 2010s, the situation fundamentally changes. With devices like the Google Cardboard [37], massive adoption of smartphones worldwide, and the possibilities of web VR, just about everyone can tap into the possibilities that VR offers [27]. A milestone in this development is a chieved in 2013, when Oculus Rift, one of the first affordable VR solutions, is released. Nowadays, a large number of manufacturers offer consumer-priced VR HMDs [27]. As a result, VR solutions have become finally feasible for education. There are a vast number of examples of VR education solutions. However, the full potential of using VR in education is far from being exploited [38].

Education & Training

Before discussing examples of VR in education, it is important to clarify the meaning of the term 'education'. During the literature research, it has become evident that the terminology used can lead to confusion, especially since the scientific community itself does not agree on what exactly "education" or "training" means [39]. In general, it can be noted that education is a more general, less specific, and less hands-on term than training[39]. In this paper, however, the term education is defined more broadly, simply as a process for acquiring knowledge through a learning experience.

Use Cases

Nowadays, there exists a multitude of examples of the use of VR systems to teach people about certain topics. Most of the application focus on small specific knowledge such as rules for fire safety [40]. A common theme seems to be that VR solutions often take advantage of the fact that they can simulate situations where people can learn something that would be too dangerous to observe or experience in real life. A good example for this is again the example just mentioned: fire safety, both for adults [41] or children [40].

Another common thread in VR education seems to be the use of VR to explain concepts that are often too complex for traditional visualization approaches. An example would be the visualization of deep neural networks in a 3D space [42, 43]. Similarly, VR solutions can take us to learning spaces that we could never experience in real life. An example would be seeing molecules and cells in 3D as if they would be as big as we are [44]. Or they can take us to places that are as of today not reachable but might be in the future - such as other planets [45].

Besides the approaches just discussed there exists the idea to leverage the advantages of VR such as immersion which can help to avoid distractions of students, to create a virtual classroom [46]. This virtual classroom then works similar to a "normal" classroom but comes with enhanced capabilities such as showing students 3D content [46].

The idea of using VR as a tool for teaching history can also be found in the literature. However, it usually focuses on the concept of giving students a virtual time machine to witness certain events or moments in history [47]. And not from the notion of giving students a tool to understand the evolution of a place over time, which is what this paper is dealing with.

Learning Theories

There exists several learning theories that help to explain what influences the application of VR could have on the learning behavior and outcomes of users. Examples include Constructivism, Social Cognitive Theory or Connectivism [48].

Constructivism builds upon the idea that people are learning by constructing meaning from what they experience [49]. An important benefit from the perspective of Constructivism is for example that VR offers the possibility to explore "authentic" simulations of situations and environments that they would otherwise not be able to experience due to monetary or physical limitations [48].

Social Cognitive Theory sees learning as something that happens when the learner observes and emulates others [50]. it proposes that the social environment has a direct influence on the motivation of the learner [50]. Hence it is always valuable to consider the social context in which a VR application will be used.

Virtual Memory Places

An interesting aspect of teaching and VR that was discovered by Krokos et. al [51] is that VR displays can enhance the use of the users' vestibular and proprioceptive senses, as compared to standard 2D displays. As a result, they can leverage better spatial awareness to create memory palaces [51]. The "Memory place" method is a well-known tool in learning theory that people use to improve their memory capability by imagining the information in a spatial context (for example imagining a castle that has important information in each room) [51]. By utilizing this method virtual environments have proven to hence users' memory recall abilities, as compared to standard 2D-solution [51].

Other Opportunities

Besides the benefits just discussed VR education applications offer a range of other advantages [48]: they can communicate spatial knowledge better, they help to boost the motivation of learners, and they can improve collaborative learning (through improved remote participation for example) and the offer more possibilities for experimentation.

Challenges

Besides these positive aspects, there are a number of barriers that are partly responsible for the fact that VR is still far from becoming a mainstream educational tool and the potential of the technology is nowhere close to being fully realized.

A major problem with integrating VR solutions into the traditional education system is the isolated learning experience [27]. This prevents teachers from applying many classical pedagogical methods and makes the application in a traditional classroom setting extremely difficult [27].

A further challenge lies in the creation of appropriate content [27]. In general, there still exists still too few developed VR solutions and teachers do often not have the capabilities to create their own content [27]. The ability to use cameras to record 360-degree content with a camera that can record in 3D seems promising but does not solve the issue yet [27].

Other problems can be found in the VR hardware itself [27]. The availability and financial affordability are largely given nowadays, as already mentioned before. However, most of the VR HMDIs are designed for the entertainment sector and not for the education domain [27]. In addition, they often require time-consuming software updates [27]. Both circumstances make the devices potentially uninteresting for educational institutions such as schools [27].

Finally, since VR is not yet a common educational tool, teachers and students often need time to get accustomed to the new technology [52]. In a study from 2019 Southgate et. al discovered that the introduction of VR into the classroom can make students feel uncomfortable and some even embarrassed [52]. The tendency to react negatively to the adoption of VR increases when students have not been exposed to VR before the introduction [52].

3.1.4 Different Approaches to VR

This section covers several VR terms that can be applied to differentiate different kinds of VR systems. There exists a vast amount of ways one could apply and design a VR experience. However, generally, all of them can be categorized in one of the following two categories:

Native & Traditional VR

Native VR refers to the creation of a completely new digital environment in which one can see in all directions and with which it is possible to interact [14]. This approach focuses on creating a whole digital world of which the user can be fully part of [14]. This type of VR focuses on immersion and in such a VR application one can look in all directions in a 360-degree view, just as in the real world [14]. On the other hand, we speak of the traditional approach when VR is applied for entertainment purposes, similar to a cinema or theatre [14]. An example of this type would be a video shown in a highly realistic form [14]. In this approach, the user is seen more as a passive consumer that gets a VR representation of an artwork such as an act or film, and does not interact with the content. A goal of traditional VR, therefore, is to open up new distribution channels and attract a larger audience by offering them a new kind of experience [14].

Besides there exist a few terms that refer to a specific subset of all VR systems.

Web VR

In recent years, one form of VR, has gained significantly in popularity - namely web VR [53]. The term refers to VR applications that are embedded in HTML and made accessible through a website [53]. Reasons for the recent success of this type of VR can be found on the one hand in the spread of HTML5, which has led to a rapid improvement in the performance of websites and thus also of apps built into them [53]. And on the other hand in the fact that access to web VR has few monetary entry barriers since inexpensive devices can be used and apps can be accessed directly via the standard browser [53].

The motivation to implement VR via WebVR is largely found in the circumstances that have made the web itself such a grand success [54]. To be more precise we are speaking here about the open and standards-based approach that allows almost everyone to generate content, as long as they comply with the developed standards [54]. The ultimate advantage of WebVR is therefore its ability to bring VR to the "masses".

3.1.5 Frameworks for Web VR

There exist a number of different standards or frameworks to implement web-based VR solutions:

WebXR

The WebVR standard or WebXR Device API (XRDA, the more recent name) was developed with the idea in mind of offering a platform-independent interface to the main abilities that are shared by all AR and VR devices [54]. XRDA promises to provide VR developers with a standardized abstraction layer that enables real-time rendering and grants access to interaction devices of the underlying XR platforms [54]. The interface is kept siple and a vast number of interaction controllers are made available to the developers [54]. A popular are application are for WebXR are the management of smart cities and urban planning [55].

Libraries

Besides the XRDA there exists a number of frameworks or libraries that offer developers an easy way to generate new VR applications with a relatively small amount of written code. Examples include

- A-Frame
- Primrose
- threejs

3.1.6 VR Challenges

This section quickly illustrates some of the major issues with VR systems and discusses solutions proposed by the literature.

Cybersickness

... can be defined as a combination of symptoms expressing discomfort that users experience when engaging with a VR application [56]. These symptoms can be similar to those of people with motion sickness [57]. Examples include disorientation, vertigo, nausea, sweating, headaches, and even vomiting [57]. Cybersickness, which is sometimes called simulator sickness, is polysymptomatic and polygenic, meaning that its occurrence depends on more than one gene [58]. The sickness is not caused by one single cause, but by several different ones [57]. As a result, it is rather complex to study and analyze.

In most cases, cybersickness does not pose a serious threat to the health of users, as most of them avoid other VR experiences or reduce their screen time when they are feeling uncomfortable during the experience and thus avoid the risk of aggravation of the disease [57]. However, two important risks associated with the topic should be considered: The first one is that symptoms of cybersickness can sometimes occur hours after the experience [57]. This can become a safety concern if the user is, for example, driving a car while experiencing these symptoms [57]. Secondly, the illness logically prevents users from continuing to utilize VR systems and thus potential target groups for VR applications are lost. Hence cybersickness poses a barrier to the commercial success of VR systems.

Presence & Cybersickness

The occurrence of cybersickness is sometimes linked to the feeling of presence [56]. Presence in the context of VR systems can be described as the feeling or the illusion of being actually present in the virtual environment [56]. Several studies have suggested that there is a negative, illness-causing influence of presence on cybersickness that is driven by the process of sensory integration [56]. This is particularly dramatic since achieving this illusion of presence has been one of the primary goals and challenges of VR development for over four decades now [56] - ever since Minsky [59] first coined the term telepresence. Therefore, to fully exploit the benefits of VR systems, further studies are needed to investigate the relationship between presence and cybersickness [56].

3.2 Augmented, Mixed and Extended Reality

The concept of VR is to be distinguished from augmented reality (AR) - while the visual experience in VR is based on a completely virtual world, that of AR includes both digital and real, physical elements [60]. AR thus creates a hybrid "world" of reality and virtuality since it enables the display of computer-generated objects in the real world [60]. To realize this vision, AR uses display solutions like see-through HMDs [61]. A famous example is Google Glass, which consists of a normal glass frame and a small glass plate onto which digital images can be projected [62]. AR solutions like Google Glass can also be applied among other areas in supporting surgeries [62]. Or they can enable computer-assisted cooperative work in a three-dimensional space by sharing an identical virtual environment with a range of different users [61].

Figure 4 shows the so-called reality-virtuality spectrum developed by Kishino & Milgram which shows that an AR experience works to a great extent with the already existing real environment [3].

Mixed Reality The combination of real and digital elements in a display solution can be called Mixed Reality (MR) [3]. MR includes all experiences that are not completely real - like viewing a bird in the sky in real life or virtual - like seeing a standard graphic simulation generated by a computer [3].

Extended Reality All of the technologies just discussed - VR, AR, and MR - can be grouped under the umbrella term Extended Reality (XR) [63].

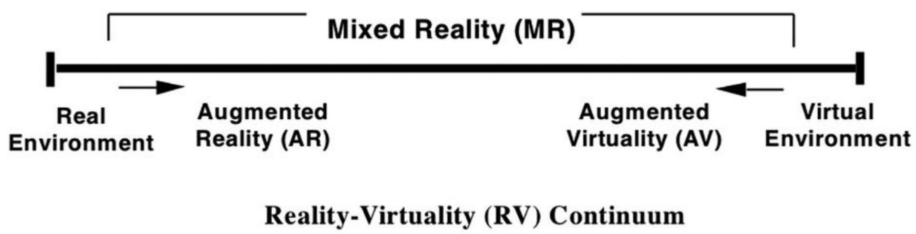

Figure 4: Reality-Virtuality Continuum coined by Kishino & Milgram [3], Visualization taken from [4]

3.3 OpenData

Through the concept of so-called "OpenData," the public receives access to a certain subset of all data [64]. A central aspect of the concept is that this subset is then freely available for usage, re-usage, and re-distribution and that it is data with a certain public interest, which is usually collected by governmental institutions [64]. Tim Burners-Lee further extends this definition by stating that open data should be stored in a way that enables direct manipulation and that a central goal of open data is to make national, and local data globally available [65]. In addition, open data can be seen as an initiative for so-called smart governance [66]. Smart governance as compared to e-governance (which simply stands for providing government service in e-lectronic form) aims to reinvent government services and improve citizen engagement through the integration of new technologies and the utilization of data [66].

The term open data can also be interpreted as a movement - closely related to the OpenSource movement, but different in that in the context of OpenData, applications can also be developed that do not have a publicly available source code [64].

In recent years, the amount of open data has increased rapidly [67]. Among the benefits of open data are an increase in government transparency and thus the ability to counter corruption [67]. Furthermore, providing open data can lead to an improvement in cooperation between governments and their citizens [67]. In addition, it can enable independent developers to build new applications that add value to society [67].

Unfortunately, there exists a number of barriers that prevent the full exploitation of all positive aspects of open data [67]. These barriers can exist for users, providers, or both of them [67]. For example, a barrier to the user would be terms of use, which could limit the user from utilizing the dataset in the way they need to, for example, to create a particular application [67]. Or the data could be stored in a user-unfriendly format and could for example lack machine-readability [67]. A barrier for providers could be that they are legally obliged to ensure the privacy of the published data, which means that they would eventually have to anonymize the data - an effort which some providers might not want to take [67]. An example for an issue that would affect both users and providers would be the lack documentation [67].

3.4 Visualization Theory

Visualization is a complex topic that has many facets and a multitude of effects. Already small circumstances in a graphic can lead to misleading or even manipulative communications - a good example of this is optical illusions. To create a suitable visualization, it is therefore of great importance to know how visual elements affect the viewer. Several theories have been developed for this purpose. The following chapter deals with, therefore, theories in more detail.

Optical illusions

As just mentioned good examples that illustrate the complexity and challenge of visualization are optical illusions. In a paper [5] from 2006, Poloschek and Bach present the so-called Shepards's Turning: Looking at Figure 5 - the left table seems to be narrower and more elongated than the right one. As a result of how the tables are presented, we perceive them as 3-dimensional objects [5]. However, what we usually do not see is that the 2-dimensional surfaces of the two tables are completely identical - on the right and on the left we see the very same parallelogram (as the lower graphic explains) [5]. This example illustrates what a strong impact a dimensional can have in visualization - which is the basic topic of this work.

In their work [5], the two scientists compare our perception and optical illusions are a good example of Plato - in which people see only the shadows of the actual entities. Therefore, it is all the more important to discover the limitations of our perception and to be aware of (possible) optical illusions.

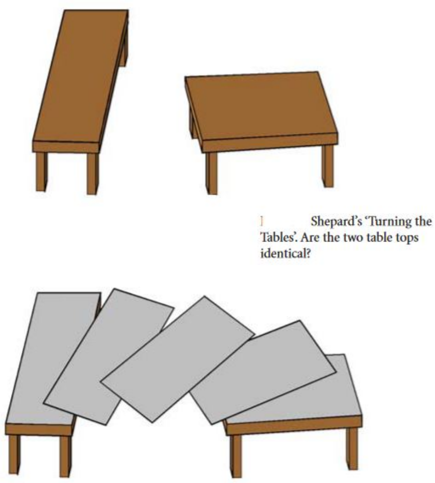

Figure 5: Optical Illusion as shown in [5]

3.4.1 Types of Visualization

When it comes to visualizing a large multivariate dataset one has a range of different possibilities to do so. Keim and Kriegel grouped these possibilities into the following six types of visualizations: [68]

- **Geometric Techniques**

  The basic idea of this type is to map or project the data to a geometric space like a coordinate system. Popular examples of this kind of visual include scatter plots, parallel coordinates, or landscapes.

- **Icon-based Techniques**

  ... map the features (columns of a dataset) to certain attributes of an icon. An example of this would be Chernoff-Faces. Here each data record is visualized as a face and the values of the record decide how large parts of the face are. For instance, a data record could have the feature "revenue" and a big revenue could result in big eyes and small revenue in small eyes.

- **Pixel-Oriented Techniques**

  The rationale behind these techniques is to map each of the feature values of the different data records of a dataset to a one-colored pixel. This technique is quite popular when it comes to really large datasets. Examples of this type of visual include space-filling curves, spiral techniques, or circle segments.

- **Hierarchical Techniques**

  ... create visualizations by partitioning the data hierarchically into subspaces. Popular hierarchical techniques are Treemaps, Dimensional Stacking, and Worlds-within-Worlds.

- **Graph-based Techniques**

  ... visualize the data as the name already suggests as a graph/network of nodes/vertices and edges. Various kind of graphs exists. A DAG (directed acyclic graph) is for example a graph that has no cycle which means that you can not navigate in circles in the network.

- **Hybrid Techniques**

  ... combine several of the just discussed visualization types.

3.4.2 Geographic Visualization

Besides the just introduced basic types of visualizations there exist a range of specific visualization techniques that are arguably sub-types of the ones just introduced. The one most relevant for this study is geographic visualization. Over the years various definitions of geographic visualization have been proposed. Taking a learning perspective it can be described as the generation and application of visuals to enable people to think about, process, and understand geospatial information [69]. Or taking a more research-driven approach as visualizations that allow people to explore information and develop hypotheses and problem solutions [70]. It can be seen as a complex process that integrates techniques from a range of visualizations research fields such as cartography, information visualization, and geographic information systems (GIS) [9].

One of the most prominent examples of geographic visualization in the context of problem-solving is probably John Snows Cholera map from 1854 [6] - as shown in figure 6. Back in the mid-19th century, a cholera outbreak happens in London [6]. Snow back then is one of the first ones to identify the cause of the outbreak: the city's water supply [6]. The map visualizes cholera-related deaths as black bars at the location where they occurred [6]. Without much explanation viewers easily see that more deaths are happening near a certain pump (in the left bottom corner of figure 6). Although it is rather unlikely that the visualization was the reason why Snow identified the outbreak of the disease [6], still this map is a great example of how you could apply visualizations to explore, solve, or at least communicate complex problems that have a spatial dimension.

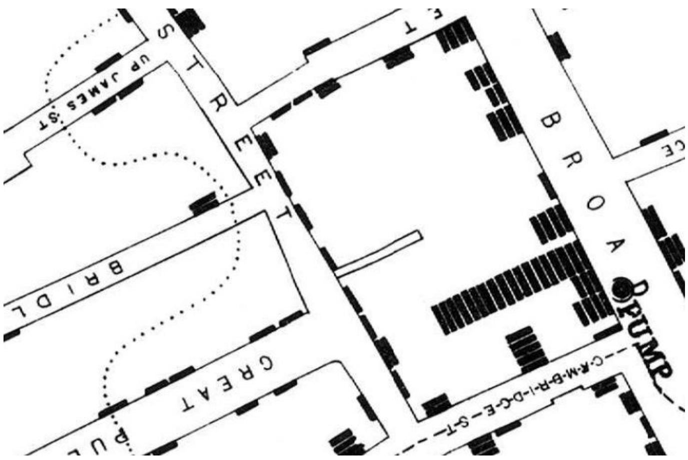

Figure 6: John Snows Cholera map taken from [6]

Geovisualization has a long history, dating back even to the stone age when humans made map-like wall paintings [71]. Computer-based visuals can build upon the cartographic knowledge developed over centuries [71]. However, although many map creators can agree on some basic principles such as using darker shades for higher or more important values, the creation of maps remains an artistic process that builds upon imagination and is hard to standardize [72].

Objectives of Geovisualizations

The scope and objectives of geovisualization projects can be manifold and complex [71]. MacEachren et al. [9] see the following level of objectives that visualization can aim for:

- Level 1: *presentation*) the lowest level is concerned with just the plain representation of geospatial information. It focuses on communication and sharing already known information
- Level 2 *analysis and synthesis*) This level focuses on the application of geovisualization to draw simple conclusions from data and provide basic insights into the interplay of specific circumstances.
- Level 3 *exploration*) This high-level goal of geovisualization involves customized and highly interactive tools that enable the discovery of the unknown and the construction of novel knowledge. Geovisualization is seen here as an active tool in the human thought process, whose ultimate goal is to transform data into visible information. Dykes et al. [73] consider interaction with data a central tool for knowledge discovery for both senior researchers and students.

Stakeholders and challenges of Geovisualizations

The stakeholders of geovisualization applications can be highly diverse and the handling of them can be complex [9]. Roughly defined, there are three groups of stakeholders [9]:

- data generators
- developers/researcher
- end users

Data Generators

Governments for example often act as spatial data generators [9]. They fuel therefore the creation of new visualizations. However what data is collected and in what form largely varies from nation to nation [9]. This generally is a major research challenge and calls for some form of standardization that would facilitate international collaborations [9].

Developers

The challenge just mentioned in the last paragraph is of special importance to the next group of stakeholders - the creators or researchers [9]. Since this group can be multidisciplinary and collaborates often internationally it is important to overcome potential issues such as language or technological barriers [9]. Furthermore, there is ongoing research happening on how improvements in methods and tools can be quickly spread to a global and multidisciplinary research community [9]. More generally, one could say that it is a grand challenge to train and educate people to employ geovisualization methods effectively [74].

End Users

There exists a wide range of different challenges that arise when trying to adapt a geovisualization to the needs of the users. The most important for this thesis was already named in section 1 namely how to exploit the opportunities provided by virtual environments by improving our understanding of 3D interface design and interaction methods in the virtual space [9].

An additional research challenge that is highly relevant to this thesis is to investigate the contexts in which geovisualization can be reasonably applied [9]. In the past, there have been voices claiming geovisualization to be beneficial for science, decision-making, and education [9]. However, there seems to be a lack of studies that investigate whether these hypotheses are scientifically valid or not [9].

Further research questions arise when it comes to integrating dynamic elements into geovisualization [74]. The most obvious is concerned with specifying the cases in which the advantages of an animated map outweigh those of a static map [74]. Additionally, if it is a temporal animation, it can be hard to communicate the temporal dimension in a meaningful way [74]. Research is for example needed to determine which display times (that can include rapidly changing animations) fit to the time in the real world [74]. In other words, designing an animation in a way that is not too fast or too slow for the user.

Other challenges exist in the context of customizing geovisualization to the users - for example when trying to design them accordingly to the individual cognitive characteristics [74]. This includes for example the implementation of user-profiles or descriptions into geovisualization applications and focuses on the question what individual users like or dislike [74].

Apart from the research challenges just mentioned, there exist several others, but they are not included here because they are not as relevant to this work.

3.4.3 Advantages of Visualization

Cognitive Benefits

Creating a visualization of content can require a significant investment of time and money. Other representations of the same content, for example, plain text, are often far more efficient in terms of costs. Therefore, it is important to be clear about why visualization is worth the effort. Shneiderman et al. identified the following four cognitive benefits of information visualization [75]:

- The search for information can become easier and more effective
- Patterns can be recognized better and faster
- Memory and processing resources of users can be improved
- Information can be stored in a manipulable and interactive form

According to them visualizing information serves us by improving our cognition [75]. The purpose of visualization should be the insight one gain from it and not the picture or graphic itself [75]. This may sound trivial but is all too often forgotten in practice. Therefore, before developing a visualization, it is of major importance to think about what benefits a visualization has over simpler representation forms, such as plain texts.

Perceptual Benefits

The advantages just discussed above can be grouped as cognitive advantages [7]. Besides these kinds of benefits visualization can have perceptual advantages as well [7]. The main argument behind the perceptual benefits hypothesis is that our visual sense can transmit the largest amount of information and delivers more information to our brain than for example our auditory sense [76]. According to Ware [76] it is therefore only logical to exploit the channel that can deliver the maximum amount of information to our brain. Shneiderman et al. identified the following two perceptual benefits of visualization [75]:

- Perceptual inference operations can be made possible
- Perceptual monitoring can be enabled

There exist two major psychological theories that help to understand how vision can be applied to achieve the most effective perception of features and shapes [76, 7]:

- Preattentive processing theory [77] ... which describes at a low level how the processing of features in visualizations can happen in an effective way.
- The Gestalt Laws ... which explain principles or laws that our brain applies to make sense of visualization. These principles are further explained in the next section.

3.4.4 Preattentive Processing

Preattentive processing builds upon the hypothesis that the process of visual analysis can be separated into two phases: A) an early preattentive phase, in which we grasp only simple features in parallel and in space, and B) a second phase, in which we need focus and attention to combine different features into coherent, meaningful objects [77]. The theory focuses, as the name already says on type A, and claims this phase happens automatically and is triggered therefore subconsciously [77].

The theory explains why we can register some visual features in an extremely fast and accurate way [7]. Figure 7 shows numerous points in two different colors. The special attribute of this visualization is that we extremely rapidly see that one dot in the center is colored in a different way [7]. This happens seemingly immediately and does not require us to think about it in any way.

Color is generally a feature that we can process to some degree preattentively, without having to focus our attention on it [7]. However, when we see a picture with a vast number of different colors, it requires our full attention to identify how many different colors are present [7].

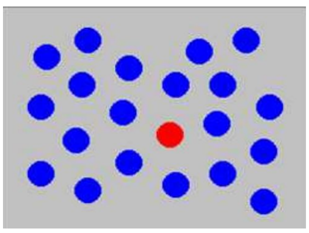

Figure 7: Example for preattentive processing taken from [7]

3.4.5 Gestalt Laws

Gestalt psychology [78] is concerned with human perception and advocates the thesis that what we perceive (e.g., a photo collage) is more than the sum of its parts (such as individual photos). Humans do not only perceive individual pieces but patterns and the way pieces are put together matter [79]. To categorize the various discovered effects in Gestalt psychology researchers have established various rules - sometimes referred to as laws or principles [79]. In the course of this research, a wide variety of these rules have been established. One often finds a different set of laws depending on the research paper. In an article from 2001 by Chang et al. the following eleven rules are presented that are some of the most common ones in the literature, in general, [80]:

1. **Symmetry/Balance** - Humans have a sense of balance and because of this, a visual object that is not symmetrical or imbalanced tends to be perceived as incomplete. A complete visual element is characterized by an equal weight on both sides. Figure 8 shows an example of this principle and most of the other principles that are discussed in the following paragraphs.

2. **Continuity** - Viewers have the habit of following a direction given by the visual field. If we see for example a horizontal path through a meadow - starting at point A and ending at point B - we assume that everything in between (when following the path with our eyes in the direction from A to B) also belongs to the path, even if these areas are hidden.

3. **Closure** - A related law to the one just mentioned is the Closure principle. It states that we tend to turn incomplete forms completely in mind. For example, if we see an object like this |_| - we can still perceive it as a U, even though the parts are not connected.

4. **Figure & Ground** - As humans, we assign elements of the visual field to either the foreground or the background in our perception. This assignment influences what we see in an image. As illustrated in Figure 8 - we either see a vase or a goblet - depending on whether we consider white or black as the background color.

5. **Focal Point** - In visualizations, humans consistently look for a key element in a group of items. Take, for example, the following elements: — . - Here the point automatically attracts our attention more than

the multitude of dashes (-) it becomes the center of our attention - the so-called focal point.

6. **Good Form** - Humans generally tend to transform a stimulus into the best possible form and thus simplify the meaning.

7. **Past experience / Isomorphic Correspondence** - In order to be able to make use of visualization, we often refer to our past experiences. If we see for example a picture or a symbol - like a "?" - we assign a meaning to it according to what it has already stood for in the past. We could then interpret the symbol as a sign for the help menu (in a computer program) because we saw it before in another program.

8. **Proximity** - We as humans have the habit of seeing objects that are visually close to each other in visualization as elements of the same group/kind, even if these elements represent quite different things.

9. **Similarity** - Viewers tend to view elements that look alike or very similar as a cohesive group. Thus, these elements are perceived not only as individual objects but also as composite entities.

10. **Unity/Harmony** - the next rule is closely related to the rule just mentioned. If elements that the viewer assigns to the same group are not in the same form or next to each other, this can lead to confusion. People then often perceive these images as inharmonious or chaotic.

11. **Simplicity** - This law states that we usually try to simplify visualizations to the extent that we understand them. If there are several interpretations for a given graphic, we tend to choose the simplest one.

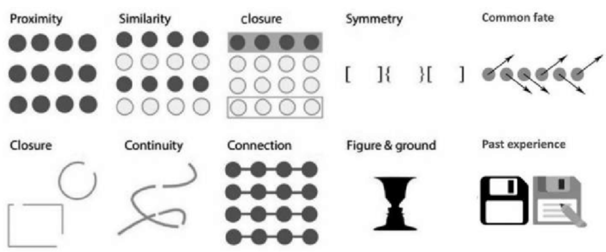

Figure 8: 10 Examples for Gestalt Laws shown in [8]

3.4.6 Dimensionality in Visualization - 2D VS. 3D

To begin with, it is important to notice that dimensionality in visualization in general can be applied to communicate more information with just a single plot/figure [81]. A classical example of this would be a scatter plot - several points in a coordinate system with an x and y axis (two dimensions) that allows showing more characteristics about data than if you would only have a line plot - points on a line (1 dimension) [81]. In that sense adding a z-axis to a coordinate system could naturally improve the expressiveness of a plot and allows us to display for example surfaces [81]. However, when only a 2-dimensional display is available to show this three-dimensional space problem starts to arise the visualization of the elements naturally starts to overlap [81]. VR is able to create a 3D dimensional virtual space and can therefore help to overcome these limitations that we face with conventional 2D displays.

3.5 Human-Computer Interaction

The term human-computer interaction refers to the interactivity of subjects with technology and includes the users-experience with the interaction, as well as the interaction environment [82, 83].

Especially in the context of VR, there have been in the past numerous open research questions on Human-Computer Interactions [84]. The reasons for this can be found in a large number of different VR systems and their diversity in terms of interaction and application areas [84].

3.5.1 Interface Design

4 Practical Part

4.1 The Use Case

The goal of the practical part of this work is to build an application that tells the story of a district - more precisely the 7th district of the city of Vienna. The seventh district is one of the city's oldest districts, originated from several suburbs, and has a history of more than a thousand years. The focus of this work is however not to tell the story of the district as accurately as possible, but to build an application that can serve as a model or template of how to convey and communicate spatial information on the one hand via 2D and on the other hand via 3D visualizations.

The knowledge that is to be communicated by the implemented application can be described as follows:

- Gaining a sense of how the district has developed over time. For example, when what infrastructure was built, etc.
- Develop an understanding of what patterns exist in urban development. For example, houses usually develop around the churches
- Getting an idea of which buildings were the most important ones in each period and which buildings, were typical for which decades.

Compared to a mere textual description of the presented information, the visualization should excel by the following advantages:

- enabling a faster pattern recognition
- allowing the user to take in and process more information
- enhancing the memory resources of users

The basic idea of both 2D and 3D visualization is to show the buildings of the district on a map or a virtual space and to enable "time travel" in the visualization with the help of animations. The user should be able to select different years and then see the buildings that stood at the respective years.

4.1.1 A short History of the 7th District

The following paragraphs are dedicated to giving a small overview of the history of the 7th district. In total there exist two information sources of major importance on this topic: Rotter's work from 1925 [85] and Faber's work from 1995 [86]. Furthermore, there are some other publications, e.g. on the history of Vienna, in which historical information about the district can be found. However, these do not cover the subject in sufficient detail. If not otherwise indicated the information presented in the following paragraphs is therefore taken from [86] - as it is the newer and more complete documentation:

The first important year in the history of the 7th district is the year 1202. Although archaeologists discovered that there were already first settlements and infrastructures on the present territory of the district before this year (one could mention for example a Roman commercial road, which runs along today's Mariahilferstrasse), no documentation about these has remained. In 1202, a village - Zeismannsbrunn - is mentioned in documents for the first time. That village is thus the first recorded settlement in the present area of the district.

The history of this village is significantly shaped by Dietrich der Reiche (German for "the Rich") - a coin master, city judge, and one of the most important persons in the city of Vienna which back in the days covered approximately the area of the current 1st district. In 1212 Dietrich donates a chapel to the village, which he dedicates to Saint Ulrich and later develops into today's St. Ulrich's Church. Around this chapel and later church, the later suburb of St Urlich develops. After Dietrich, who owned most of the land of that time, dies, his heirs sell his properties, to a number of new parties, among them the Order of the Scots. Based on the division of the land, which took place in the course of the sale, the land was divided into different areas. The partition marked the boundary of the settlements that would later develop into the suburbs of Spittelberg, St. Ulrich, Neubau, and Schottenfeld.

In the following decades, the settlement flourishes and several buildings are erected. One of the reasons for this positive development is that rich citizens of the city of Vienna at this time often are choosing to live both inside and outside the city, as the city walls offer protection, but the city itself is overpopulated and polluted. With their stays outside the walls, the rich and powerful bring plenty of funds and invest in the suburbs' development. In this period - more precisely in 1408 - the chapel of St. Ulrich is transformed into a real church, which at that time quickly becomes the center of the settlements.

In 1529 the Turks besiege Vienna for the first time. Many houses fall victim to this siege. Among them was the Berchtesgardener Hof. In 1683 Vienna is besieged for the second time by the Ottoman Empire. Again, a range of settlements on the present territory of the district is destroyed, including the Oberhof.

In the late Middle Ages, an increasing number of citizens from the Habsburg hereditary lands heads for Vienna, as the city was considered to be the economic center of the empire. However, as the former official walled city was already reaching its capacity limits, a growing amount of people are settling in the city's surroundings. This leads to massive population growth in the city's suburbs, which included several settlements on today's 7th district territory.

In 1850, by a decree of the former Emperor of Austria-Hungary, Franz Joseph, the settlements officially become part of the city of Vienna. This is a logical decision since the area was almost continuously populated and had grown more or less with the rest of the city.

At the beginning of the 20th century, the district stands out with its cultural achievements. In the early 1900s, a great number of cinemas are built. Already in 1888, the Volkstheater was built. In this decade it becomes one of the most important theaters in the city and presents, among others, plays by Arthur Schnitzler and Franz Grillparzer.

Several important events happen in the district during the Second World War and its prehistory. In 1932, members of the underground Nazi organization Vienna SS carry out an attack with tear gas on the department store Gerngroß. In 1934, the National Socialist putschists of the "July Putsch" gather in the Turnerhalle in Siebensterngasse in the 7th district [87]. From there, SS men disguised as soldiers and policemen enter the Federal Chancellery, killing former Chancellor Engelbert Dollfuß and several others, in hope of unification with Nazi Germany [87]. The coup fails, but a few years later Austria becomes part of Nazi Germany. During the time of the Second World war several nazi penal labor camps are established, marking some of the darkest days of the district's history.

After the Second World War, the district stands out again mainly for its culture. Among other things, a former cavalry casern (the Hofstallungen) is transformed into the "Museums Quartier" - Vienna's biggest museum, art, and leisure complex of its kind.

4.2 The Dataset

The dataset[1] used to build the application is taken from the website of Open Data Austria (data.gv.at) and was downloaded on the 11th of March 2023. It contains information about 15 542 historically important buildings or other objects (such as statues) for all 23 districts of Vienna - as you can see in Table 1 on the left side. These objects are described with a total of 27 features that you can see in table Table 1 on the right side.

Table 1: Description of the Dataset

District	No. Objects
1	2 573
2	888
3	852
4	369
5	277
6	386
7	350
8	308
9	558
10	787
11	485
12	503
13	689
14	792
15	395
16	470
17	358
18	357
19	770
20	278
21	1 053
22	1 326
23	718
Total	15 542

Feature Name	No. Rec.
fid	350
objectid	350
shape	350
address	350
other_name	30
type_of_organization	30
type_of_structure	139
type_of_event	1
kind_of_object	85
named_by	113
district	285
district_txt	161
date_to	1
date_from	73
insert number	1
former_designation	21
category	350
category_txt	350
location	17
name_page	17
pageid	350
celebrities_residents	8
celebrities_persons	12
pageid_name	350
city plan	350
weblink1	350
se_anno_cad_data	0

[1] https://www.data.gv.at/katalog/dataset/wien-geschichte-wiki

In total, there exist 350 records of objects that are or were located in the 7th district. However, not all features for all objects are recorded (as shown in Table 1 on the previous page on the right side). The most relevant features for the application are the shape and address of the object - which contains the spatial information of it (shows where it is located), those features that help to explain what the object was (which type of organization or structure or event), The date_from column and the data_to column which give the information on when the object was built and eventually destroyed.

Open Data Austria

The source of the data just introduced is a website[2] developed by the Austrian government which aims to boost the visibility and transparency of national data by introducing a central data catalog, that records the metadata of the decentralized data catalogs of the administration in Austria and makes them retrievable. The platform offers information on a wide range of topics such as health, culture, or transport and lists more than 40 000 data sets (as of early 2023). One reason for the existence of the platform is the European Union, which is considered a global pioneer in promoting open government data with its public sector information directives dating from 2003 and 2013 [88].

Open data initiatives like the one just introduced usually try to follow the so-called FAIR principles [89] meaning that data should be F-indable) which is include requirements such as rich metadata that is indexed or registered in a resource that is searchable; A-accessible) which means that conditions for accessing the data should be clearly specified (for example an open, free protocol should be used); I-nteroperable) which refers to aspects such as the use of a formal, accessible, knowledge language or common vocabularies; R-euseable) which means for example terms that the terms of usage are clearly defined.

The principles just described are largely followed by the website of Open Data GV. The respective dataset is relatively easy to find, has rich metadata, is accessible via an open, free protocol (can be accessed with a standard web browser) and the usage terms are clearly specified. The re-usage of the dataset is permitted under the Creative Commons License "Attribution 4.0 International" [3] meaning that the data can be shared and adapted in any way, as long as appropriate credit given, the license is named and possible changes are listed.

[2]https://www.data.gv.at/

[3]https://creativecommons.org/licenses/by/4.0/

File Format - CSV Files

The dataset used is available in a range of different formats. It was decided to download it as CSV file as this file format is easy to use for building the application. CCSV files are one of the most commonly used file formats for open data [90]. The abbreviation used to stand for comma-separated values [91]. Nowadays it means character-separated values which pays tribute to the fact that many data providers used different characters or commas as separators (like ";" or ",") [91]. The principle behind CSV files is the following: tabular data is stored as plain text, each new line (row) in the text represents a data record that has a number of values (columns), and the start or end of a value in a line is indicated by a separator (like a ";") [91]. Besides that CSV files sometimes also have header lines that provide information on the type of values you have in one row (an example for this would be "Name; ID; Location").

Missing Values Analysis

Data Transformation

Web Scraping

Web scraping refers to the task of retrieving information from one or a range of websites and saving the information in a new, simple structure (for example in a CSV file) [92]. In the case of this work, web scraping is applied to partially solve the problem of missing values.

4.3 The 2D App

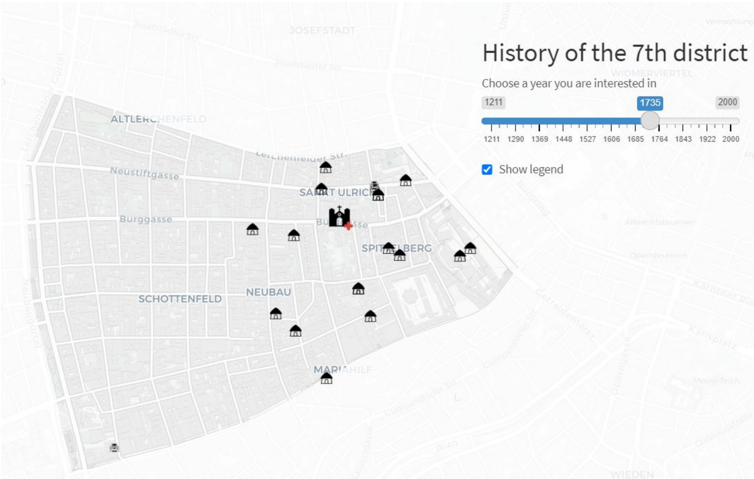

Figure 9: The 2D Application

4.4 The 3D App

5 Analysis

6 Findings & Discussion

7 Conclusion - Limitations - Future Research

8 References

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9 Appendix