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Interweaving Physical Artifacts with Data Visualization on Digital Media in Museums

DISSERTATION

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Erklärung zur Verfassung der Arbeit

Dipl.-Ing. Kerstin Blumenstein, BSc

Hiermit erkläre ich, dass ich diese Arbeit selbständig verfasst habe, dass ich die verwendeten Quellen und Hilfsmittel vollständig angegeben habe und dass ich die Stellen der Arbeit – einschließlich Tabellen, Karten und Abbildungen –, die anderen Werken oder dem Internet im Wortlaut oder dem Sinn nach entnommen sind, auf jeden Fall unter Angabe der Quelle als Entlehnung kenntlich gemacht habe.

Wien, 20. September 2020

Kerstin Blumenstein

Acknowledgements

When I look back at the beginning of my doctoral studies, I have to look at the year 2012 - the year in which I completed my diploma studies and got a full-time position as a Junior Researcher at St. Pölten University of Applied Sciences. I was involved in a lot of different projects, especially in the field of mobile development. The idea of continuing my studies and doing a doctorate was born. This is, however, not the usual path for a student at the University of Applied Sciences. After some time spent searching for the most suitable university, my future supervisor fortunately joined the institute in St. Pölten. With him, it was easy to enroll at TU Wien in 2014. However, it was not easy to find a suitable research project, as I am still not the classic visualization researcher. It was clear that the topic should have something to do with data visualization (because of Wolfgang) and something with mobile (because of me). There was this initial idea for my thesis to research interactive mobile data visualization for the second screen. We then tried twice to submit a project on this topic for funding. It was evaluated positively both times but in the end, we did not get any funding. During this time, I had two academic mentors and supporters: Grischa Schmiedl and Markus Seidl. I would like to thank both of you for your support, especially Markus for submitting the MEETeUX project, which was in line with my mindset and, more importantly, for getting the funding.

And so we find ourselves in 2017 when MEETeUX started. But even with a project, I had to learn that there was not just one individual thesis topic in this project. It took some time and the support of Markus, Peter Judmaier, and Wolfgang Aigner to focus. A big thank you goes to the project team who walked the MEETeUX path with me. Thank you: Stefanie Größbacher, Alexis Ringot, Niklas Thür, and Florian Taurer. The project team included another three people who especially accompanied me. Firstly, Laura Breban who fortunately was there when I was diagnosed with ulcerative colitis during my doctoral studies. Even though she would probably say that she did not do anything, she nevertheless showed me that it is possible to live with such a diagnosis, even if things do not look so rosy sometimes. Secondly, Magdalena Boucher who is an excellent illustrator (and now it is written in black and white). Thanks for the fantastic sketches for my thesis. And thirdly, Victor Adriel de Jesus Oliveira who joined the MEETeUX team last and turned out to be the best thing that could have happened to my progress in completing my doctoral studies and to myself personally. Victor, I am sure that you will supervise your own doctoral student one day!

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In the context of MEETeUX, we were able to realize an interactive exhibition in Klosterneuburg Monastery which included the two design studies for my thesis. Many thanks to the team of the library of Klosterneuburg Monastery for allowing us to contribute our ideas to your exhibition, especially Martin Haltrich (for forwarding my question to the appropriate person). This appropriate person was Wolfgang Huber. Thanks for discussing my thoughts on Physical Space, as this was maybe the most complicated subspace for me without any previous knowledge of museums and collections. In this context, Kathrin Kratzer also deserves a thank you.

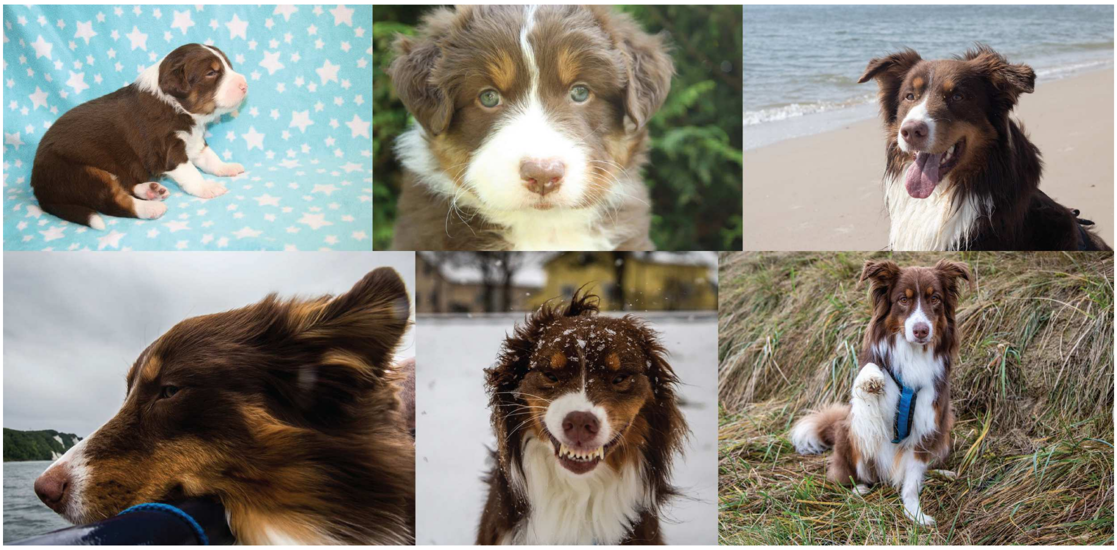
Besides the MEETeUX team, I would also like to thank all my colleagues at the Institute of Creative\Media/Technologies and the Department of Media and Digital Technologies at the St. Pölten University of Applied Sciences, notably Markus Wagner (you showed me that it is possible to complete the doctoral studies in time), Christina Stoiber (for being there as a fellow doctoral student after Markus finished so quickly), Florian Grassinger (for always finding an answer to my D3.js questions), Alexander Rind (for providing me with the right files), Astrid Ebner-Zarl (for holding regular online meetings during the COVID-19 lockdown), and Alois Frotschnig (for being my boss and for approving the educational leave to finish my thesis).

And last but not least, on the academic side: the last and maybe greatest thank you goes to THE supervisor, Wolfgang Aigner. I call it luck that you joined the IC\M/T at the perfect time to accompany me on the way to my doctorate. I am sure that I could never have had a more helpful and dedicated supervisor than you. It turns out that even Visual Analytics is not as bad as I thought.

A long journey thus comes to an end and I would not have been able to complete this thesis without the support of my family. Thanks to my husband Christian who often had to remind me that it is the weekend - but there are no weekends until the dissertation is finished; my brother Raik who I think is the only one who really wanted to read it; my parents and grandparents who supported me maybe the most by accepting that I was not available.

I thank you all for guiding me and helping me find my way!

I never wanted to dedicate this thesis to anyone or, even stranger, to an animal. Out of the blue, however, extraordinary things happen. A few days before this work was handed over for printing, our dog Mosquito had to undergo emergency surgery. Fortunately, he survived and shows us all that fighting is worthwhile.



To Mosquito, who has accompanied me since the beginning of my doctoral studies.

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Abstract

In recent years, digital media have increasingly found their way into museums and its surroundings. Today, museums digitize their cultural heritage artifacts, create virtual museums that mainly exist online, or offer a digital extension to expand their audience and complement the physical exhibition. On the one hand, interactive installations are integrated into exhibitions, such as interactive screens, hands-on installations, or digital augmentations of exhibits. On the other hand, there is a growing market for mobile applications developed for museums or exhibitions. Museums usually present physical artifacts that are generally passive and silent, i.e., the objects themselves do not provide any additional information or recommendations. Quite often, however, there are more data available than can be presented in an exhibition. The use of such data can show visitors other perspectives or tell stories that cannot be exhibited. Currently, hardly any installation with visualization published in the scientific community is interwoven with physical artifacts. We want to strengthen the connection between the physical and the digital worlds. Therefore, this thesis aims to examine how visualization methods can be used to interweave physical artifacts with digital media in museums.

Based on literature research, we draw an overall picture of the current state of interweaving physical artifacts with data visualization on digital media in museums in the form of a structured overview as a design space. We derive research gaps by applying the Design Space to existing scientific literature on installations with data visualization in museums. To fill four out of six research gaps that were both identified and validated for the proposed Design Space, we conducted two design studies. In the first design study, we developed visualization designs for a location-aware mobile application for visualizing historical data. We explain the iterative development of different designs, the reasons for our design decisions, and comparative evaluations. For our second design study, we developed Babenberg GenVis – an interactive, multi-device visualization of a historical genealogy painting. In addition to applying the two design studies to our Design Space, we also apply two examples from literature that do not originate in the museum environment to generalize the Design Space. Finally, we present guidelines derived from the reflections on our research and possible directions for future research on interweaving physical artifacts with data visualization on digital media in museums.

Kurzfassung

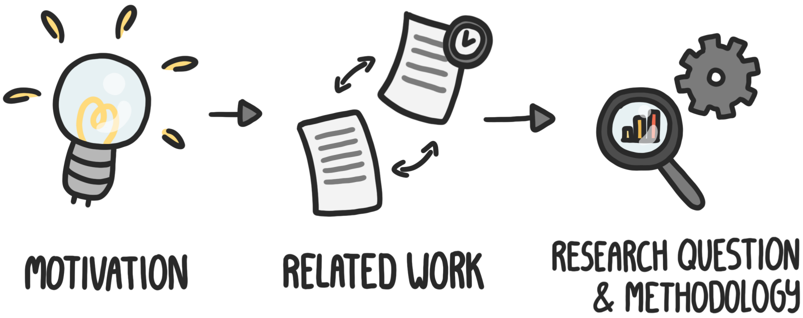
In den letzten Jahren haben digitale Medien zunehmend den Weg in die Museen gefunden. Heute digitalisieren Museen ihre Kulturerbe-Artefakte, schaffen virtuelle Museen, die hauptsächlich online existieren, oder bieten eine digitale Erweiterung, um ihre Besucher*innengruppen zu erweitern und die physische Ausstellung zu ergänzen. Einerseits werden interaktive Installationen in Ausstellungen integriert, wie z.B. interaktive Displays, Hands-on-Installationen oder digitale Erweiterungen von Exponaten. Andererseits gibt es einen wachsenden Markt für mobile Anwendungen, die für Museen oder Ausstellungen entwickelt werden. Museen präsentieren physische Artefakte, die im Allgemeinen passiv und still sind, d.h. die Objekte selbst bieten keine zusätzlichen Informationen oder Empfehlungen. Oft stehen jedoch mehr Daten zur Verfügung, als in einer Ausstellung präsentiert werden können. Die Verwendung solcher Daten kann den Besucher*innen andere Perspektiven aufzeigen oder Geschichten erzählen, die nicht ausgestellt werden können. Gegenwärtig ist kaum eine in der wissenschaftlichen Gemeinschaft veröffentlichte Installation mit Visualisierung mit physischen Artefakten verwoben. Wir wollen die Verbindung zwischen der physischen und der digitalen Welt stärken. Deshalb soll in dieser Arbeit untersucht werden, wie Visualisierungsmethoden bei der Verknüpfung von physischen Artefakten mit digitalen Medien in Museen eingesetzt werden können.

Basierend auf Literaturrecherchen erstellen wir ein Gesamtbild des aktuellen Stands zur Verknüpfung von physischen Artefakten mit Datenvisualisierung auf digitalen Medien in Museen in Form einer strukturierten Übersicht als Design Space und leiten Forschungslücken ab, indem wir den Design Space auf bestehende wissenschaftliche Literatur anwenden. Zudem haben wir zwei Designstudien durchgeführt, die vier von sechs Forschungslücken betrachten. In der ersten Designstudie entwickelten wir Visualisierungsdesigns für eine ortsbezogene mobile Anwendung zur Visualisierung historischer Daten. Wir erklären die iterative Entwicklung verschiedener Designs, die Gründe für unsere Designentscheidungen und vergleichende Evaluierungen. Für unsere zweite Designstudie entwickelten wir Babenberg GenVis - eine interaktive, multi-device Visualisierung eines historischen Genealogie-Gemäldes. Neben der Anwendung der beiden Designstudien auf unseren Design Space wenden wir auch zwei Beispiele aus der Literatur an, die nicht aus dem Museumsumfeld stammen, um den Design Space zu verallgemeinern. Abschließend stellen wir Richtlinien vor, die sich aus den Reflexionen über unsere Forschung ableiten, sowie zukünftige Forschungsmöglichkeiten zur Verknüpfung von physischen Artefakten mit Datenvisualisierung auf digitalen Medien in Museen.

Contents

CHAPTER 1

Introduction



This chapter describes the general motivation for this thesis (Chapter 1.1), which refers to digital media in museums and the use of data visualization on digital media. We present state-of-the-art reports in relation to museums and related disciplines (Chapter 1.2). Research questions as well as the general research methodology for this thesis are defined (Chapter 1.3). At the end of the chapter, the contributions of the thesis (Chapter 1.4), the dissemination activities related to this work (Chapter 1.5), and a structural overview of the thesis (Chapter 1.6) are presented.

1.1 Motivation

In recent years, digital media have increasingly found their way into museums and their surroundings. Museums digitize their cultural heritage artifacts (e.g., Godin et al., 2002; Mohan et al., 2007; Singh, 2014), create virtual museums that mainly exist online, or offer digital extensions to expand their audience and complement the physical exhibition (Hornecker and Ciolfi, 2019).

Virtual or digital museums are of growing interest in research. Pan et al. (2009), for example, developed the Digital Olympic Museum. “Visitors” can explore the virtual representation of the “original” museum located in Lausanne (Switzerland) in Virtual Reality (VR) via a website. Fu et al. (2020) compared a VR tour to experience the Dunhuang Mogao Grottoes (China) with traditional methods (documentary integrated into the VR system) showing that the VR tour was a significantly more engaging and immersive experience. Virtual museum experiences can be provided for everybody, everywhere.

Today, many museums integrate interactive installations, such as horizontal touch tables (e.g., Chu et al., 2015; Correia et al., 2010; Geller, 2006), hands-on installations (e.g., Clarke and Hornecker, 2013; Maquil et al., 2017; Schmitt et al., 2010), or digital augmentations of exhibits (e.g., Bellucci et al., 2015; Hornecker, 2010; Pollalis et al., 2018). Chu et al. (2015), for example, presented a tangible table installation at the Robert C. Williams Paper Museum (Atlanta, USA). Visitors can invent and share stories by interacting with the tangible exhibits and thereby learning symbolic and non-linguistic mapping concepts. Clarke and Hornecker (2013) implemented a hands-on exhibit alongside the real Glen Douglas steam locomotive (Riverside Transport Museum in Glasgow, UK) to get a steam train running by interactively controlling water, coal, and steam levels. Hornecker (2010) augmented a dinosaur skeleton in the Museum of Natural History (Berlin, Germany) to let visitors experience the dinosaur live in 3D through a periscope pointed at the skeleton. Ichino et al. (2019) conducted a study on the influence of age on the use of interactive exhibits, which showed that visitors between the ages of 20 and 50 were most likely to enter an interactive exhibition space, observing that the engagement was the same across all age groups.

Many museums also offer the opportunity to access a mobile application for downloading audio or additional information to smartphones (e.g., Deutsches Museum (Munich, Germany)[1], Museum Niederösterreich (St. Pölten, Austria)[2]). More recent research deals with the use of mobile applications in museums. Cesário et al. (2020) offer implications for the design of museum applications aimed at young people, based on a comparison of a story-based tour and a game-based tour through a mobile app. The app *Never let me go* (Ryding, 2020) is an example of a mobile web application by means of which two

[1]Deutsches Museum in Munich, Germany: https://www.deutsches-museum.de/en/whats-on/app/, last access July 21, 2020.

[2]Museum Niederösterreich in St. Pölten, Austria: https://www.museumnoe.at/de/das-museum/museumsapp/museums-app, last access July 21, 2020.

visitors to an art museum can exchange impromptu experiences. The app was used by the visitors to communicate with each other during the visit, often without speaking. Petrelli and O'Brien (2018) conducted a comparative evaluation of the use of smart replicas, mobile phones, and smart cards. Interestingly, the mobile phone was stated as the most disliked option, but at the same time, the most popular means of interaction. A correlation with the age group could not be established.

A major advantage of mobile applications and interactive installations is that they make the content more attractive for younger generations of visitors, offer knowledge transfer methods beyond traditional text reading, contribute to a more engaging museum experience (Skowronski et al., 2018), and provide museums with visitor tracking capabilities (Craig et al., 2019).

The examples mentioned above can be roughly divided into two areas: 1) the interactive installation is the exhibit (e.g., Chu et al., 2015), and 2) the installation/application is interwoven with physical artifacts (e.g., Hornecker, 2010). In our research, we focus on the second area, as our main emphasis is to interweave physical artifacts with digital media.

In general, most physical artifacts in museums are passive and silent, i.e., the objects themselves do not provide any additional information or recommendations. Therefore, artifacts are often supplemented by short text descriptions or oral explanations from a guide. Often, there are more data available (e.g., knowledge of curators or information in databases and documents) than those that can be written on a small plate or quickly told. The use of these data and their integration through interactive data visualization on digital media could provide visitors with additional information depending on the exhibit that is of interest to them.

There are already several examples of the use of data visualization in museums. Most of them focus on interactive tables (e.g., Hinrichs et al., 2008; Isenberg et al., 2010). ART + COM Studios (2012), for example, realized a large horizontal table showing a landscape map of the Hamburg area at the Hamburgmuseum (Hamburg, Germany). The visitors were able to choose an era from the Middle Ages to the present using tangibles. The development and evaluation of interactive visualization for the simulation of marine microbes on a horizontal touch screen were the topic of several scientific articles (Ma et al., 2012, 2015, 2019). Hinrichs et al. (2008) presented one of the few multi-device approaches in which data on the artist Emily Carr were visualized alongside temporal and contextual dimensions using a touch table. The interaction was mirrored onto a projection. This setup allowed visitors to see interactions across the entire exhibition floor. Other examples in museums visualize an earth data set on a large spherical display representing a huge globe (Science On a Sphere, 2019) or extending a printed visualization on the wall across different rooms by projections (ART + COM Studios, 2009).

All these examples are not interwoven with physical artifacts and are therefore non-situated visualizations. The recently introduced term *situated visualization* describes a data representation that depends on the situation the user is in or the object near the user (Willett et al., 2017). An everyday use case for situated visualization is mobile maps, e.g., showing traffic information depending on the user's position. Willett et al. (2017) note that there is a need for additional research on the design of situated data representations in this area.

The aim of this doctoral research is to focus on interweaving existing physical artifacts in a museum with data visualization on digital media to enrich the museum visit and support learning through active participation (Hein, 1998). The goal is to draw an overall picture of the current state of interweaving physical artifacts with data visualization on digital media in museums in the form of a structured overview as a design space. Based on this, this design space has been applied using two design studies carried out within the research project MEETeUX[3]. Both design studies deal with individual knowledge gaps identified in the course of this research.

In order to substantiate the need for this research, related work in the form of existing state-of-the-art reports (STARs) is addressed in the following.

1.2 Related STAR reports

On the one hand, this section gives an overview of surveys concerning museums (e.g., visualization on interactive tables (Isenberg et al., 2010) or information and communication technology (ICT) in general (Pujol-Tost, 2011)). On the other hand, relevant STARs in related disciplines are presented.

1.2.1 Museums

In 2012, Li et al. (2012) discussed challenges and solutions for digital museums. One conclusion is that "Casual InfoVis can be described as a rudiment of utopia in the cultural organization." Isenberg et al. (2013) underlined this statement when publishing a research agenda for data visualization on interactive tables. They state that only a few projects exist in museums, and thus more alternative reports and evaluations are needed. Interactive tables were also of interest in the study by Isenberg et al. (2010) comparing information visualization in work settings and public settings (e.g., museums). The authors proposed challenges for information exploration in public spaces such as contextual challenges, missing visitors' goals, and brief interactions with the exhibits.

Ardito et al. (2015) analyzed in their survey the use of large displays based on visualization technology, display setup, interaction modalities, application purpose, and location They found such installations in public places such as museums (9 out of 206). The authors derive challenges for the design of installations for large displays, such as collaboration, privacy, and blended and gesture interaction.

Pujol-Tost (2011) addressed ICT in museums in general. They conducted an evaluative study in the United Kingdom to provide an overview of the issues when integrating ICT

[3]MEETeUX: https://meeteux.fhstp.ac.at/, last access July 21,2020.

and guidelines for designing more effective solutions. One main finding was the weak connection between physical artifacts and interactive installations. Hornecker and Ciolfi (2019) published a book that represents a comprehensive overview of human-computer interaction (HCI) in museums. The book explores how digital interactive technologies influence and shape galleries, exhibitions and their visitors, and provides examples, reflections, and illustration of relevant concepts and problems.

Concerning interactive tables in museums in general, Creed et al. (2013) summarized the results of several research studies in the cultural heritage field, based on how multiple users interact with interactive tables, how they approach the tables, interface design and content, and the interaction techniques.

Focusing on mobile computing, Luna et al. (2019) analyzed Augmented Reality (AR) applications for heritage sites in Europe. Most of the 35 studied apps (23) used AR to reconstruct spaces and buildings. Only ten apps extended physical artifacts. The authors conclude that the non-existence of studies and evaluations on these apps complicated the comparison. However, the educational opportunities for learning and teaching cultural heritage with AR and mobile devices deserve further research and scientific attention. Also, museum applications for mobile phones were evaluated by Economou and Meintani (2011). Most of them function as guided tours and representations of exhibitions, which is why maps or lists are often integrated to allow visitors to navigate according to the spatial layout or the chronological or alphabetical order of exhibits.

1.2.2 Related Disciplines

Müller et al. (2010) presented a related design space for interactive public displays. They discuss categories for mental models and interaction modalities.

An exhaustive study by Brudy et al. (2019), including 510 research papers, shows the great interest in multi-/cross-device ecologies research. They provide a taxonomy of key characteristics with six dimensions (temporal, configuration, relationship, scale, dynamics, and space) and further address application domains, tracking characteristics, interaction techniques, and evaluation strategies. *Museum experiences* is one of the subcategories presented in the application domains *Games and Installations*. *Data Exploration* is mentioned as another application domain as well as *Mobile Computing*.

Focusing on InfoVis for mobile devices, we found a survey article by Isenberg and Isenberg (2013). They showed that smartphones were only used in 6% of the 100 analyzed research projects, although the user base of smartphones had been continuously growing for years. In recent years, visualization on mobile devices has attracted more and more attention in research (e.g., Blumenstein et al., 2016; Brehmer et al., 2019; Choe et al., 2019; Lee et al., 2018; Watson and Setlur, 2015) and practice (e.g., Ros and Bocoup, 2016; Sadowski, 2018). The STAR by Blumenstein et al. (2016) dealt explicitly with mobile visualization evaluations and reported three challenges (reporting for reproducibility, device variety, and knowledge about the usage environment).

1.2.3 Summary

The body of literature in researching interactive installations in museums is continuously growing, including works on visualizing data. However, we found no structured report on interactive data visualization in museums. To focus our work, we address the connection between the interactive installation with data visualization and its surroundings, as the museum is a special place usually presenting physical artifacts. Next, we describe the research questions underlying this thesis and the research methodology.

1.3 Research Questions & Research Methodology

This research aims to study visualization methods for interweaving physical artifacts on digital media in museums. This leads to the following main research question:

- How can visualization methods be used in interweaving physical artifacts with digital media in museums?

To achieve this goal, the following research subquestions will be investigated:

- What types of interweaving physical artifacts with digital media are feasible in museums?
- What types of visualization and types of interaction can best be used for the chosen design studies?
- If the physical artifact itself is a visualization - how can the artifact be dynamically extended through a backchannel?
- How can multi-device ecologies enrich such settings?
- What are best-practice guidelines for interweaving physical artifacts with digital media in museums?

This thesis' research approach can be divided into two main areas: (1) the development and validation of the design space and (2) the implementation of the two design studies.

We followed an iterative process in our literature research for the modeling and validation of a design space for interweaving physical artifacts with data visualization on digital media in museums (Part I). First, we looked at a broader range of applications in museums and data visualization in general to develop a categorization for our design space. Then, we reduced the scientific literature by including and excluding criteria (Kitchenham, 2004). We performed an additional systematic search to expand the already found and matching papers focusing on applications with data visualization in museums. Finally, we used the identified literature to validate our design space in a state-of-the-art report.

At the end of this thesis (Part IV), we applied the design space to our design studies, generalized it with existing literature outside the museum context, and discussed its descriptive, evaluative, and generative power (Beaudouin-Lafon, 2004).

> "Visual representations of objects are often misinterpreted, either because they do not match our perceptual system, or they were intended to be misinterpreted." (Ward et al., 2010)

Therefore, visualizations must be developed and tested in the context of specific tasks, users, and application areas (Munzner, 2009). To use visual methods effectively, professional planning (e.g., user and task analysis) and empirical evaluation (e.g., usability tests) are required (Lam et al., 2012; Miksch and Aigner, 2014). We followed this advice when we conducted the two design studies using the design study methodology (Sedlmair et al., 2012). Therefore, we started with a problem characterization and data and a task abstraction for both studies.

For the first design study to develop a visualization of historical data for mobile devices (Part II), we implemented a design process with two iterations. First, we developed three basic visualization concepts and implemented them as clickable mockups for evaluation. For the second iteration, we developed three linear concepts based on the chosen timeline concept from the first iteration and implemented them as fully functional prototypes for evaluation. Both iterations were completed with a comparative evaluation, combining a tasked-based user test and structured Likert-scale questions to compare the designs while taking user experience into account.

For the second design study for the development of an interactive visualization of a historical genealogy painting with multiple devices (Part III), we followed the process of iterative design and evaluation (Nielsen, 1993). A specific domain problem was addressed by involving collaborators and users from the domain (Sedlmair et al., 2012). We started with a research and idea creation phase to determine the actual state of demand in the sector and developed concrete ideas based on personas and scenarios (Cooper et al., 2014; Nielsen, 1993). To refine our concept, we developed paper prototypes, thus defining the entire setup and clarifying conceptual issues at an early stage (Dumas and Fox, 2009). We then developed functional prototypes and evaluated them with a tasked-based usability test in a laboratory environment (Lazar, 2017). We refined our prototypes, implemented the installation in the museum, and conducted an evaluation with observations and semi-structured interviews (Lazar, 2017) on site. After a second refinement, we once again evaluated the results through observation and log-data analysis. Finally, we reflected upon the entire process with museum staff in semi-structured interviews (Lazar, 2017).

For both design studies, we formulated lessons learned and implications based on the insights gained from the process. As a final step of this thesis, we defined guidelines for the design and development of the interweaving of physical artifacts with data visualization in museums based on the lessons learned (Part IV).

1.4 Contributions

This work aims to explore how we can interweave physical artifacts with data visualization on digital media in museums. Understanding how to combine the physical and digital worlds and how to design visualizations for museum visitors will benefit HCI as well as the visualization community and the digital heritage field. The results of this thesis will contribute to the development of future interactive visualization experiences in museums. The contributions of this thesis are as follows:

- An adapted methodology for developing a state-of-the-art report describing an iterative development of conducting a literature survey (Chapter 2);

- A design space for interweaving physical artifacts with visualization on digital media in museums identifying dimensions and aspects in four subspaces (Physical Space, Digital Media Space, Contextual Space, and Visualization Space) (Chapter 3); The validation, application, and generalization of the design space through its application to existing literature (Chapter 4), the application to our research (Chapter 16.1), the discussion of strengths and weaknesses (Chapter 16.2) and the generalization (Chapter 16.3);

- A systematic literature review of existing scientific literature implementing interactive data visualization in museums and its classification into clusters derived from the analyzed literature and the discussion of open research topics (Chapter 4);

- A first design study on the time-oriented visualization of historical data on mobile devices contributing with the design of situated, mobile visualization concepts, their prototypical implementation and application in a real museum setting, the results of two consecutive comparative studies (Chapter 7 and Chapter 8), and a set of lessons learned and implications about visualization & interaction, and the design process based on the insights derived from the study process (Chapter 9);

- A second design study on an interactive, multi-device visualization of a historical genealogy painting contributing with a problem characterization with data and task abstraction (Chapter 11), the iterative design of a multi-device visualization concept, its prototypical implementation and application in a real museum setting (Chapter 12, Chapter 13, and Chapter 14), and a set of general lessons learned and implications that are grounded during the process (Chapter 15);

- Guidelines for the design and evaluation of future projects that interweave physical artifacts with data visualization on digital media in museums that address the topics of visualization, installations in museums, multi-device ecologies, mobile applications, and evaluation (Chapter 17).

1.5 Dissemination

Parts of this thesis have been published and presented at international scientific conferences. The work at hand elaborates on and complements these publications:

Blumenstein, K., Kaltenbrunner, M., Seidl, M., Breban, L., Thür, N., and Aigner, W. (2017a). Bringing Your Own Device into Multi-device Ecologies: A Technical Concept. In *Proceedings of the ACM International Conference on Interactive Surfaces and Spaces*, ISS '17, pages 306–311. ACM Press

Blumenstein, K. (2018). Interweaving Physical Artifacts with Visualization on Digital Media in Museums. In *Companion Proceedings of the ACM International Conference on Interactive Surfaces and Spaces*, ISS '18, pages 1–6. ACM Press

Blumenstein, K., Oliveira, V. A. D. J., Größbacher, S., Boucher, M., Seidl, M., and Aigner, W. (2019). Design of Time-Oriented Visualization for Mobile Applications in Museums: A Comparative Evaluation. In *Adjunct Proceedings CHItaly19*, pages 39–43

Blumenstein, K. (2019). Interweaving Physical Artifacts with Visualization on Digital Media in Museums. In *Adjunct Proceedings CHItaly19*, pages 26–28

In addition to the publications included in this thesis, other publications have contributed to this thesis' development, but are not included:

Blumenstein, K. (2015). Interactive Mobile Data Visualization for Second Screen. In *Doctoral Consortium on Computer Vision, Imaging and Computer Graphics Theory and Applications (DCVISIGRAPP)*. SCITEPRESS Digital Library

Blumenstein, K., Wagner, M., Aigner, W., von Suess, R., Prochaska, H., Püringer, J., Zeppelzauer, M., and Sedlmair, M. (2015b). Interactive Data Visualization for Second Screen Applications: State of the Art and Technical Challenges. In *Proceedings of the International Summer School on Visual Computing*, pages 35–48. Frauenhoferverlag

Blumenstein, K., Wagner, M., and Aigner, W. (2015a). Cross-Platform InfoVis Frameworks for Multiple Users, Screens and Devices: Requirements and Challenges. In *DEXiS 2015 Workshop on Data Exploration for Interactive Surfaces. Workshop in conjunction wirth ACM ITS'15*

Blumenstein, K., Niederer, C., Wagner, M., Schmiedl, G., Rind, A., and Aigner, W. (2016). Evaluating Information Visualization on Mobile Devices: Gaps and Challenges in the Empirical Evaluation Design Space. In *Proceedings of the Workshop on Beyond Time and Errors on Novel Evaluation Methods for Visualization*, BELIV '16, pages 125–132. ACM Press

Blumenstein, K., Leitner, B., Thür, N., Kirchknopf, A., Seidl, M., and Aigner, W. (2017b). LiveVis: Visualizing Results of Second Screen Surveys in Real Time at TV Stages. In *Workshop Vis in Practice - Visualization Solutions in the Wild, IEEE VIS 2017*. IEEE

Blumenstein, K., Niederer, C., Wagner, M., Pfersmann, W., Seidl, M., and Aigner, W. (2017c). Visualizing Spatial and Time-oriented Data in a Second Screen Application. In *Proceedings of the International Conference on Human Computer Interaction with Mobile Devices and Services*, MobileHCI '17, pages 84:1–84:8. ACM Press

1.6 Structural Overview

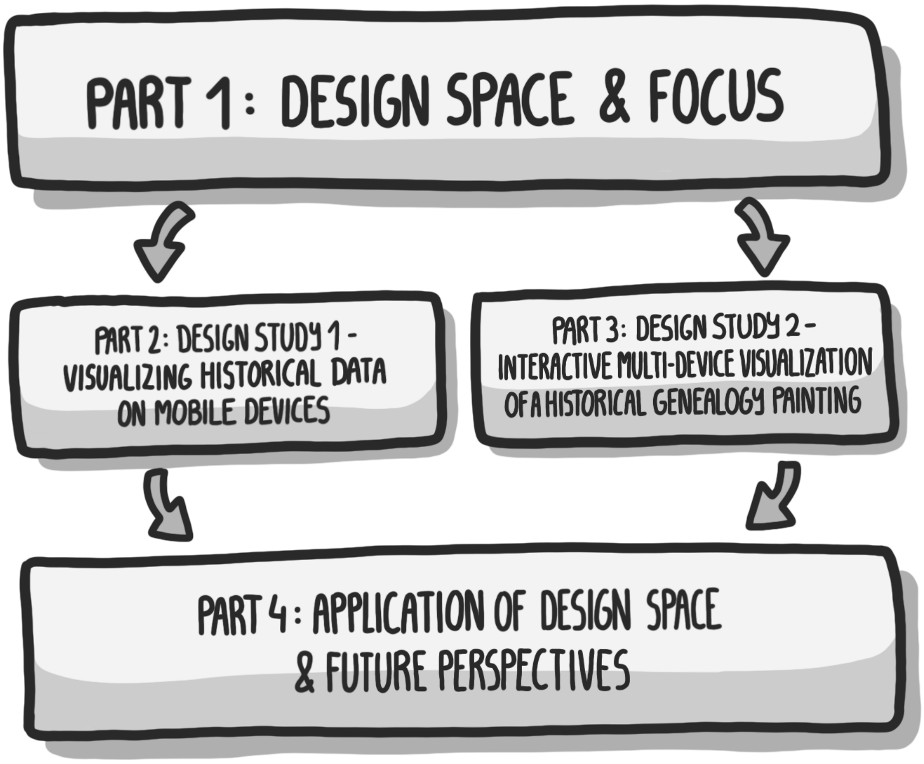


Figure 1.1: Graphical overview of the thesis structure.

This thesis is divided into four parts (see Figure 1.1): Design Space & Focus, Design Study 1, Design Study 2, and Application of the Design Space & Future Perspectives. The first part, Design Space & Focus (Part I), models a design space for the interweaving of physical artifacts with visualization on digital media in museums and applies it to existing scientific literature in the sense of a state-of-the-art report. We also describe the environment of the two design studies carried out within the framework of this thesis. In the second and third parts of this thesis, we document two design studies that apply to our design space. For the first one, Design Study 1: Visualizing Historical Data on Mobile Devices (Part II), the iterative development of a time-oriented visualization for mobile devices is document and reflected upon. The second one, Design Study 2: Interactive, Multi-Device Visualization of a Historical Genealogy Painting – Babenberg GenVis (Part III), documents and reflects upon the iterative development of a time-oriented visualization in a multi-device setting that extends a reproduction of a historical painting. In the fourth and last part, Application of the Design Space & Future Perspectives (Part IV), the design space is applied to the design studies from Part II and Part III, and the strengths and weaknesses of the modeled design space are discussed . This part also derives guidelines and presents future research directions. In this way, an overview of results is provided, and this thesis reaches its conclusion.

The results and findings will help designers and developers of museum installations in creating interactive data visualizations for museums that are interwoven with physical artifacts, and support museum curators in understanding how visualization could fit into their exhibition.

1.7 Conventions

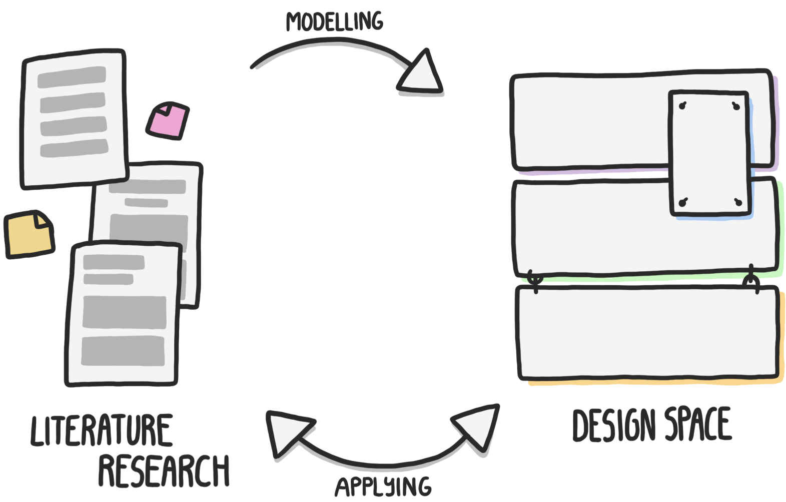
The presented work in this doctoral thesis was conducted in the context of the FFG-funded research project MEETeUX (no. 856308). Although designs and evaluations were elaborated on and carried out by myself, research results were shaped on the basis of valuable discussions and inputs by my advisors and colleagues. Therefore, I decided to use the pronoun “we” instead of “I” within this thesis.

Part I

Design Space & Focus

CHAPTER 2

Method



This chapter describes the procedure to develop the Design Space for interweaving physical artifacts with visualization on digital media in museums. Based on a systematic literature research (Chapter 2.1), we modeled the Design Space (Chapter 2.2). Finally, we will validate our Design Space by applying it to existing scientific literature (Chapter 2.3).

Usually, the process of conducting a literature review is sequential (Kitchenham, 2004). However, Kitchenham (2004) already described that some of the performed stages involve iteration such as refining inclusion and exclusion criteria for the selection of primary studies, refining data extraction forms based on quality criteria, or changing data synthesis methods once data has been collected. We used the iterative process to create the entire state-of-the-art report. First, we addressed a broader scope to develop a categorization for our Design Space. Then, we reduced the scientific literature through inclusion and exclusion criteria and performed an additional systematic search to expand the already found and matching papers.

2.1 Literature Research

To establish the Design Space for interweaving physical artifacts with visualization on digital media in museums, we conducted a systematic literature research which consisted of three phases. The goal was to gain an overview of as much relevant literature as possible.

In phase 1, our focus was on interactive installations in museums and public spaces as well as on museums in general. Therefore, we performed a keyword search for *interactive installation museum*, *interactive public display*, *museum categorization*, *exhibit museum*, and *artifact museum*.

Furthermore, we investigated 39 interactive exhibits in museums. Methodically, we used literature research for 25 exhibits as well as an observation of 14 museums[1].

In phase 2, we ran systematic searches to back our research (1) with additional literature about museum installations and (2) with visualization literature for mobile devices and multi-device ecologies (MDE). Table 2.1 gives an overview of the searched venues and the number of papers found for the following searches from 2008 to 2019[2]:

1. The proceedings of ACM CHI as the main venue for publishing scientific research in HCI, ACM MobileHCI as the dedicated conference in the field of mobile HCI, and ACM ISS/ITS[3] as the conference for interactive surfaces were searched for *museum*, *exhibit*, *culture*, and *cultural*.

2. The proceedings of IEEE InfoVis, IEEE VAST, EuroVis, and IV[4] as leading conferences for data visualization as well as ACM CHI and ACM Mobile HCI were searched for *mobile*, *touch*, *small*, *smartphone*, *tablet*, *pad*, *phone*, *scalable*, *natural user interface*.

[1] The categorization of the researched exhibits can be found at http://meeteux.fhstp.ac.at/assets/matrix/.

[2] 2020 for ACM CHI.

[3] We made this selection based on the papers found in phase 1.

[4] The selection of the conferences was adapted from Isenberg and Isenberg (2013).

3. The proceedings of IEEE InfoVis, IEEE VAST, EuroVis, and IV, as well as ACM CHI, ACM Mobile HCI, and ACM ISS, were searched for *cross* or *multi*.

Table 2.1: Overview of the systematic literature research in phase 2.

Venue	**Years**	**Number of Papers**	**Museum**	**Mobile Visualization**	**MDE Visualization**
ACM CHI	2008 - 2020	11131	34	26	6
ACM Mobile HCI	2008 - 2019	1061	10	16	3
ACM ISS	2008 - 2019	703	12	-	21
IEEE InfoVis	2008 - 2019	659	-	11	2
IEEE VAST	2008 - 2019	598	-	3	0
EuroVis	2008 - 2019	883	-	7	2
IV	2008 - 2019	1097	-	20	3

In phase 3, we extended our literature search based on paper citations in two ways:

- using the cited-by feature of Google Scholar[5] of relevant papers, and
- checking the references of the relevant papers.

2.2 Modeling the Design Space

Building upon the knowledge within the papers and projects found, the main dimensions were gathered for three main areas: Physical Space, Digital Media Space, and Visualization Space. Wherever possible, we used existing taxonomies or categorizations. If necessary, we combined or extended them. Otherwise, we discussed the categorization (esp. the type of artifacts) with experts in the field.

During the modeling, we noticed that some dimensions are application-centric and therefore combine the Physical and Digital Media Space. We added the Contextual Space as a separate space for such dimensions.

Overall, we defined four subspaces of our Design Space:

- Physical Space for artifact-related dimensions
- Digital Media Space for the dimensions concerning the devices used
- Visualization Space for visualization-specific dimensions
- Contextual Space for intertwining Physical Space and Digital Media Space to address application-centric dimensions

[5] https://scholar.google.at/

2.3 Validating & Applying the Design Space

To demonstrate our Design Space's validity and applicability, we decided to use it to categorize the scientific literature that focuses on installations with visualization in museums. We started with the papers that we had already collected in our first three phases of literature research (see Chapter 2.1). Nineteen of them were suitable for this state-of-the-art report. We also conducted an additional search to find all relevant papers in IEEE Xplore and ACM Digital Library. We searched for *museum* in the abstract and *visualization* in the title and abstract (see Table 2.2 for the detailed results). In the next step, we reduced the total number of hits by focusing on installations in museums. For this purpose, we excluded works on virtual museums, visualization of museum collections, visitor tracking, artifact reconstructions, works published at doctoral consortiums, and papers in which the installation was not sufficiently described. The remaining papers were reviewed to see if they contained data visualization. This search allowed us to add fourteen new papers to our selection so that we ended up with a total of 33 relevant papers (see Figure 2.1). We then went through all papers and excluded those that described the same project without differences in visualization, action, or perception. For example, the installation described by Ma et al. (2019) is the same as the one described by Ma et al. (2012). We chose the paper that was published first. In this way, we excluded five papers and reduced the number of papers to 28.

We then categorized the papers based on the dimensions of our Design Space (Chapter 4.1). Whenever the description was not clear, we contacted the authors to categorize the works as precisely as possible. During this categorization, we refined the initial description of the Design Space to be more applicable.

To describe the papers we found, we also performed a hierarchical cluster analysis with R. After testing several techniques, we decided to use agglomerative hierarchical clustering combined with complete linkage. We analyzed the items for each space individually as well as all spaces and all possible combinations of the spaces together to find the most suitable clusters. Thus, we ended up with five clusters:

- 2D visualization on horizontal touch display (ten items)
- Embodied action combined with vertical or room display (six items)
- Use of controls together with horizontal, vertical, or room display (six items)
- Volumetric visualization with direct touch manipulation (three items)
- Mobile interaction combined with visualization (one item)

Through this clustering, we also identified two outliers. One paper (Danyun et al., 2016) lacks information about action and perception within the Digital Media Space. The second paper (Ress et al., 2018) describes the wizard-of-oz prototyping phase. While we did not exclude them from categorization, they are not covered by clustering.

Table 2.2: Overview of the literature research for *museum* in abstract and *visualization* in title and abstract.

Search Engine	Total Hits	Museum Installation	With Visualization	New Papers
IEEE Xplore	224	44	10	5
ACM Digital Library[6]	26	8	4	4
ACM Digital Library[7]	126	21	10	4

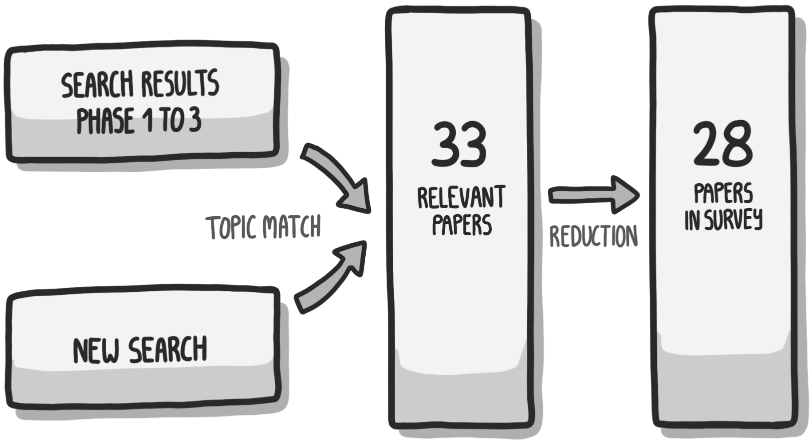


Figure 2.1: Paper-reduction of the literature search, focusing on papers that correspond to our specific topic of visualization in museums. Illustration by M. Boucher, idea by K. Blumenstein.

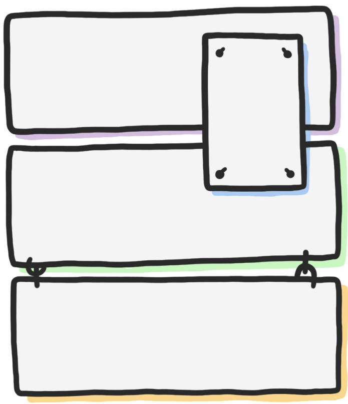
Based on the state-of-the-art report, we discuss open research topics (Chapter 4.3) and fill two gaps with our research in Part II and Part III of this thesis. We discuss the descriptive, evaluative, and generative power (Beaudouin-Lafon, 2004) of our Design Space at the end of this thesis (Part IV).

In the next chapter, we examine the Design Space by describing the four subspaces, their dimensions or aspects, and categorizations.

[6] Basic search phrase was adapted to "[Publication Title: visualization]."
[7] Basic search phrase was adapted to "[Abstract: visualization]."

CHAPTER 3

Exploring the Design Space



This chapter defines the entire Design Space for interweaving physical artifacts with visualization on digital media in museums. Focusing on the topic, we divided this space into three subspaces: 1) Physical Space (Chapter 3.1), 2) Digital Media Space (Chapter 3.2), and 3) Visualization Space (Chapter 3.4). Besides, we modeled the Contextual Space which intertwines Physical Space and Digital Media Space (Chapter 3.3). We describe each subspace, their dimensions and aspects, and how the categorizations were derived.

Our Design Space serves as an overview of the entire thesis. We explore the different dimensions and aspects and explain them through existing literature and applications. We discuss the fundamentals for creating data visualization applications that are interwoven with physical artifacts in museums. The Design Space should therefore serve a comprehensive guide for designers, developers, and researchers.

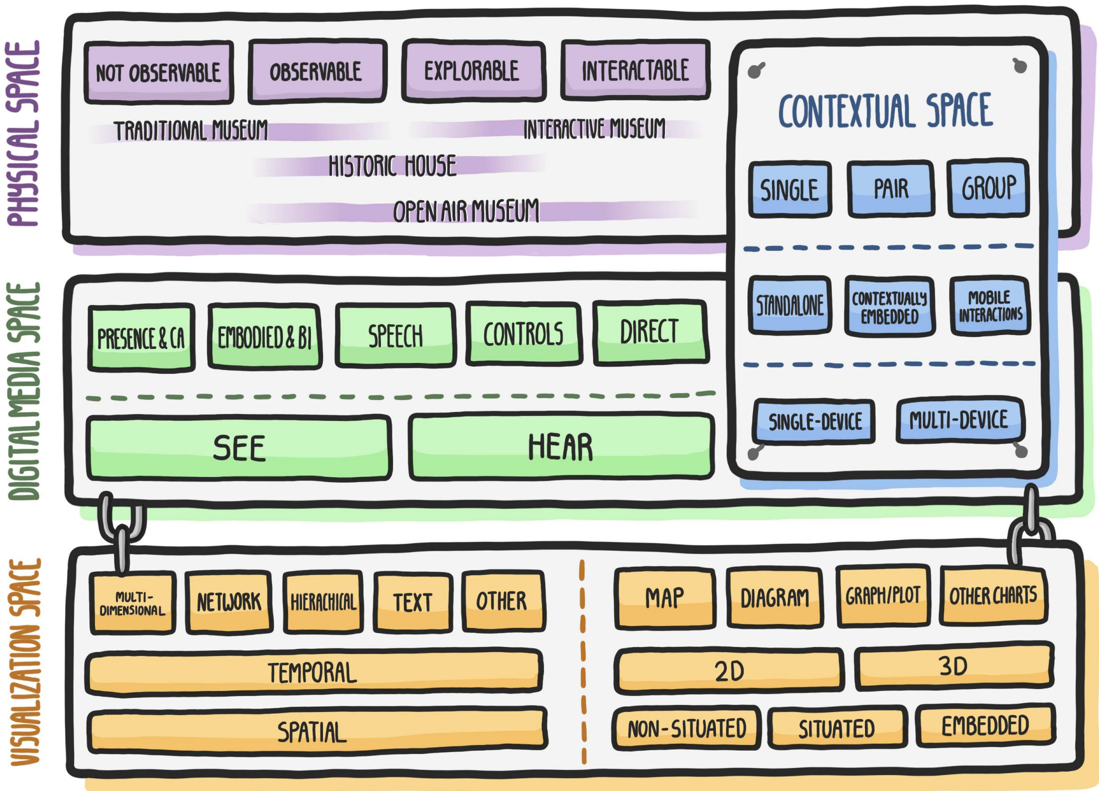


Figure 3.1: Overview of our Design Space with Physical Space, Digital Media Space, Contextual Space, and Visualization Space. Illustration by M. Boucher, idea by K. Blumenstein.

We start with Physical Space (Chapter 3.1), which addresses the artifact itself and its surroundings to give an overview of the different types of artifacts and the environment - the museum. Next, Digital Media Space (Chapter 3.2) describes the possibilities to interact with and to perceive content on digital media. To address application-centric dimensions and aspects such as the visitor or the relation of the application to Physical Space, we defined Contextual Space that intertwines Physical and Digital Media Space (Chapter 3.3). Finally, Visualization Space (Chapter 3.4) describes the dimensions and aspects concerning the data and representation possibilities of data visualization.

3.1 Physical Space

When interweaving physical artifacts with digital media, artifacts are central in the entire Design Space. Different types of artifacts can result in different options to interweave an artifact. Figure 3.2 gives an overview of Physical Space. Our Physical Space consists of two dimensions: 1) the type of physical artifact and 2) the type of museum.

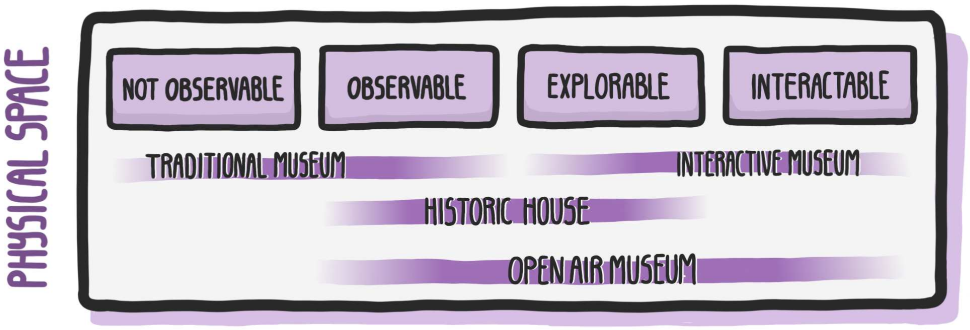


Figure 3.2: Overview of Physical Space with the aspect of type of physical artifact (not observable, observable, explorable, and interactable) and the dimension of type of museum (traditional, historic house, open air, and interactive museum). Illustration by M. Boucher, idea by K. Blumenstein.

Type of Physical Artifact

To define physical artifacts in a museum, we focus on what should have the visitor's attention. This attention focuses on the physical artifact (e.g., painting, sculpture, book). Thus, we do not include digital exhibits (e.g., video presentations running on a television or digital representations using a touch table) as physical artifacts.

For the inventory of such artifacts, several categorizations exist for different types of collections. In art history, for example, the following object classifications are standard: drawing, painting, sculpture, architecture, photography, film, and printmaking (Esaak, 2019). We can reduce these into three main categories: paintings (everything flat), sculptures (everything which is three-dimensional), and architecture (everything which is accessible). For this aspect in our Design Space, however, we were seeking a more general categorization that was not dedicated to a specific discipline (e.g., art history or natural history). So, we decided to address the accessibility of the artifact. Allen (2014) provided a differentiation by describing interactive exhibits. The key feature of interactive artifacts is reciprocity. Such artifacts can react to the interaction of the visitor in some way or other. On the other hand, traditional or static artifacts may be available for touching, but this is not necessarily the case. It is also possible that an artifact cannot be shown in an exhibition because of environmental conditions. The distinction between these options helps to understand how we can interweave the artifact. Therefore, we integrate the following categorization in our Design Space:

Not Observable. Because of environmental conditions, artifacts cannot be shown in an exhibition. For example, the artifact cannot be moved (e.g., Babenberg Family Tree - a huge 8x4 m monumental painting (see Figure 3.3a)), humidity and lighting conditions cannot be guaranteed (Bradley, 2015), or there is not enough space available (Bradley, 2015). For this category, interweaving is only possible through an analog or digital replication or reinterpretation of the original artifact.

Observable. The artifact can be observed from a distance. Historical artifacts in art history frequently fall into this category. Visitors can observe paintings such as the Mona Lisa (see Figure 3.3b) from a distance, sometimes indicated by a barrier. Other artifacts, like old books or manuscripts, may be presented behind glass. Such artifacts are well-suited to being supplemented by digital media, from adding additional information through a mobile application to extending the artifact itself through projection mapping or augmented reality.

Physically Explorable. The artifact can be physically explored. Visitors can touch the artifact, take it into their hands, or enter it like, for example, the cable car at Technisches Museum Wien (Austria) (see Figure 3.4a). A digital extension for such an artifact can react to physical exploration.

Physically Interactable. Visitors can physically interact with the artifact. The artifact reacts to the visitor's physical interaction, such as starting a mechanical process by pushing a button (Allen, 2014). We can use digital media, for example, to visualize the process behind the interaction as it was implemented for the Abakus in Technisches Museum Wien (Austria) (see Figure 3.4b).

Type of Museum

The International Council of Museums (ICOM) defines museums as follows:

> A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment. (ICOM, 2007)

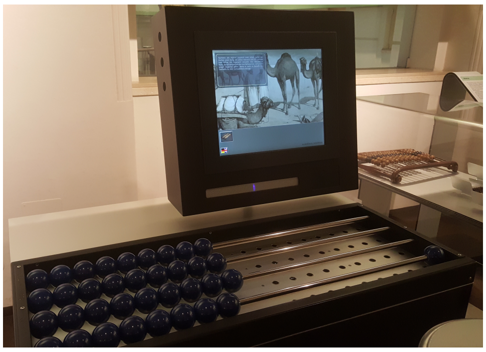
Nowadays, many museums take on roles other than the traditional ones in the definition. Museums have changed to become more interactive by adding creative elements and digital media. Ambrose and Paine (2012) describe different possibilities to classify museums: by collections, management, geographical area, type of audience, or mode of exhibition. Within the Design Space, we wanted to introduce a dimension that distinguishes museums based on visitors' expectations when they enter museums since such visitor rituals vary widely (Bell, 2002). Hornecker and Ciolfi (2019), for example, found that when visitors enter an art gallery, they "behave almost as in a church -

(a) The Babenberg Family Tree as an example of a not observable artifact when it comes to moving it to another exhibition space. Photographed by M. Seidl in 2017.

(b) The Mona Lisa in the Louvre is an example of an observable artifact that can be viewed from a distance (Josh Hallett / CC BY-SA, https://creativecommons.org/licenses/by-sa/2.09).

Figure 3.3: Examples of a non-observable and an observable artifact.

(a) The cable car at Technisches Museum Wien is an example of a physically explorable artifact. Visitors can enter it and sit down. Photographed by K. Blumenstein in 2017.



(b) With the Abakus at Technisches Museum Wien, visitors can interact physically and solve tasks visualized on a screen. Photographed by K. Blumenstein in 2017.

Figure 3.4: Examples of a physically explorable and a physically interactable artifact.

wandering around, standing still to watch, and being silent" (Hornecker and Ciolfi, 2019, p.4). Science or technical museums are on the other end of the spectrum, presenting various machines and installations that visitors can interact with (Sandifer, 2003). Thus, the mode of exhibition is of interest (Ambrose and Paine, 2012):

Interactive Museum. Interactive museums promote the practical experience of visitors. Examples of such museums are science and technology museums. They usually focus on the aspects of science. Visitors can experience the artifacts by physically engaging or actively interacting with them (Bell, 2002).

In such museums, digital media are often used as stationary installations. E.g., Ma et al. (2015) have realized a multi-touch table at the Exploratorium (San Francisco, USA) which visitors can use to explore the distribution of phytoplankton in the world's oceans. The Technisches Museum Wien (Austria) houses various interactive installations ranging from information screens to combinations of physical artifacts and screens (e.g., see Figure 3.4b). The Deutsches Museum (Munich, Germany) uses a mobile app to allow its visitors to discover the exhibitions and museum highlights in self-determined guided tours (Deutsches Museum, 2018).

Open-air Museum. Open-air museums present their artifacts outdoors ("open-air museum", 2020). E.g., in the Roman city of Carnuntum (Austria), visitors can explore reconstructed ancient houses, the amphitheaters, and the Carnuntinum Museum as Carnuntum's treasure house (Luzar, 2020). Other examples of open-air museums are archaeological parks or living museums where costumed performers depict the life of an earlier epoch.

Such exhibitions are often extended with a mobile application. In Carnuntum, the app allows visitors to experience previously invisible areas in 3D through location (GPS[1]) and visual tracking technologies (K. Höbart, personal conversation, March 30, 2020). Ardito et al. (2008, 2009) developed a mobile educational game for the Egnathia archeological park with location tracking (GPS).

Historic House Museum. Historical houses are open to the public, should be left in their original state, and have not been rebuilt to integrate collections from different sources. Examples of such museums include "sites of all sizes and kinds, ranging from royal palaces to residences of powerful personages, the houses of famous personages, artists' studios, rich bourgeois houses and even modest cottages" (Pinna, 2001, p. 4).

Currently, digital media are not widely used in house museums, apart from using mobile apps (Ciolfi, 2015; Claisse et al., 2018; Szymanski et al., 2008). Claisse et al. (2018) designed an example of a well-integrated installation in the Bishop's House (Sheffield, England). Visitors can select one of five smart objects that belonged to

[1] Global Positioning System: https://web.archive.org/web/20180131184150/http://www.loc.gov/rr/scitech/mysteries/global.html, last access August 30, 2020.

figures from different periods. During their tour of the museum, these objects then trigger reactions in a tableau of the figures.

Traditional Museum. We classify museums that do not fit into the above categories as traditional museums. Art museums, galleries, cultural, and historical museums are examples of such museums.

In traditional museums, audio guides are frequently offered (Bell, 2002). However, these museums are also interesting for interactive installations or mobile applications. E.g., Hinrichs et al. (2008) developed a visualization about the artist Emily Carr for the Glenbow Museum (Calgary, Canada) - an art and history museum. A mobile tourist guide was implemented by Damala et al. (2005) for the Museum of Fine Arts (Lyon, France).

When we combine the two categorizations in Physical Space (type of artifact and museum), we see that interactive museums often integrate physically explorable and physically interactable artifacts. Traditional museums, on the other hand, have collections with not observable and observable artifacts. Historic house museums usually integrate observable and physically explorable artifacts, while open-air museum feature observable, physically explorable, and physically interactable artifacts.

3.2 Digital Media Space

Based on the phrase “the medium is the message” (McLuhan and Lapham, 1994, p. 7), we want to transport data visualization through digital media. Logan (2010) distinguishes “new” media from traditional ones by defining them as “digital, interactive, incorporate two-way communication, involve some form of computing” (Logan, 2010, p. 10). Therefore, according to Logan (2010), the main functions of digital media are interactivity and two-way communication using a computer. Users can interact with the presented content or with the content creator. Compared to traditional “old” media (e.g., print, radio, television), where people can only perceive, the “new” (digital) media enable users to both perceive and act. These two processes (perception and action) are used to describe how people interact with the world. Neuroscientists call it the perception-action cycle (Fuster, 2004). Norman (1988) transfers this cycle to product development and calls it the Gulfs of Execution and Evaluation.

> When people encounter a device, they face two gulfs: the Gulf of Execution, where they try to figure out how to use it, and the Gulf of Evaluation, where they try to figure out what state it is in and whether their actions got them to their goal. (Norman, 2013, p. 39)

Based on this differentiation, we want to describe the digital media space through the two aspects of 1) action and 2) perception. Figure 3.5 gives an overview of Digital Media Space. According to the description of digital media, in Digital Media Space, we generally speak of (touch) displays (from small smartwatches up to large wall displays) and interactive settings with speakers, cameras, or sensors.

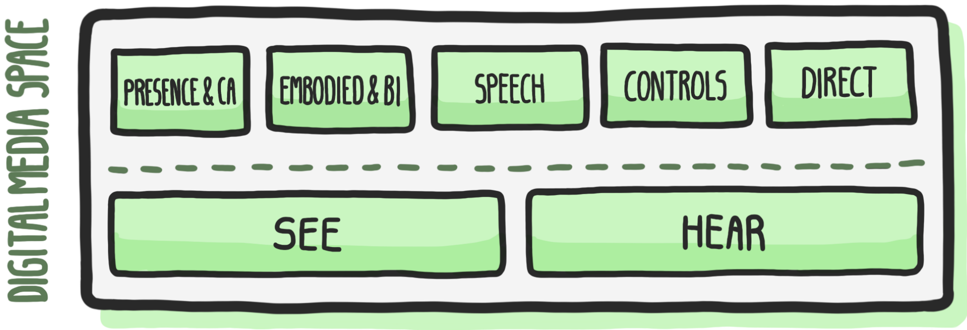


Figure 3.5: Overview of Digital Media Space with the aspects of action (presence & context awareness (Presence & CA), embodied & bodily interaction (Embodied & BI), speech, controls with physical and touch controls, and direct manipulation (direct) through tangibles and touch) and perception (seeing (see) through mobile, horizontal, vertical or room displays, and hearing (hear)). Illustration by M.Boucher, idea by K. Blumenstein.

Action

Actions should integrate all forms of how visitors can interact with digital media in museums. Our categorization was inspired by the ten interaction modalities of Müller et al. (2010) in their design space for the interactive public. Besides, we analyzed the interaction frames described by Hornecker and Ciolfi (2019) and combined this differentiation with the interaction modalities of Müller et al. (2010) to categorize our action aspect.

Presence and Context Awareness. Sensors such as cameras, microphones, pressure sensors, Bluetooth, RFID[2] scanners (Müller et al., 2010), or GPS track the presence of visitors. Therefore, technology can be used that leads to an implicit interaction for visitors, as they may not be aware of such interactions.

In museums, presence is mainly used to react to visitors' locations, often in combination with mobile devices. Ghiani et al. (2009) present a location-based guide using mobile devices that are equipped with RFID tags and can recognize nearby artwork. GPS was used for the mobile educational game for the Egnathia archeological park (Ardito et al., 2008, 2009). Based on GPS and the camera, the Carnuntum app shows previously invisible areas in 3D (7reasons, 2018). An interactive floor was installed in the Swarovski Kristallwelten (Irschitz, 2015). Cristalline traces follow the visitors in the Ice Passage realized by infrared spotlight and cameras (O. Irschitz, personal conversation, April 20, 2020).

[2] Radio-frequency identification: https://passive-components.eu/what-is-rfid-how-rfid-works-rfid-explained-in-detail/, last access July 20, 2020.

Embodied and Bodily Interaction The visitors' body interactions are tracked using technologies such as (depth) cameras, motion tracking, and low-frequency waves for embodied and bodily interaction (Müller et al., 2010). Usually, visitors are aware of such interactions as body position, body postures, gestures, facial expressions, or gaze. The installation Videoplay (Krueger, 1975) is an early example of embodied action without the use of computers.

Nowadays, visitors can reveal an artwork with their entire body at ARTLENS Gallery (Cleveland Museum of Art, USA) (Alexander et al., 2017). For this purpose, a depth camera tracks the movement of the visitors. Trajkova et al. (2020) used Microsoft Kinect to track the visitors' bodies to let them interact with an interactive globe. The Virtual Conductor at Haus der Musik (Vienna, Austria)[3] works with gestural recognition via an infrared baton. Thus, visitors can influence the speed, volume, and emphasis of the entire orchestra (Hornecker and Ciolfi, 2019). An example of facial expressions was implemented at ARTLENS Gallery (Cleveland Museum of Art, USA) (Alexander et al., 2017). Through the ARTLENS exhibition game Make a Face, visitors can interpret the emotion of the figure of an artwork. Their facial expressions are then compared to another portrait.

Speech. Microphones are used to react to speech actions. The content could be changed based on the number of visitors in front of the installation or voice commands (Müller et al., 2010).

Controls. Visitors interact indirectly with the installation via an additional device such as a keyboard, a mouse, a physical button, or an additional touch device. The display with the object of interest is not located on the same device as the one on which the interaction is performed. We differentiate between physical and touch controls.

Physical controls using a standard keyboard or mouse interaction seem rare for modern museum installations. The Technisches Museum Wien (Austria)[4] still has some computer terminals which can be navigated by trackball and keys. Also, visitors to the medien.welten area can access the Internet via computers with classic keyboard and mouse interaction. For an exhibition in the Cultural Center of Hermoupolis in Syros island, Vosinakis and Xenakis (2011) implemented a virtual world installation that visitors can access by keyboard to post comments or talk to remote visitors. Kenderdine (2012) also used a game controller to navigate through images in a cave environment.

Touch controls usually utilize an additional touch device such as a tablet to control installations on displays that are often room-filling. Kenderdine and McKenzie (2013) and Marton et al. (2014) created examples for this setting.

[3] Haus der Musik in Vienna, Austria: https://www.hausdermusik.com/en/museum/4-etage-der-virtuelle-dirigent/, last access April 9, 2020.

[4] Technisches Museum Wien, Austria: https://www.technischesmuseum.at/language/en-us/home, last access July 20, 2020.

Direct Manipulation. Visitors interact with the "displayed object of interest using physical, incremental, reversible actions whose effects are immediately visible on the screen" (Sherugar and Budiu, 2016). Shneiderman (1983) introduced the term in connection with command-line interfaces. We differentiate between direct tangible and touch manipulation.

Tangible user interfaces (TUIs) (Ishii and Ullmer, 1997) transform the world itself into an interface by combining everyday physical objects and environments with digital information. Tangibles are used as extensions for tabletop applications (e.g., Chu et al., 2015; Horn et al., 2008; Loparev et al., 2016; Ma et al., 2015). On the other hand, Marshall et al. (2016) use tangible smart replicas equipped with NFC[5], which visitors can collect at the beginning of their museum visit to trigger audiovisual content. Moreover, Maquil et al. (2017) present a tangible interactive workbench. By inserting battery components and turning a handle, visitors can experience the steps for creating a battery.

Since the introduction of the iPhone in 2006, *touch* interaction began to become famous and familiar. Thus, a variety of touch interactions are present in museums nowadays (e.g., Ghiani et al., 2008a; Hinrichs et al., 2008; Kourakis and Parés, 2010). Besides, studies were conducted on the use of touch gestures. For example, Hinrichs and Carpendale (2011) studied multi-touch gestures on a multi-touch table at the Vancouver Aquarium (Canada). Anthony et al. (2016) performed a study about touch gestures on a large vertical and horizontal touch display using Google Earth at a marine science center in the Pacific Northwest (USA).

Perception

When visitors act on a digital system, digital media respond with an output - a representation of the computed result. The visitor can perceive this through the human senses: usually seeing and hearing. Feeling, smelling, and tasting are also subject to HCI research (Batch et al., 2020; Obrist et al., 2016) but are currently not common in museums. Miotto (2016) presents one of these rare examples of using the smelling sense in the culinary heritage in Singapore.

See. Graphical user interfaces (GUIs) are flat and often rectangular displays. Interactive installations in museums usually use horizontal and vertical (touch) screens, smartphones, tablets, or projections. Also, glasses and smartwatches are used from time to time. To differentiate the surfaces based on their intended use, we created the subcategories mobile, horizontal, vertical, and room displays.

Mobile displays such as smartphones, tablets, smartwatches, and glasses are special because of their small displays. Nevertheless, smartphones or tablets are used in museums for different purposes such as guides (Damala et al., 2005, 2008; Ghiani

[5]Near-field communication: https://www.androidauthority.com/what-is-nfc-270730/, last access July 20, 2020.

et al., 2008a,b), learning platforms (Jalil et al., 2016), for (educational) games (Damala et al., 2010; Yiannoutsou et al., 2009), or as the controlling interface (Jimenez and Lyons, 2010, 2011). The use of smartwatches is still at an early stage. First projects try to use them as a personal curator (MAK Museum Wien, 2016) or integrate them into a multi-device environment to balance personal and public interactions (Banerjee et al., 2018). Virtual and mixed reality glasses are present on the market. However, there are only a few examples that use them for museum visitors. The Microsoft Hololens is used for the ARtLens project (Pollalis et al., 2018) to promote visitors' engagement with African art. At voestalpine Stahlwelt (Linz, Austria)[6], visitors could experience a flight over the steel mill in Corpus Christi (USA) using virtual reality glasses. In a research project, Rzayev et al. (2019) investigated the effect on the understanding of the guide's speech and the perceived co-presence of the mixed reality presentation of a guide (human, realistic virtual, abstract virtual, or audio). The test in a lab environment showed that a virtual guide's realistic representation leads to a higher co-presence than the abstract or audio guide.

Horizontal displays (table-like) are successfully used in museums (Hornecker and Ciolfi, 2019), which has been shown by various projects (e.g., Block et al., 2012; Correia et al., 2010; Hinrichs et al., 2008; Hinrichs and Carpendale, 2010; Horn et al., 2012, 2016; Hsueh et al., 2016; Huang et al., 2014; Klinkhammer et al., 2011; Ma et al., 2015; Van Dijk et al., 2012; Von Zadow et al., 2011). Hornecker (2008) conducted one of the first in-the-wild studies of an interactive table application at the Berlin Museum of Natural History (Germany). Visitors were able to browse through the 'Tree of Life' based on questions and received answers visualized in the form of text and images.

Vertical displays (frame-like) are often used as information screens (Hornecker and Ciolfi, 2019). Roberts et al. (2018) have also used them for digital labels. Besides, visitors were able to see the results of answering questions on smaller vertical displays in a multi-device environment (Van Dijk et al., 2012). Projections in the sense of vertical displays are also used to extend artifacts by projection mapping (Basballe and Halskov, 2010) or to reproduce them by a holographic projection (Caggianese et al., 2018).

Room displays are often implemented as projections to achieve a more immersive environment. Through combining multiple projectors, a large 360-degree, panoramic projection lets the visitors dive into an immersive experience. One example of such an installation is the Pure Land project (Kenderdine, 2012; Kenderdine et al., 2014), which takes visitors to Cave 220 of the Caves of the Thousand Buddhas in Dunhuang (China). Deep Space 8K at the Ars Electronica (Linz, Austria) is a 16x9 meters wall and a floor projection of the same size. Through the 8K resolution, visitors can experience, for example, 3D renderings of the human body or the finest

[6] voestalpine Stahlwelt in Linz, Austria: https://www.voestalpine.com/stahlwelt/en, last access July 20, 2020.

brushstrokes of Leonardo da Vinci (Ars Electronica, 2020). Room displays are also used to create large interactive screens (Kourakis and Parés, 2010).

Hear. To address the sense of hearing, Acoustiguide (2014) invented audio guides as early as in the 1950s. Today, audio guides are still around. However, for the Biennale Art Exhibition in Venice (Italy), Pittarello (2019) developed an augmented reality experience with smartphones through audio augmentation. Also, Fosh et al. (2013) extended their mobile guide for the sculpture garden of Rufford Abbey (England) with audio descriptions and suitable background music. Besides, the previously mentioned Pure Land project used music to enhance the immersive experience (Kenderdine, 2012). Ryding (2020) tested an approach for an art museum using headphones. Visitors used the mobile app *Never let me go* for communicating with each other, often without speaking.

3.3 Contextual Space

We have discovered aspects and dimensions for our Design Space that are application-centric and therefore interweave Physical and Digital Media Space. Figure 3.6 gives an overview of this space. We are concerned 1) with the visitors, esp. the number of visitors interacting with the digital media, 2) with the relationship of the digital media and the artifact, and 3) with the number of digital media devices used.

Number of Visitors

As already stated in Chapter 3.1, visitors, their expectations, and expected behavior in the museum depend on the type of museum (Hornecker and Ciolfi, 2019). In general, museum audiences are diverse and vary in age, interests, and experience with technology (Hinrichs et al., 2013). Falk and Dierking (2013) distinguish the museum audience based on the experience they seek in the museum (explorers, facilitators, professionals/hobbyists, experience seekers, rechargers, respectful pilgrims, and affinity seekers). Eschenfelder (2019) responded to visitor's different interests when she defined four visitor categories: active, knowledge-thirsty, communicative, and curious. She suggests that the offer in exhibitions should also respond to these categories. However, it might be difficult to reconcile such a categorization with interactive installations.

As visitors act individually or in groups, we want to address the number of visitors interacting with the digital media devices in our Design Space:

Single. Even when visitors enter a museum in groups, roughly 30% of all visitors interact with an artifact and interactive installations alone (Block et al., 2015; Hinrichs et al., 2008). Therefore, the design should not be based on input from multiple users.

Applications that support individual visitors are often applications with mobile devices (e.g., Ardito et al., 2009; Damala et al., 2005; Ghiani et al., 2009).

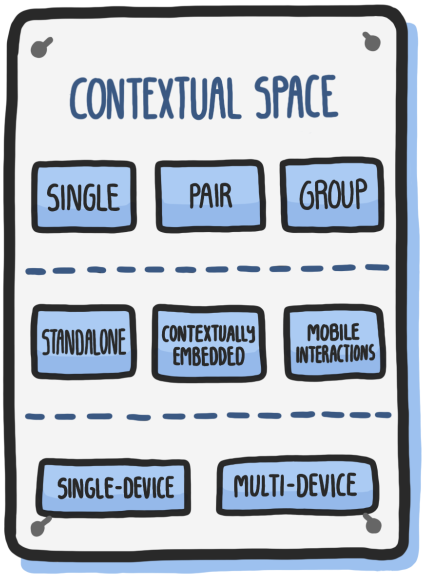


Figure 3.6: Overview of Contextual Space that intertwines Physical and Digital Media Space with the dimension number of visitors (single, pair, and group), the aspect relationship to Physical Space (standalone, contextually embedded, and mobile), and the dimension number of devices (single-device and multi-device through simultaneous, sequential, or mirrored use). Illustration by M.Boucher, idea by K. Blumenstein.

Pair. Block et al. (2015) revealed that groups of two engaged significantly longer with an interactive tabletop application then single visitors. Their suggestion is to design for groups of two.

An example that confirms this suggestion is the installation EMDialog (Hinrichs et al., 2008). The installation at the Glenbow Museum (Calgary, Canada) was used mostly by groups of two.

Group (three or more). Studies show that visitors explore museums in groups (Screven, 1999; Vom Lehn et al., 2001). However, Block et al. (2015) state that only a small number of visitors interact with the exhibits in groups of four or more. The implementation of the possibility of group interaction opens up the possibility of exploring the content collaboratively (Isenberg et al., 2010).

Not least, due to the possibility to serve such kinds of groups, interactive table applications started to be of interest in museums at the beginning of the 21st century (e.g., Block et al., 2012; Hinrichs et al., 2008; Hinrichs and Carpendale, 2010; Horn et al., 2012, 2016; Hsueh et al., 2016; Huang et al., 2014; Ma et al., 2015; Van Dijk et al., 2012; Von Zadow et al., 2011).

Relationship to Physical Space

"Whenever ICT failed to serve its purpose, it was not due to the technological component but to a problem in the overall design of the exhibition" (Pujol-Tost, 2011). It is therefore essential to understand how digital media can be integrated into Physical Space.

Hornecker and Ciolfi (2019) defined interaction frames to describe different types of relationships to the physical context that are well-suited for our Design Space (standalone installation, mobile interaction) However, this categorization lacked the augmentation of artifacts. Therefore, we integrated contextually embedded installations defined by Hornecker (2016) into our categorization. Hornecker and Ciolfi (2019) already described them as "midway between standalone and assembly" but integrated them into a different categorization.

Standalone. Such installations are isolated and have no direct interaction with the environment, even if other interactive elements are present within the exhibition (Hornecker and Ciolfi, 2019). The interactions are self-contained.

Kiosks (Serrell and Raphling, 1992) are an early example of standalone installations that still exist as information screens (e.g., at the Technisches Museum Wien (Austria) (see Figure 3.7a)). Today, interactive tables are often standalone applications. Another example is Deep Space at the Ars Electronica Center (Linz, Austria) (see Figure 3.7b). On an 8K wall and floor projection, visitors can experience worlds of images (Ars Electronica, 2020). The WeTangram application combines a shared display with mobile devices with which visitors can play Tangram (Jimenez and Lyons, 2010, 2011).

Contextually Embedded. Such installations are strongly intertwined with the museum environment and the surrounding elements (Hornecker, 2016). With contextually embedded installations, attention is drawn to the exhibits to engage visitors with the exhibit (Hornecker and Ciolfi, 2019).

One of the few examples of contextually embedded installations is the Tele-Jurascope by Hornecker (2010) at the Museum of Natural History (Berlin, Germany). Visitors can experience the dinosaurs live in 3D by pointing a periscope-like device at a specific skeleton. Other examples encourage visitors to explore cultural artifacts through digital labels (Roberts et al., 2018) or supplement historical objects with information in an interactive display case (Not et al., 2019). Bellucci et al. (2015) presented a see-through display to augment cultural objects with user-generated digital content.

Mobile Interactions. When it comes to mobile interactions, visitors carry devices that trigger interactions depending on their location. It can also be a specific moment of a content narrative (Hornecker and Ciolfi, 2019).

Starting with audio guides (Acoustiguide, 2014) in the 1950s, research with PDAs and pocket PCs in the 1990s (e.g., Petrelli and Not, 2005) was followed by several other visitor guides (e.g., Cardoso et al., 2019; Damala et al., 2005; Ghiani et al., 2008a; Othman et al., 2015). One consequence of the current widespread use of smartphones with affordable data rates is that the phrase 'Bring your own device' (BYOD) is also gaining in importance in museums (e.g., Deutsches Museum, 2018; Fluxguide, 2018; Keltenmuseum Hallein, 2006). Smartwatches are also used for mobile interactions (e.g., Banerjee et al., 2018; MAK Museum Wien, 2016). However, the documented projects are at an early stage of research.

The combination of using a portable element (e.g., a mobile app with *mobile interactions*) together with installations that can be standalone or contextually embedded installations is referred to as assembly. Thus, assemblies have an overall unified activity, a common information space, a group of interactive displays with conventional interaction techniques, and a portable element (Fraser et al., 2003).

Based on these principles, Ciolfi and McLoughlin (2018) developed the installation Reminisce for Bunratty Folk Park, an Irish open-air museum. The installation consists of a mobile app that allows visitors to collect auditory memories throughout the museum, and tangible tokens (card with RFID) as input for an interactive desk at the end of their visit. Another example is the smart objects by Claisse et al. (2018, 2020). At the beginning of their tour, visitors select an NFC-tagged object. During their visit, this object triggers various contents on digital displays.

A portable analog element (bar code) is used at the Science Centre Tietomaa (Oulu, Finland)[7]. Visitors can identify themselves at 12 interactive stations of the exhibition 'X or Y - male or female' and solve quests such as guessing where north is, or mixing colors. The same analog technique was used at the Museon in The Hague (Netherlands) where an interactive table in the entrance hall was combined with terminals (vertical touch displays) spread across the exhibition. Visitors were able to create a personal quest at the beginning, answering questions at the terminals, and end up with a final game (Van Dijk et al., 2012).

Number of Devices

With the arrival of smartwatches, smartphones, and tablets in households, the use of devices changed. Not only do we use several different devices throughout the day, but we increasingly use them simultaneously (Götz and vom Orde, 2019; United Internet Media, 2016). Multi-device settings are also implemented in museums. Therefore, we want to distinguish between single- and multi-device use in our Design Space.

Single Device. When visitors deal with only one digital media device at a time, we refer to this as using a single device.

[7] Science Center Tietomaa in Oulu, Finland: https://www.ouka.fi/oulu/luuppi-english/science-centre-tietomaa, last access July 20, 2020.

(a) Standalone information screen at the Technisches Museum Wien. Photographed by K. Blumenstein in 2017.

(b) Standalone installation as wall and floor projection at the Ars Electronica Center Linz (Tobias1984 / CC BY-SA, https://creativecommons.org/licenses/by-sa/2.09).

Figure 3.7: Examples of standalone installations.

Examples of the use of single devices are the extension of the museum visit through a mobile application (e.g., Cardoso et al., 2019; Damala et al., 2005; Deutsches Museum, 2018; Fluxguide, 2018; Keltenmuseum Hallein, 2006). Additional examples are kiosks, information screens (e.g., Serrell and Raphling, 1992), and interactive tables (e.g., Block et al., 2012; Horn et al., 2012; Ma et al., 2015).

Multiple Devices. When visitors have to deal with more than one device, we categorize such installations as multi-device. We distinguish between simultaneous, sequential, and mirrored use (Brudy et al., 2019).

In *simultaneous* settings, the devices are used at the same time. Examples of such settings are combinations of mobile devices and shared larger displays. Shared displays are distributed throughout the museum (Dini et al., 2007; Ghiani et al., 2009; Jimenez and Lyons, 2010, 2011), and games can be played in distributed views. Beheshti et al. (2017) presented another example where they used a tablet for augmenting an electrical circuit on an interactive table to visualize the constructed circuit's electron simulation.

Van Dijk et al. (2012) implemented a *sequential* setting in which shared displays are positioned throughout the museum. Visitors use them one after the other to answer questions.

Another example of multi-device use is EMDialog (Hinrichs et al., 2008), which uses a combination of an interactive table and a projection. Visitors were able to interact with the table. The interactions were mapped onto the large wall projection that was visible across the floor. This is, therefore, a *mirrored* use.

3.4 Visualization Space

Visualization Space represents the content that is displayed on the digital media. Figure 3.8 gives an overview of this space. To gain a better understanding of the visualizations, we address two dimensions in this space: 1) the type of data and 2) the type of visualization.

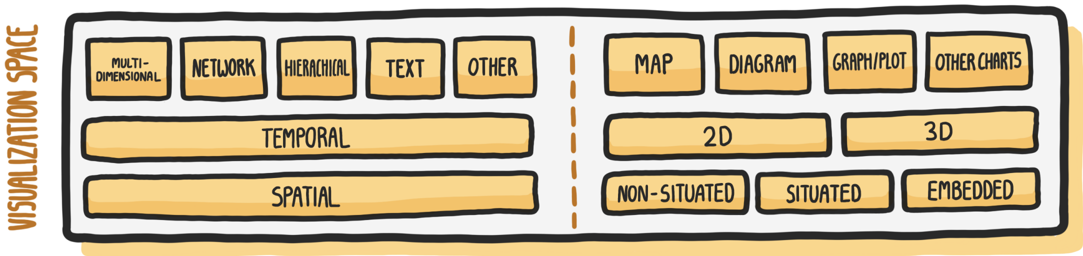


Figure 3.8: Overview of Visualization Space with the dimensions type of data (multidimensional, network, hierarchical, text, other, temporal, and spatial) and type of visualization (map, graph/plot, diagram, other charts, 2D, 3D, non-situated, situated, and embedded). Illustration by M.Boucher, idea by K. Blumenstein.

Type of Data

Various categorizations have already been published to describe the type of data on which the visualization is based (e.g., Isenberg and Isenberg, 2013; Keim, 2002; Munzner, 2015; Shneiderman, 1996). All these categorizations differ only slightly. The categorization of Shneiderman (1996) seems to be the basis for Keim (2002) and Isenberg and Isenberg (2013). We base our categorization mainly on Isenberg and Isenberg (2013), although with the difference that we separate spatial and temporal semantics as orthogonal aspects (see Figure 3.8).

Multidimensional. Such data consist of data items with more than two attributes. One example is tabular data (Isenberg and Isenberg, 2013).

Cafaro et al. (2013) and Roberts et al. (2014) made the US Census data available for exploration, first at a small history museum and later at a mid-sized urban science museum. Ma et al. (2015) and Hsueh et al. (2016) visualized the behavior of different species in the oceans for science museums. The underlying data are also examples of multidimensional data.

Network. Such data have relationships to other information (Keim, 2002). Examples are graphs (Isenberg and Isenberg, 2013) that are made up of a set of objects (nodes) and connections between these objects (edges) (Keim, 2002).

The Max Planck Research Network (Truth & Beauty, 2014), a project for the Max Planck Science Gallery (Berlin, Germany), uses network data to visualize the collaborations of Max Planck Institutes. Similarly, visitors can explore the huge network of École Polytechnique Fédérale de Lausanne (EPFL) along with the main themes, people, topics, and impact with EPFL Data Monolith (Truth & Beauty, 2017).

Hierarchical. Such data are directory structures, organizational hierarchies, branching processes, genealogies, or classification hierarchies and can also be referred to as tree data (Börner and Polley, 2014).

Hierarchical data form the basis for the Deep Tree application (Block et al., 2012; Davis et al., 2013; Horn et al., 2016) in a natural history museum.

Text. Such data cannot be described in dimensions (Keim, 2002). Examples are news articles and web documents (Keim, 2002), as well as document collections or software codes (Isenberg and Isenberg, 2013).

In their project EM Dialog, Hinrichs et al. (2008) worked with text data, among other data, by showing and contextualizing statements of an artist.

Other. This category describes data that do not fit into the above categories. E.g., we would classify photo collections in this category (Isenberg and Isenberg, 2013).

For example, Hinrichs and Carpendale (2010) visualized an image and video collection with the Collection Viewer Table at the Vancouver Aquarium (Canada).

These five data types can hold data with the following semantics (Munzner, 2015):

Temporal. Temporal data are any kind of information that relates to time (Munzner, 2015).

In EM Dialog (Hinrichs et al., 2008), for example, text and other data are combined with the temporal dimension.

Spatial. Such data are positions that "could be points, or one-dimensional lines or curves, or 2D surfaces or regions, or 3D volumes" (Munzner, 2015, p. 29).

Spatial semantics were used in combination with multidimensional and other data for GeoLens (Von Zadow et al., 2011). Also, Rönneberg et al. (2014) used spatial semantics in their multidimensional data.

Furthermore, projects often combine spatial and temporal semantics with at least one of the other data types (e.g., Hsueh et al., 2016; Ress et al., 2018; Roberts et al., 2014).

Type of Visualization

There are also various categorizations to describe different visualization types (e.g., Aigner et al., 2011; Harris, 1999; Isenberg and Isenberg, 2013; Keim, 2002; Willett et al., 2017).

A fundamental distinction is made between data visualization and data physicalization (Willett et al., 2017). Data physicalization is used to describe computer-supported physical representations of data (Jansen et al., 2015). In this field of research, the geometry or material of an artifact itself encodes data. In our work, the artifact itself does not have to be a data representative. For this reason, we concentrate on data visualization.

The categorizations of Harris (1999), Keim (2002), and Isenberg and Isenberg (2013) differ slightly. We base our categorization mainly on Harris (1999). The main difference is the integration of the dimensionality (2D or 3D) and the relation to the physical artifact as orthogonal dimensions (see Figure 3.8).

Map. Maps visualize information related to its spatial position (e.g., country maps) (Isenberg and Isenberg, 2013).

In the museum context, several examples of map usage exist (e.g., Cafaro et al., 2013; Hinrichs and Carpendale, 2010; Ress et al., 2018; Von Zadow et al., 2011). Hsueh et al. (2016) and Von Zadow et al. (2011) present examples of using map visualizations on interactive tables. Rönneberg et al. (2014), for example, visualize various data sources (e.g., description or data origin) related to the geospatial object on a map using a large vertical touch display.

Graph (plot). A graph visualizes "quantitative information using position and magnitude of geometric objects" (Lohse et al., 1994) and is thus based on a coordinate system (Isenberg and Isenberg, 2013).

Currently, graphs are not frequently used in museums. One of the three visualizations linked by Rogers et al. (2014) was a bar graph showing an overview of the creation time of all artifacts in the exhibition when comparing in-situ and remote explorations of museum collections.

Diagram. Diagrams are a visualization of relational structures (Harris, 1999). Information is visualized mainly through geometric shapes (circles, rectangles, or triangles) connected by lines or arrows (Harris, 1999).

Examples are node-link diagrams or tree visualizations (Isenberg and Isenberg, 2013). Deep Tree applications are representatives of this category (Block et al., 2012; Davis et al., 2013; Horn et al., 2016). The interactive table exhibit visualizes the phylogenetic relationship of all life on earth as a tree.

Other charts. We categorize visualization types that do not fit into one of the other categories as Other charts.

Hinrichs et al. (2008), for example, visualize different eras as tree rings. Besides, Ma et al. (2015) present a lense with icons of different planktons. The proportion of the icons equals their distribution of the represented types at the selected location on a map.

These four representation types can be presented as two- or three-dimensional visualizations (Aigner et al., 2011).

2D. A 2D representation addresses the spatial dimensions of computer displays, that is, the x axis and the y axis (Aigner et al., 2011). We describe all graphical elements in relation to the x and y coordinates.

The 2D representation is currently the most commonly used in museums. All but one mentioned example (Ma et al., 2015) implement a 2-dimensional visualization.

3D. In addition to the x and y dimensions of a 2D representation, 3D uses a third dimension (z axis) to describe geometry. Therefore, the visualization can be more complex and can preserve volumetric structures (Aigner et al., 2011).

Cho et al. (2019) developed a 3D visualization to compare 3D volume data of living persons and mummies.

As it is essential to understand the connection between the visualization and the physical artifact, we add an additional orthogonal dimension to the type of visualization: We want to differentiate between non-situated visualization, situated visualization, and embedded visualization (Willett et al., 2017).

Non-situated. In a non-situated visualization, the visualization is presented regardless of a physical referent (Willett et al., 2017). This means that the installations could be easily moved to another space or exhibition without changing anything.

Almost all of the examples mentioned above fit into this category. Exceptions are explained with the next two categories.

Situated. White (2009) defined three critical characteristics for situated data representations: 1) the visualized data are related to the physical context, 2) the visualization is based on the relevance of the data for the physical context, and 3) the representation of the visualization is in the physical context. For our setting, we define a physical artifact as the physical context. Therefore, the visualization must be placed next to a physical artifact for the two to be experienced together.

The projects by Cho et al. (2019) and Ynnerman et al. (2016) allow visitors to experience the 3D visualizations together with a physical artifact, a mummy.

Embedded. For an embedded data representation, data visualizations are displayed in relation to their respective physical referent. Therefore, multiple physical presentations are used to place each visualization closer to its corresponding referent (Willett et al., 2017). Embedded visualization can be achieved using, for example, projection or see-through technology.

Maquil et al. (2017) implemented such an example where visitors were able to select different components of a battery. Depending on the selection, the resulting electron flow was visualized on a see-through display.

3.5 Summary

This chapter explored the Design Space for interweaving physical artifacts with data visualization on digital media in museums. We performed a systematic literature research to gain insights into affected areas for such applications and end up with four subspaces:

Physical Space describes the different types of artifacts and the environment.

Digital Media Space deals with the possibilities of interacting with and perceiving digital media.

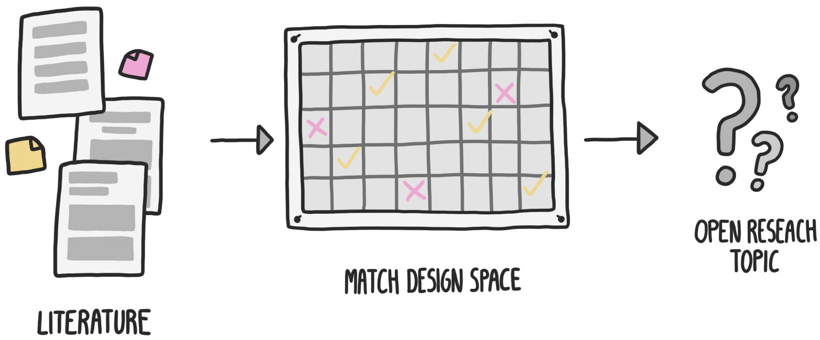
Contextual Space connects Physical Space and Digital Media Space to address application-centric dimensions.

Visualization Space describes options for data and representations with a focus on data visualization.

Our Design Space serves as an overview of the entire topic. In the next chapter (Chapter 4), we prove our Design Space by applying it to existing scientific literature researching data visualization in museums.

CHAPTER 4

Applying the Design Space: Survey of Data Visualization on Digital Media in Museums



This chapter applies our Design Space to existing scientific literature researching data visualization in museums. We first present the categorization of the 28 scientific papers addressing data visualization in museums based on our Design Space (Chapter 4.1). We then describe the found literature through the identified clusters (Chapter 4.2) and conclude with open research topics backed by the state of the art report (Chapter 4.3).

4.1 Categorization & Comparison

We have categorized all installations along our Design Space (see Chapter 3) to provide a systematic overview of our literature research results. Thus, we present the 28 found papers based on

- Physical Space (the type of artifact associated with the installation and the type of museum),
- Digital Media Space (options for action and perception),
- Contextual Space (number of visitors who can interact, the relation to the Physical Space, and the use of devices), and
- Visualization Space (the type of data and type of visualization).

Physical Space

Physical Space describes the artifact-related dimension. We therefore address the type of artifact associated with the installation and its surroundings - the type of museum.

Table 4.1: Physical Space – Categorization overview of the found literature concerning the type of physical artifact interwoven with the installation and the type of museum. The literature is sorted by year and first author.

		Cosley et al. (2008)	Hinrichs et al. (2008)	Asai et al. (2010)	Hinrichs and Carpendale (2010)	Von Zadow et al. (2011)	Block et al. (2012)	Chua et al. (2012)	Horn et al. (2012)	Ma et al. (2012)	Cafaro et al. (2013)	Kenderdine and McKenzie (2013)	Brunet (2014)	Marton et al. (2014)	Roberts et al. (2014)	Rogers et al. (2014)	Ma et al. (2015)	Danyun et al. (2016)	Hsueh et al. (2016)	Jönsson et al. (2016)	Ynnerman et al. (2016)	Maquil et al. (2017)	Mishra and Cafaro (2018)	Ress et al. (2018)	Roberts et al. (2018)	Mallavarapu et al. (2019)	Reddy and Kota (2019)	Cho et al. (2019)	Trajkova et al. (2020)	SUM (28)
Type of Artifact	not observable	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	2
	observable	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	✓	-	-	-	✓	-	-	✓	-	5
	explorable	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	interactable	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	none	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	-	✓	✓	✓	✓	-	✓	✓	✓	-	✓	✓	-	✓	22
Museum Genre	interactive	-	-	✓	-	✓	-	-	-	✓	-	-	-	-	✓	-	✓	-	✓	✓	-	✓	✓	-	-	✓	-	-	✓	11
	historic house	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	open air	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	1
	traditional	✓	✓	-	✓	-	✓	✓	✓	-	✓	-	✓	✓	-	✓	-	✓	-	-	✓	-	-	-	✓	-	-	✓	-	14
	n/a	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	2

As shown in Table 4.1, visualizations in museums are usually not linked to a physical artifact in the exhibition (22 times). Through the visualization of stone statues (Marton et al., 2014) and the integration of artifacts that are not exhibited (Rogers et al., 2014), two papers dealt with non-observable artifacts that cannot be presented in an exhibition. The approaches in five papers dealt with observable (exhibited) artifacts such as statues (Cosley et al., 2008), mummies (Cho et al., 2019; Ynnerman et al., 2016), or artifacts behind glass (Roberts et al., 2018).

The majority of papers developed their installation for traditional (14 times) and interactive (11) museums. The interactive museum that occurs most often (three times) is the Exploratorium, a museum of science, art, and human perception in San Francisco (USA) (Hsueh et al., 2016; Ma et al., 2012, 2015). Traditional museums are, for example, natural history museums (Block et al., 2012; Danyun et al., 2016; Horn et al., 2012; Roberts et al., 2018), art museums (Cosley et al., 2008), or aquariums (Hinrichs and Carpendale, 2010). Only one approach dealt with an open-air museum - the Historic New Harmony in southwest Indiana (USA) (Ress et al., 2018). We did not find any applications with visualization for a historic house. In two papers, we could not find any information about the type of museum addressed (Kenderdine and McKenzie, 2013; Reddy and Kota, 2019).

Digital Media Space

Digital Media Space describes dimensions concerning the devices used. We categorize the approaches in relation to the dimensions action and perception.

Table 4.2: Digital Media Space – Categorization overview of the found literature concerning their action and perception possibilities. The literature is sorted by year and first author.

			Cosley et al. (2008)	Hinrichs et al. (2008)	Asai et al. (2010)	Hinrichs and Carpendale (2010)	Von Zadow et al. (2011)	Block et al. (2012)	Chua et al. (2012)	Horn et al. (2012)	Ma et al. (2012)	Cafaro et al. (2013)	Kenderdine and McKenzie (2013)	Brunet (2014)	Marton et al. (2014)	Roberts et al. (2014)	Rogers et al. (2014)	Ma et al. (2015)	Danyun et al. (2016)	Hsueh et al. (2016)	Jönsson et al. (2016)	Ynnerman et al. (2016)	Maquil et al. (2017)	Mishra and Cafaro (2018)	Ress et al. (2018)	Roberts et al. (2018)	Mallavarapu et al. (2019)	Reddy and Kota (2019)	Cho et al. (2019)	Trajkova et al. (2020)	SUM (28)
Action	presence		-	-	-	-	-	-	-	-	-	✓	-	-	-	✓	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	3
	embodied		-	-	-	-	-	-	-	-	-	✓	-	-	-	✓	-	-	-	-	-	-	-	✓	-	-	✓	✓	-	✓	6
	speech		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	controls	*physical*	✓	-	✓	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-	-	4
	↪	*touch*	-	-	-	-	-	-	-	-	-	-	✓	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
	direct man.	*tangible*	-	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	✓	-	-	✓	-	-	-	-	-	-	-	4
	↪	*touch*	-	✓	-	✓	✓	✓	✓	✓	✓	-	-	-	-	-	✓	✓	-	✓	✓	✓	-	-	✓	✓	-	✓	✓	-	16
	n/a		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-	-	-	-	-	-	1
Perception	see	*mobile*	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	✓	-	-	-	-	-	-	-	-	-	✓	-	-	-	3
	↪	*horizontal*	-	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	✓	-	-	✓	-	✓	-	✓	✓	-	-	✓	-	-	-	-	14
		vertical	✓	-	✓	-	-	-	-	-	-	✓	-	✓	-	✓	-	-	-	-	-	-	-	✓	-	-	-	✓	✓	✓	9
		room	-	✓	-	-	-	-	-	-	-	-	✓	-	✓	-	-	-	-	-	-	-	-	-	✓	-	✓	-	-	-	5
		display n/a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	✓	-	-	-	-	-	-	-	-	-	2
	hear		✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

Direct manipulation was used to interact with the visualizations by the majority of installations as shown in Table 4.2. Sixteen of them implemented touch interaction. In addition to the classic finger-touch interaction, one installation (Chua et al., 2012) implemented a direct interaction with the hand and arm. Only four papers used tangibles for interaction with physical objects. Examples are cards with flags to switch languages (Maquil et al., 2017) or species information cards to highlight this species at the touch table (Hsueh et al., 2016), markers to change information on the lunar surface map (Asai et al., 2010), or physical rings to see details at a selected position (Ma et al., 2015). Two of the installations combine tangible and touch interaction (Hsueh et al., 2016; Ma et al., 2015). Six papers documented the use of controls. Four papers used physical controls such as a wheel to move a time axis (Maquil et al., 2017), a joystick to control the lunar rover (Cosley et al., 2008), a guitar pedal to change speed (Brunet, 2014), and a standard keyboard and mouse (Cosley et al., 2008). Touch controls were developed for two approaches (Kenderdine and McKenzie, 2013; Marton et al., 2014). In six installations, visitors were able to act through embodied and bodily interaction, e.g., the position of the visitors influenced the choice of time (Roberts et al., 2014) or hand gestures influenced a sphere (Reddy and Kota, 2019). Besides, body interaction was implemented with Microsoft Kinect (Cafaro et al., 2013; Mallavarapu et al., 2019; Mishra and Cafaro, 2018; Trajkova et al., 2020). Three of them combined the embodied action with presence, e.g., to identify users nearby via RFID (Cafaro et al., 2013; Roberts et al., 2014) or to let the visitors see the visualization by being in the designated space (Mallavarapu et al., 2019). None of the applications used speech interaction. In one paper, we found no information about the intended interaction (Danyun et al., 2016).

All installations can be categorized as see in the perception dimension. The majority (14) used horizontal displays (table-like). Nine installations implemented vertical displays (frame-like). To achieve a larger vertical display and thus more immersion, five installations used room displays. Only three installations were developed with mobile displays using tablets in particular (Kenderdine and McKenzie, 2013; Mallavarapu et al., 2019; Rogers et al., 2014). We did not find any approaches with smartphones or glasses. One of the examples was used to control the large visualization by touch (Kenderdine and McKenzie, 2013). The second mobile approach integrated the tablet showing a non-interactive visualization on the tablet (Mallavarapu et al., 2019). And the third one is a direct touch implementation (Rogers et al., 2014). Besides, two papers reported a display without any further information (Danyun et al., 2016; Jönsson et al., 2016). Only one paper also dealt with the sense of hearing (Cosley et al., 2008) by playing an individual sound when selecting a person.

Combining perception and action, one can see that mobile and horizontal displays are used primarily in combination with direct touch manipulation (12 out of 17 contributions). Vertical and room displays are mainly combined with controls (5 out of 14 papers) and embodied and bodily (6 out of 14 papers) actions.

Contextual Space

Contextual Space connects Physical Space and Digital Media Space and addresses application-centric dimensions. The number of visitors who can interact with the installation, the relation to Physical Space, and the use of devices are of interest for this categorization (see Table 4.3).

Eight installations were aimed at single visitors, while six contributions were aimed at pairs, and seven at groups. The combination of pairs and groups was covered by three papers (Maquil et al., 2017; Roberts et al., 2014; Von Zadow et al., 2011). Besides, one paper each was addressed to single visitors and groups (Block et al., 2012), and single

Table 4.3: Contextual Space – Categorization overview of the found literature concerning the number of visitors who can interact, the relationship to Physical Space, and the number of devices a visitor has to focus on. The literature is sorted by year and first author.

			Cosley et al. (2008)	Hinrichs et al. (2008)	Asai et al. (2010)	Hinrichs and Carpendale (2010)	Von Zadow et al. (2011)	Block et al. (2012)	Chua et al. (2012)	Horn et al. (2012)	Ma et al. (2012)	Cafaro et al. (2013)	Kenderdine and McKenzie (2013)	Brunet (2014)	Marton et al. (2014)	Roberts et al. (2014)	Rogers et al. (2014)	Ma et al. (2015)	Danyun et al. (2016)	Hsueh et al. (2016)	Jönsson et al. (2016)	Ynnerman et al. (2016)	Maquil et al. (2017)	Mishra and Cafaro (2018)	Ress et al. (2018)	Roberts et al. (2018)	Mallavarapu et al. (2019)	Reddy and Kota (2019)	Cho et al. (2019)	Trajkova et al. (2020)	SUM (28)
Visitor	single		✓	-	-	-	-	✓	-	-	-	✓	✓	✓	✓	-	✓	-	-	-	-	-	-	-	-	-	-	✓	-	-	8
	pair		-	-	✓	-	✓	-	-	-	-	✓	-	-	-	✓	-	-	-	-	-	-	✓	✓	-	-	-	-	-	-	6
	group		-	-	-	-	✓	✓	-	✓	-	-	-	-	-	✓	-	-	-	-	-	✓	✓	-	-	-	✓	-	-	-	7
	n/a		-	✓	-	✓	-	-	✓	-	✓	-	-	-	-	-	-	✓	✓	✓	✓	-	-	-	✓	✓	-	-	✓	✓	12
Relation	standalone		-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	-	✓	24
	contextually embedded		✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	✓	-	3
	mobile		-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Device	single		✓	-	-	✓	✓	✓	✓	✓	✓	✓	-	✓	-	-	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	-	-	✓	✓	20
	multi	*simultaneous*	-	-	-	-	-	-	-	-	-	-	✓	-	✓	-	-	-	-	-	-	-	✓	-	-	-	✓	-	-	-	4
	↪	*sequential*	-	-	✓	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	3
		mirrored	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

visitors and pairs (Cafaro et al., 2013). In twelve contributions, we could not find any information concerning the number of visitors that could interact with the installation.

Nearly all approaches (24) implemented standalone installations and therefore have less relation to Physical Space. Three applications developed contextually embedded applications, all three of them with displays next to the corresponding exhibits (Cho et al., 2019; Cosley et al., 2008; Roberts et al., 2018). Only one approach documented a mobile interaction (Rogers et al., 2014). We did not find the combination of categories (assembly).

The majority of contributions (20) used single surfaces for their installations, while eight papers constructed multi-surface environments. These environments were used in different ways. In four environments, visitors had to deal with all surfaces at the same time (simultaneous use) (Kenderdine and McKenzie, 2013; Mallavarapu et al., 2019; Maquil et al., 2017; Marton et al., 2014). Visitors of three approaches had to use one surface to specify their data first before entering the installation with another surface (sequential use) (Asai et al., 2010; Reddy and Kota, 2019; Roberts et al., 2014). In one setting, the content of the surface to be operated was mirrored to a second device (Hinrichs et al., 2008).

Visualization Space

Visualization Space describes the visualization-specific dimensions. Therefore, we focus on the type of data and type of visualization. An overview of our results regarding Visualization Space is shown in Table 4.4.

Table 4.4: Visualization Space – Categorization overview of the found literature regarding the type of data and the type of representation. The literature is sorted by year and first author.

		Cosley et al. (2008)	Hinrichs et al. (2008)	Asai et al. (2010)	Hinrichs and Carpendale (2010)	Von Zadow et al. (2011)	Block et al. (2012)	Chua et al. (2012)	Horn et al. (2012)	Ma et al. (2012)	Cafaro et al. (2013)	Kenderdine and McKenzie (2013)	Brunet (2014)	Marton et al. (2014)	Roberts et al. (2014)
Data	md	✓	-	-	✓	✓	-	-	-	✓	✓	-	✓	-	✓
	network	-	✓	-	-	-	-	-	-	-	-	-	-	-	-
	hierarchical	-	-	-	-	-	✓	✓	✓	-	-	-	-	-	-
	text	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-
	other	-	✓	✓	-	-	-	-	-	-	-	✓	-	✓	-
	spatial	-	-	✓	✓	✓	-	-	-	✓	✓	✓	✓	✓	✓
	temporal	-	✓	-	-	✓	✓	✓	-	✓	-	-	✓	-	✓
Representation	map	-	-	✓	✓	✓	-	-	-	✓	✓	✓	-	-	✓
	diagram	-	✓	-	-	-	✓	✓	✓	-	-	-	-	-	-
	graph (plot)	-	-	-	-	-	-	-	-	-	-	-	✓	-	-
	other charts	✓	✓	-	-	-	-	-	-	-	-	✓	-	✓	-
	2D	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	✓
	3D	-	-	-	-	-	-	-	-	-	-	-	-	✓	-
	non-situated	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	situated	✓	-	-	-	-	-	-	-	-	-	-	-	-	-
	embedded	-	-	-	-	-	-	-	-	-	-	-	-	-	-

		Rogers et al. (2014)	Ma et al. (2015)	Danyun et al. (2016)	Hsueh et al. (2016)	Jönsson et al. (2016)	Ynnerman et al. (2016)	Maquil et al. (2017)	Mishra and Cafaro (2018)	Ress et al. (2018)	Roberts et al. (2018)	Mallavarapu et al. (2019)	Reddy and Kota (2019)	Cho et al. (2019)	Trajkova et al. (2020)	SUM (28)
Data	md	✓	✓	✓	✓	-	-	✓	✓	-	✓	✓	✓	-	✓	17
	network	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
	hierarchical	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
	text	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
	other	-	-	-	-	✓	✓	-	-	✓	-	-	-	✓	-	8
	spatial	✓	✓	✓	✓	-	✓	-	✓	✓	-	-	-	✓	✓	18
	temporal	✓	✓	✓	✓	-	-	✓	✓	✓	✓	✓	-	-	-	16
Representation	map	✓	✓	✓	✓	-	-	-	✓	✓	-	-	-	✓	✓	15
	diagram	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
	graph (plot)	✓	-	-	✓	-	-	✓	-	✓	✓	✓	-	-	-	7
	other charts	-	-	-	-	✓	✓	-	-	-	-	-	✓	✓	-	8
	2D	✓	✓	✓	✓	-	-	✓	✓	✓	✓	✓	✓	-	-	23
	3D	-	-	-	-	✓	✓	-	-	-	-	-	-	✓	✓	5
	non-situated	-	✓	✓	✓	✓	-	-	✓	✓	-	-	✓	-	✓	21
	situated	✓	-	-	-	-	✓	✓	-	-	✓	✓	-	✓	-	7
	embedded	-	-	-	-	-	-	✓	-	-	-	-	-	-	-	1

Multidimensional data are the most commonly used data type (17 times). Besides, hierarchical data were used three times for a tree of life exhibit (Block et al., 2012; Chua et al., 2012; Horn et al., 2012). Two approaches integrated text data (Cosley et al., 2008; Hinrichs et al., 2008), while one approach took network data into account (Hinrichs et al., 2008). Eight out of 28 approaches used other data for their visualizations. Most of the found papers used only one particular data type. Only two papers (Cosley et al., 2008; Hinrichs et al., 2008) combined two ore more data types. A large number of papers documented the integration of spatial (18 times) and temporal (16 times) semantics. Ten of them combined these semantics.

Comparing the visualization techniques found, it is evident that maps are the most frequently used type of visualization (15 times). Maps seem to be obvious, as spatial semantics are often visualized in museums. Graph visualizations (seven times) were mainly line graphs (Hsueh et al., 2016; Mallavarapu et al., 2019; Maquil et al., 2017; Rogers et al., 2014), bar graphs (Mallavarapu et al., 2019; Rogers et al., 2014), timelines (Ress et al., 2018; Roberts et al., 2018), and one radar graph (Brunet, 2014). Diagrams were used four times. All of them were tree visualizations (Block et al., 2012; Chua et al., 2012; Hinrichs et al., 2008; Horn et al., 2012). Eight out of 28 approaches used other chart visualization techniques. A detailed analysis of other charts revealed five different types of visualizations: volumetric ones (Cho et al., 2019; Jönsson et al., 2016; Marton et al., 2014; Ynnerman et al., 2016), a word cloud (Cosley et al., 2008), an image collection (Kenderdine and McKenzie, 2013), a sphere (Reddy and Kota, 2019), and the use of the metaphor of tree rings to represent the time dimension (Hinrichs et al., 2008). Most of the found papers used only one particular visualization technique. Six tools (Cho et al., 2019; Hinrichs et al., 2008; Hsueh et al., 2016; Kenderdine and McKenzie, 2013; Ress et al., 2018; Rogers et al., 2014) combined two techniques.

The majority of the 28 papers visualized the data in 2D (23 times). Only five papers used 3D visualizations, four of them for volumetric renderings (Cho et al., 2019; Jönsson et al., 2016; Marton et al., 2014; Ynnerman et al., 2016), and one for data visualization in three-dimensional space (Trajkova et al., 2020).

Most of the approaches were categorized as non-situated visualizations (21 times) since they do not have an exhibit as a physical referent. Seven approaches explained data visualizations categorized as situated; four are presented next to the corresponding exhibit (Cho et al., 2019; Cosley et al., 2008; Roberts et al., 2018; Ynnerman et al., 2016), two as mobile visualizations, which are used in the same space as the physical referents (Mallavarapu et al., 2019) but are not necessarily location-aware (Rogers et al., 2014). We found one approach that combined situated (visualization next to the battery) and embedded visualizations (visualization of electrons associated with the battery plates) (Maquil et al., 2017).

4.2 Clustering the State of the Art

Table 4.5: Overview of clusters in our Design Space. The literature is sorted by year and first author.

	Cosley et al. (2008)	Hinrichs et al. (2008)	Asai et al. (2010)	Hinrichs and Carpendale (2010)	Von Zadow et al. (2011)	Block et al. (2012)	Chua et al. (2012)	Horn et al. (2012)	Ma et al. (2012)	Cafaro et al. (2013)	Kenderdine and McKenzie (2013)	Brunet (2014)	Marton et al. (2014)	Roberts et al. (2014)	Rogers et al. (2014)	Ma et al. (2015)	Danyun et al. (2016)	Hsueh et al. (2016)	Jönsson et al. (2016)	Ynnerman et al. (2016)	Maquil et al. (2017)	Mishra and Cafaro (2018)	Ress et al. (2018)	Roberts et al. (2018)	Mallavarapu et al. (2019)	Reddy and Kota (2019)	Cho et al. (2019)	Trajkova et al. (2020)	SUM (28)
2D visualization on horizontal touch display	-	✓	-	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-	✓	-	✓	-	-	-	-	-	✓	-	-	-	-	10
Embodied action combined with vertical or room display	-	-	-	-	-	-	-	-	-	✓	-	-	-	✓	-	-	-	-	-	-	-	✓	-	-	✓	✓	-	✓	6
Use of controls together with horizontal, vertical, or room display	✓	-	✓	-	-	-	-	-	-	-	✓	✓	✓	-	-	-	-	-	-	-	✓	-	-	-	-	-	-	-	6
Volumetric visualization with direct touch manipulation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓	-	-	-	-	-	-	✓	-	3
Mobile interaction combined with visualization	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	1

Through investigating and categorizing the found papers, we identified five clusters within this literature. Table 4.5 gives an overview of our clusters and their corresponding papers. The clusters describe the approaches presented in the papers along with the subspaces of our Design Space (Physical Space, Digital Media Space, Contextual Space, and Visualization Space):

2D visualization on horizontal touch display: These approaches focus on horizontal touch displays (mostly touch tables) and use them to present visualizations in 2D. This cluster is created through the combination of Digital Media Space and Contextual Space.

Embodied action combined with vertical or room displays: Approaches in this cluster provide embodied and bodily actions to interact with data visualizations on vertical or room displays. This cluster is present in the Digital Media Space.

Use of controls together with horizontal, vertical, or room display: This cluster is suitable for approaches that use physical or touch controls to interact with visualizations on horizontal, vertical, or room displays. It is present in the Digital Media Space.

Volumetric visualization with direct touch manipulation: Volumetric visualization that renders 3D spatial data that fit into this cluster. Visitors can interact with them through direct touch manipulation. This cluster is present by combining the Digital Media Space and the Visualization Space.

Mobile interaction combined with visualization: This cluster contains approaches in which visitors can use mobile devices that trigger interactions depending on their location. It is present by combining the Physical Space and the Contextual Space.

Analyzing the clusters based on the publication years of the papers, one can see a trend towards changing the mode of interaction in scientific research projects (see Figure 4.1). From 2008 to 2012, the clusters *2D visualization on horizontal touch displays* and *Use of controls together with horizontal, vertical, or room display* were dominant. Afterward, the cluster *Embodied action in combination with vertical or room displays* became more relevant. The beginning of this cluster also correlates with the introduction of Microsoft Kinect and its release for Windows in 2012 (Kinect for Windows Team, 2012). *Volumetric visualization with direct touch manipulation* did not become interesting for research in our context until recently (since 2016).

In the following, we will describe the clusters and their respective approaches in more detail.

2D Visualization on Horizontal Touch Display

The first cluster contains approaches designed as 2D visualization using horizontal touch displays (Block et al., 2012; Chua et al., 2012; Hinrichs et al., 2008; Hinrichs and Carpendale, 2010; Horn et al., 2012; Hsueh et al., 2016; Ma et al., 2012, 2015; Roberts et al., 2018; Von Zadow et al., 2011). On the one hand, we have larger interactive tables with which groups of visitors can also interact (see Figure 4.2a and 4.2c). On the other hand, we integrated smaller displays into this cluster which are primarily aimed at single visitors or pairs (see Figure 4.2d). Such approaches can usually be found in interactive

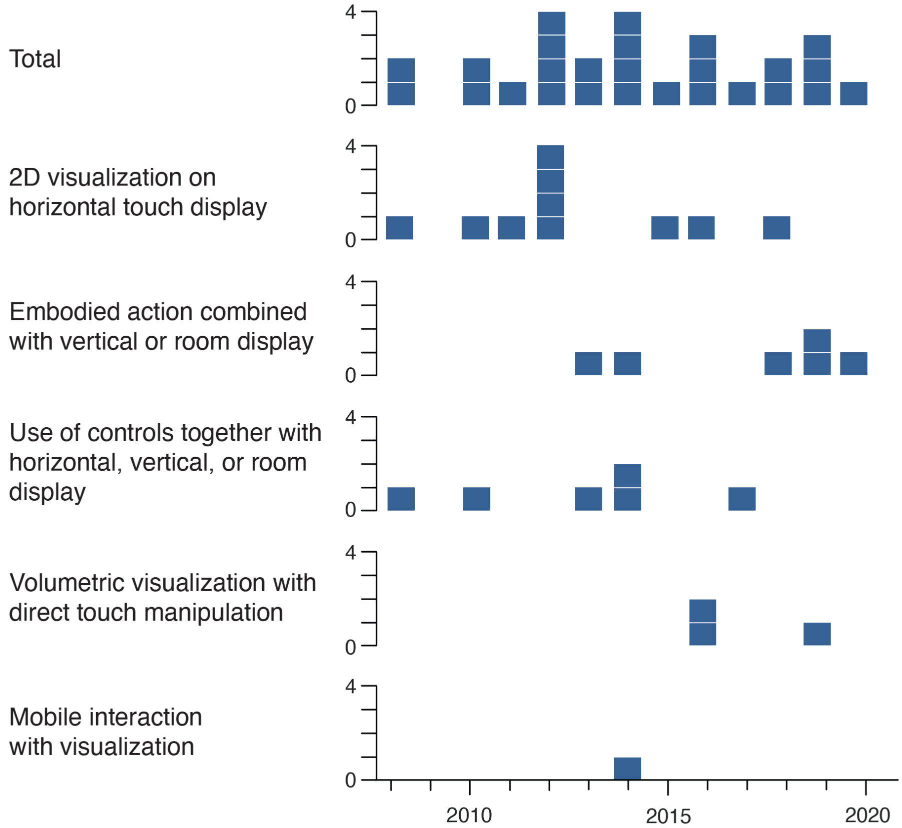


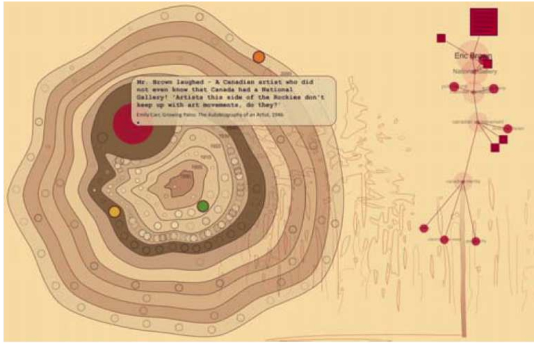
Figure 4.1: Overview of the five clusters and their distribution over time. Own representation.

and traditional museums. Almost all examples are developed as standalone installations and are therefore non-situated visualizations that have no physical artifact as a referent. Roberts et al. (2018) introduced an exception when they developed digital labels to enhance artifacts with information (see Figure 4.2d).

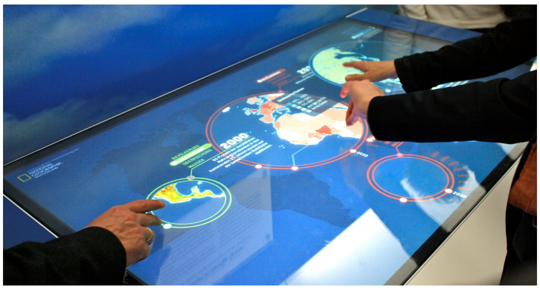
Such horizontal displays are often used as single devices. The exception is EMDialog (Hinrichs et al., 2008) (see Figure 4.2a). Hinrichs et al. (2008) created a multi-device environment consisting of a horizontal touch display and a room display. The interactions on the horizontal display were mirrored.

When describing the cluster based on the data and visualization representations used, we usually have multidimensional data combined with temporal or spatial semantics, which often leads to a map visualization. The exception is a sub-cluster of three papers (Block et al., 2012; Chua et al., 2012; Horn et al., 2012) representing hierarchical data as a diagram (tree of life).

(a) Exploring the work of Emily Carr with EMDialog consisting of a touch table and a projection (Hinrichs et al., 2008).



(b) EMDialog. Selected statement in cut section visualization (left) and the corresponding tree visualization (right) (Hinrichs et al., 2008).



(c) Multiple users can interact with rich geographic information on the GeoLens touch table (Von Zadow et al., 2011).

(d) Digital labels on touch displays extend artifacts with information (Roberts et al., 2018).

Figure 4.2: Examples for the cluster *2D visualization on horizontal touch displays.*

Embodied Action Combined with Vertical or Room Display

The second cluster brings together approaches that implement embodied and bodily interaction on vertical or room displays (Cafaro et al., 2013; Mallavarapu et al., 2019; Mishra and Cafaro, 2018; Reddy and Kota, 2019; Roberts et al., 2014; Trajkova et al., 2020) (see Figure 4.3). Representation in interactive museums is predominant in this cluster. Usually, the installations have no connection to a physical artifact. They are therefore standalone applications implementing a non-situated visualization. As an exception, Mallavarapu et al. (2019) have created a multi-device environment integrating a situated visualization on a tablet that reacts to interactions with the surrounding installation. Embodied and bodily interaction is also used in combination with presence

(a) Visitors interacting with CoCensus data using their body position to choose the year (Roberts et al., 2014).

(b) Using gestures and body movements to interact with a Human-Data Interaction system (Trajkova et al., 2020).

Figure 4.3: Examples for the cluster *Embodied action combined with vertical or room display*.

(Cafaro et al., 2013; Mallavarapu et al., 2019; Roberts et al., 2014), e.g., to display appropriate user data (see Figure 4.3a).

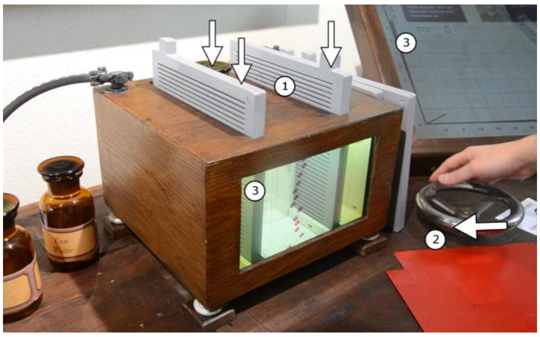
In this cluster, the vertical or room displays used were implemented as a single (Cafaro et al., 2013; Mishra and Cafaro, 2018; Trajkova et al., 2020) or multi-device environment with simultaneous use (Mallavarapu et al., 2019; Reddy and Kota, 2019; Roberts et al., 2014).

Multidimensional data are ubiquitous and often combined with spatial data. The combination with spatial semantics leads to map visualizations, usually in 2D. The exception is the implementation of a 3D globe visualization (Trajkova et al., 2020) (see Figure 4.3b).

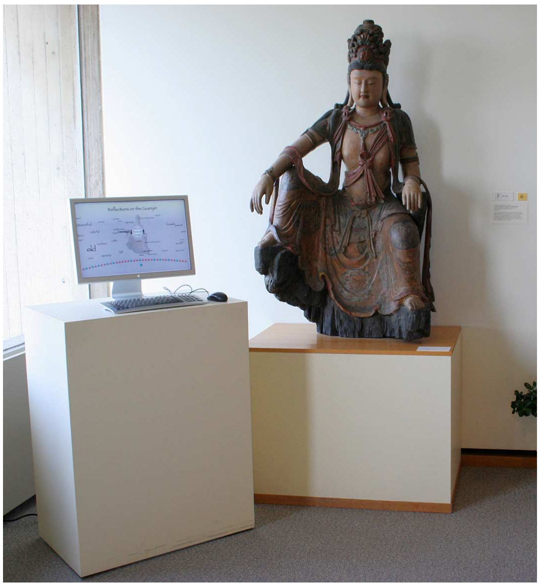
Use of Controls Together with Horizontal, Vertical, or Room Display

Approaches in the third cluster use controls to allow visitors to interact with horizontal, vertical, or room displays (Asai et al., 2010; Brunet, 2014; Cosley et al., 2008; Kenderdine and McKenzie, 2013; Maquil et al., 2017; Marton et al., 2014). Such controls are divided into two categories: 1) physical controls (Asai et al., 2010; Brunet, 2014; Cosley et al., 2008; Maquil et al., 2017), e.g., a handle to form the battery (see Figure 4.4a and 4.4b) or keyboard/mouse (see Figure 4.4c), and 2) touch controls to control the visualization on a larger display (Kenderdine and McKenzie, 2013; Marton et al., 2014) (see Figure 4.4d). Typically, the installations are set up in traditional or interactive museums and have no connection to any artifact presented. An exception, presented by Cosley et al. (2008), is the word cloud visualization as an extension of a sculpture (see Figure 4.4c).

(a) BatSim. A tangible user interface to experiment with creating batteries in the form of a notebook, a battery casing, and graph paper (Maquil et al., 2017).



(b) BatSim. Combining physical controls (handle - 2) with direct manipulation (battery modules - 1) to visualize the capacity of the battery built (Maquil et al., 2017).



(c) Using physical controls (keyboard and mouse) to interact with a word cloud visualization enhancing a sculpture (Cosley et al., 2008).

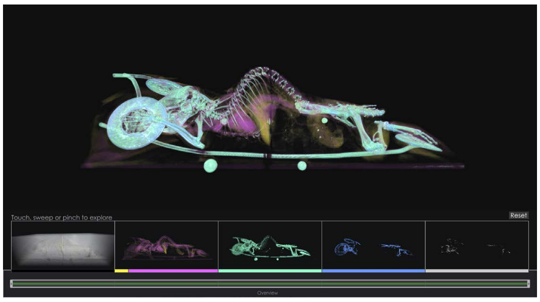
(d) Interacting with a visualization on a room display using a touch control (Kenderdine and McKenzie, 2013).

Figure 4.4: Examples for the cluster *Use of controls together with horizontal, vertical, or room display.*

The approaches in this cluster are often multi-device environments with simultaneous (Kenderdine and McKenzie, 2013; Maquil et al., 2017; Marton et al., 2014) and sequential use (Asai et al., 2010).

The use of data type and visualization representation is diverse in this cluster. Multidimensional and other data in combination with spatial or temporal semantics are used. These data types have been implemented as a graph/plot, map, or other chart visualizations, mostly in 2D. Marton et al. (2014) implemented the only 3D visualization in the cluster.

Volumetric Visualization with Direct Touch Manipulation



(a) Using a dynamically generated image gallery (bottom of the screen) to edit the presented data domain shown in the final rendering (top) (Jönsson et al., 2016).

(b) Exploring the thoracic region of a human being (Cho et al., 2019).

Figure 4.5: Examples of the cluster *Volumetric visualization with direct touch manipulation.*

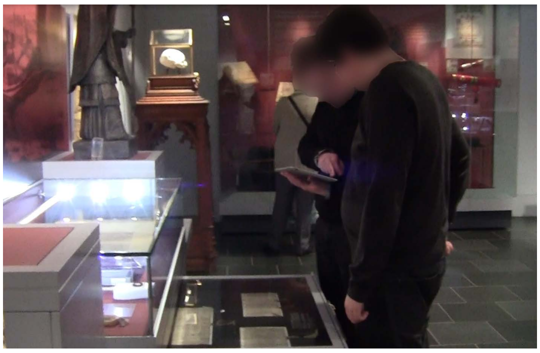
In this cluster, we gathered volumetric visualizations (3D, other chart) of 3D spatial data (other data) that are implemented with a direct touch manipulation (Cho et al., 2019; Jönsson et al., 2016; Ynnerman et al., 2016) (see Figure 4.5). Such approaches are placed in interactive or traditional museums and are single device applications. The uses of display types are diverse, horizontal as well as vertical displays are used. Cho et al. (2019) and Ynnerman et al. (2016) extend an observable artifact. The installation is placed next this artifact. Thus, these two are situated visualizations.

Mobile Interaction Combined with Visualization

The use of visualizations on mobile devices characterizes this cluster. In our survey, only one paper fits into this cluster (Rogers et al., 2014).

However, it represents aspects common for mobile devices, such as the connection to physical artifacts in the museum and, thus, the implementation of a situated visualization (see Figure 4.6a). The mobile device is usually used as the only device (single device).

Besides, Rogers et al. (2014) presented a graph/plot and a map visualization (see Figure 4.6b). These representation types are also the most common visualization types on mobile devices (Blumenstein et al., 2016).



(a) Visitors using the tablet visualization to explore the gallery (Rogers et al., 2014).

(b) Map and graph/plot visualization on a tablet (Rogers et al., 2014).

Figure 4.6: Examples of the cluster *Mobile interaction combined with visualization.*

4.3 Discussion & Future Challenges

Based on the results of our systematic comparison of the state of the art in data visualization in museums (Chapter 4.1), we can derive findings and propose challenges for future research.

Full Spectrum of Interaction Techniques Is Not Used for Visualizations

In Chapter 4.2, we identified five clusters, the first cluster (*2D visualization on horizontal touch displays*) constituting the most common representation of Digital Media Space: horizontal displays in combination with direct touch manipulation. Compared to the use of this combination, all other action methods (presence, embodied, speech, and controls) are underrepresented. Speech might not be suitable for individual visitors in museums. Nevertheless, the analysis and visualization of the sound in a designated space, such as for the Activity Wallpaper (Skog, 2004), could be interesting for museums. Embodied and bodily interaction have become attractive only in recent years. This method of action (and also presence) allows visitors to interact with installations without touching a device. It may require a steeper learning curve to interact with the visualization, which is why more research is needed. Interestingly, tangibles (direct manipulation) are also integrated in four cases only. However, tangibles are widely used in museums (see Chapter 3.2), and research in the field of tangible visualization is also available (e.g., Claes and Moere, 2015; Huron et al., 2014; Quintal et al., 2016).

Underrepresented Auditory Channel

Only one installation used the audio channel to present an individual sound for selected items (Cosley et al., 2008). All other contributions focused exclusively on visual perception.

However, limitations of perception restrict the visual channel (Ware, 2019). Audio guides are still widely used in museums. New developments such as NOUSsonic (NOUS Wissensmanagement GmbH, 2020) - an interactive audio system for controlling sounds by movement in space - show improvement for the visitors' listening experience. Moreover, the use of sonification - meaning "nonspeech audio to convey information" (Kramer et al., 2010) - to enrich data visualization is still in its infancy (Rind et al., 2018). Nevertheless, addressing the audio channel could also improve accessibility for visitors with disabilities. Therefore, further research is needed to understand how audio and visualization can best be combined for museum visitors.

Missing Mobile Visualization for Museums

We found two papers that presented visualizations on tablets. Only one of them is categorized as mobile interaction, as described in Contextual Space (see Chapter 3.3). Smaller devices, like smartphones or smartwatches, were not addressed. However, research on designing visualizations for these devices has increased in recent years (e.g., Blascheck et al., 2019; Blumenstein et al., 2016; Brehmer et al., 2019; Choe et al., 2019; Lee et al., 2018), and the use of mobile devices has already arrived in museums (see Chapter 3.2 and Chapter 3.3). With the integrated technology (e.g., GPS, Bluetooth, or camera), mobile devices offer the possibility to create location-aware and thus situated visualizations, which are also underrepresented in our state of the art. Open-air museums in particular could benefit from such applications, as GPS offers a ready-to-use outdoor option. Using mobile devices could mean that museums do not need additional hardware to integrate interactive experiences as the visitors could use their own devices (Bring your own device). However, the design of visualizations for mobile devices, especially for museum visitors who are casual users, is still underrepresented in scientific research.

Full Spectrum of Representation Techniques Is Not Used

The integration of temporal and/or spatial semantics (16 and 18 times, respectively) seems obvious since museums often intend to present history in a time- and/or location-related way. The map is therefore the most frequently used representation technique (15 times). Diagrams (4 times) for the representation of hierarchical or network data and graphs/plot (7 times) for displaying quantitative patterns are underrepresented. The use of volumetric visualization in museums is also rarely investigated. However, the digitization and reconstruction of 3D objects have been of interest in scientific research for years (e.g., Godin et al., 2002; Mohan et al., 2007; Singh, 2014). On the other hand, museum visitors have a rather low level of visualization literacy, and they are more familiar with basic graphs/plots, other charts, and maps (Börner et al., 2016). Using different visualization techniques in museums could counteract the low level of visualization literacy and allow visitors to learn different representation techniques. This requires an easily understandable implementation and maybe an adaption of existing techniques.

Physical Artifacts Are Not Often Linked to Visualization

Interestingly, a large number of installations have no relation to a physical artifact within the museum (22 times). Besides, we found no installations that address glasses or mobile devices using see-through technology to link data to the time and space (context) in which visitors are currently located. These situated analytics are described as one of the six opportunities that are described in the research agenda for immersive analytics - that should “support data understanding and decision making everywhere and by everyone” (Dwyer et al., 2018). The interweaving of particularly observable artifacts and their enrichment could lead to a more immersive museum experience.

Furthermore, all installations in interactive museums are standalone applications without any reference to an artifact (11 times). There is a need to present interactive visualizations in interactive museums; visitors should interact and learn from such exhibits. These museums thus seem to seek standalone exhibits. In contrast, all non-standalone installations have been integrated into traditional museums (4 times), indicating the importance of artifact collections in traditional museums and the interest in combining artifacts with visualization on digital media. Future research on the combination of exhibited artifacts and visualization could lead to more situated and embedded visualizations. However, there is still a lack of knowledge about combining physical and digital worlds. For example, we need to understand how to integrate digital assets that enrich the physical artifact but do not distract visitors from said artifact, or how to interact and switch visitors’ attention between the physical and digital worlds.

Multi-Device Ecologies Integrating Visualization Are Rare

Eight out of 28 contributions used multiple devices for their installation. Only four of them implemented the simultaneous use of the devices. However, people are becoming increasingly accustomed to using different devices in their everyday lives (Nagel and Fischer, 2013). In the home, for example, the use of tablets or smartphones is increasing as an extension of the television experience (second screen). Multi-device ecologies can thus enable “new ways to engage with digital content” (Brudy et al., 2019) and data visualization. However, current research in the field of multi-device visualization focuses mainly on technical aspects (e.g., Frosini and Paternò, 2014; Hartmann et al., 2013; Marquardt et al., 2011), working environments with expert users (e.g., Horak et al., 2016; Prouzeau et al., 2018), or the combination of several mobile devices (e.g., Langner et al., 2018; Marquardt et al., 2018; Perelman et al., 2019; Zagermann et al., 2020). Further research could deal with the combination of visualization and MDEs in museums. For example, visualization on mobile devices could be used and connected to installations in the museum. Such combinations would lead to assemblies that are not yet available with data visualization.

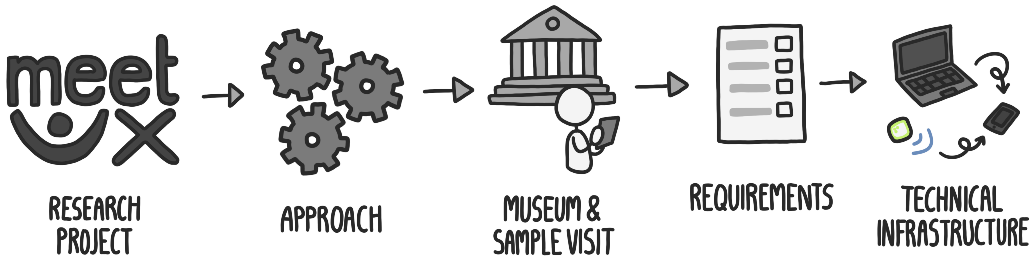
4.4 Summary

In this chapter, we presented a systematic review of scientific literature dealing with data visualization in museums. We categorized each approach along with our Design Space which is divided into Physical Space (the type of artifact associated with the installation and the type of museum), Digital Media Space (options for action and perception), Contextual Space (number of visitors who can interact, the relation to Physical Space, and the use of devices), and Visualization Space (the type of data and type of representation) (Chapter 4.1). Based on this categorization and hierarchical cluster analysis, we identified five clusters that describe our literature (Chapter 4.2). The majority of contributions (10) deal with *2D visualization on horizontal touch display*. Six papers each could be divided into the clusters *Embodied action combined with vertical or room display* and *Use of controls together with horizontal, vertical, or room display*. Three installations focus on *Volumetric visualization with direct touch manipulation*, and one on *Mobile interaction combined with visualization*. The provided comparison leads to challenges for future research that show the potential of data visualization in museums (Chapter 4.3).

Based on these findings, in the next chapter (Chapter 5), we describe the research and application context for the two design studies (Part II and Part III) that were carried out in the context of this thesis.

CHAPTER 5

Research and Application Context for Design Studies



In this chapter, we describe the environment of the two design studies conducted in this thesis. For this purpose, we start with the research project (Chapter 5.1) and the underlying approach (Chapter 5.2). Following the goal-oriented design process (Cooper et al., 2014), we defined personas and usage scenarios in the project and subsequently adapted them for the exhibition (Chapter 5.3). For a better understanding of the idea, we describe a usage scenario as a sample visit to the exhibition (Chapter 5.4). We formulate requirements (Chapter 5.5) and describe the technical infrastructure built up within the research project based on this usage scenario (Chapter 5.6).

5.1 Research Project

The work for this thesis was carried out within the research project MEETeUX (Multi-device Ecologies towards elaborate user experience)[1]. The project discusses future-relevant questions in the fields of interaction design and user experience design for the integrated use of digital media in multi-device ecologies (MDEs). We designed usage scenarios to integrate different devices that show the use of MDEs in a museum. MEETeUX therefore concentrates on the integration of the visitors' devices (*Bring Your Own Device* (BYOD), usually smartphones) in existing device ecologies. Using visitors' devices allows to adapt them to the specific needs of the visitors, thus improving accessibility. In the course of the project, we developed and evaluated an MDE for an exhibition. The MDE was set up with three stationary installations and the visitors' devices.

5.2 Approach

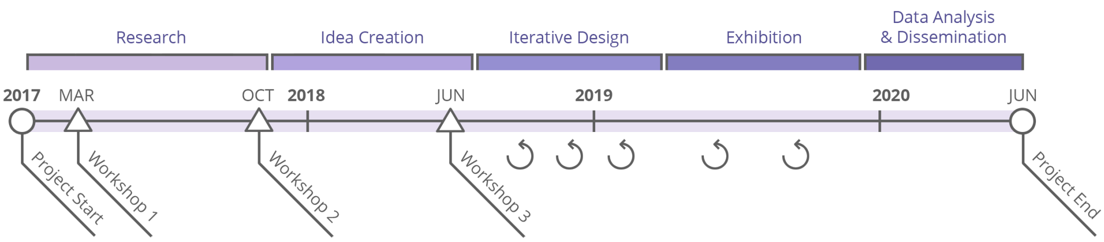


Figure 5.1: Timeline of the MEETeUX project from January 2017 to June 2020. Illustration by M. Boucher & K. Blumenstein.

Within the research project, we used a mixed-method approach. We started with a goal-directed design according to Cooper et al. (2014) to research users and the domain, to model the users and use contexts, and to define requirements. We continued with idea creation, followed by iterative design (Nielsen, 1993). Figure 5.1 illustrates the MEETeUX project's timeline with the mentioned phases from January 2017 to June 2020. During the exhibition, we also carried out continuous evaluations and refined our installations. The project was completed with a data analysis and dissemination phase.

During the early project phase, we conducted three workshops. The participants were experts from various scientific and business fields ranging from the cultural heritage, HCI, data visualization, and museum application development to accessibility.

The goal of the first workshop with 18 participants was to determine the actual state of and demand in the sector to prepare for the conception and development of future installations. In three groups, the participants discussed users, contents, and goals of such installations. We combined the outcomes of this discussion with those of our research in

[1] https://meeteux.fhstp.ac.at

museums[2] and developed personas and usage scenarios (see Appendix A). Afterward, we constructed a fictitious usage scenario as a sample visit to a museum and defined requirements as well as the MDE architecture based on this visit.

The start of the idea creation phase was the second workshop with 24 participants. The aim was to generate as many ideas as possible based on the defined personas and scenarios. We conducted an in-depth workshop within the project team to refine and assess all ideas and determine the top five among them. These top five ideas constituted the basis of the third workshop discussion with 20 participants, which aimed to connect the concrete data of the planned exhibition to our top five ideas.

We then started to work with the five exhibition curators to apply the findings to the real use case and define the installations that were implemented for the exhibition within the iterative design phase, including various evaluations.

Based on this, we were able to focus on visualization research for one of the stationary installations (Design Study in Part III) and the mobile application for visitor devices (Design Study in Part II).

Next, we describe the context of the museum and the exhibition (Chapter 5.3). We then present a sample visit within the exhibition (Chapter 5.4) that was adapted from the aforementioned fictitious sample visit[3]. We define the requirements for our MDE (Chapter 5.5) and describe the developed technical infrastructure (Chapter 5.6) based on the sample visit.

5.3 Museum & Exhibition

The exhibition "Des Kaisers neuer Heiliger" (The Emperor's New Saint) at Klosterneuburg Monastery, Austria, told the stories of Emperor Maximilian I (Habsburg) and Margrave Leopold III (Babenberg) at a time of media in transition (Stift Klosterneuburg, 2018).

The museum was a mixture of the two extreme types (highly interactive science museums vs. do-not-touch art museums and galleries) described by Hornecker and Ciolfi (2019). On the one hand, historical artifacts were placed behind glass, and paintings were displayed. On the other hand, visitors were able to interact by taking selfies on a throne or handling letterpress tools. In general, the museum addresses a wide range of age groups, which is not uncommon (see Chapter 3.3).

The exhibition space was divided into two areas (first and ground floors). The areas were not directly connected (e.g., through stairs) and served different purposes. The ground floor was mainly intended for individual visitors' free exploration, while the upper floor

[2]We investigated 39 interactive exhibits. The categorization of the researched exhibits can be found at http://meeteux.fhstp.ac.at/assets/matrix/. Methodically, we used literature research for 25 exhibits and observations of 14 museums.

[3]The fictitious sample visit is documented in Appendix B.

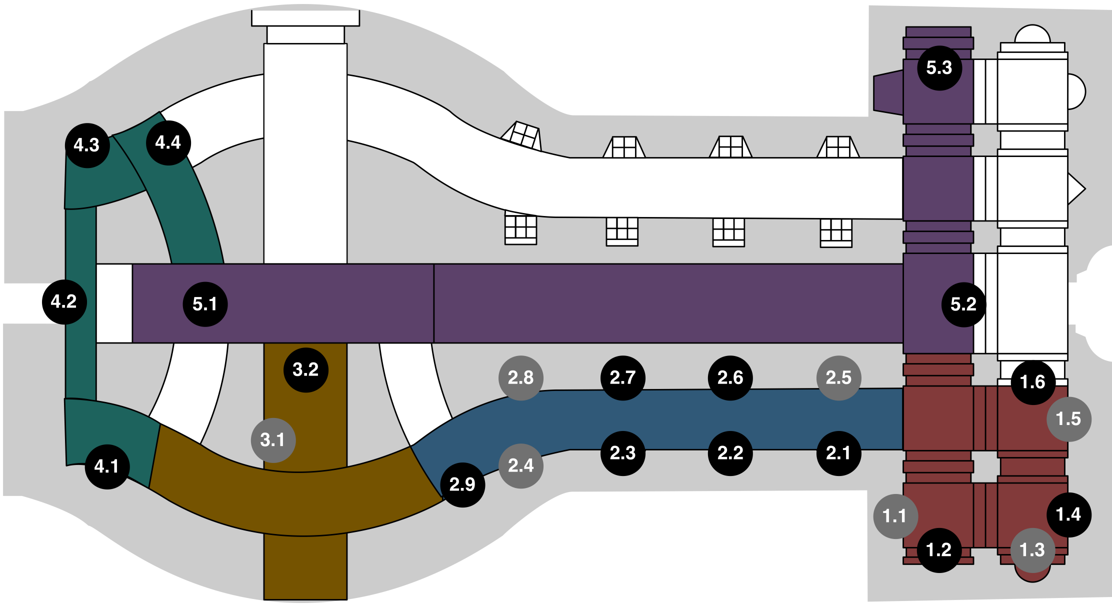


Figure 5.2: Exhibition plan of the ground floor. Black and grey circles mark artifacts within the exhibition. The black ones are integrated into the mobile application. Color coding differentiates the sections. Illustration by V. Oliveira & K. Blumenstein.

featured valuable exhibits, which is why it was accessible only through guided tours. In the context of MEETeUX, we concentrated on the ground floor, as the museum intended to support the free exploration by digital media.

5.4 A Sample Visit

In the following usage scenario, we describe a visit to the exhibition "Des Kaisers neuer Heiliger" by the Egger family (Lena, 10 years of age, and her parents Peter and Olivia, both in their mid-30s) from Lower Austria[4].

Upon entering the museum, the Egger family buy a family ticket. At the ticket office, the cashier informs the family about the possibility of using their own mobile devices (OD) during the visit. To do so, they must log into the exhibition Wi-Fi and download the app.

While walking through the exhibition, they pass an old accounting book behind glass (Figure 5.2 (1.4)). Lena's OD automatically detects the exhibit and vibrates to draw her attention to the app. The visualization in the app scrolls automatically to the exhibit. Lena gains more information about the accounting book by selecting the appropriate item. However, she cannot read the writing on the exhibit because the book is written in Old German. Therefore, she chooses to explore the book using the provided augmented

[4]See Appendix A for detailed personas.

reality (AR) functionality. With the AR option, Lena pans her OD over the book, and the transcript is displayed.

While browsing through the different sections within the app, Lena sees that the *Weißkunig quiz* is almost in the same period as the accounting book. The quiz sounds exciting, and the entire family wants to try it (Figure 5.2 (3.2)). When they are near the large display, their ODs directly scroll to the *Weißkunig quiz* and display the information on how to interact with the exhibit - it is a multiple choice quiz with different questions that run in a loop. The large display shows a picture from the *Weißkunig* (a book with 251 woodcut illustrations about the life of Emperor Maximilian and his deeds) and questions with corresponding answer options. The aim is to answer as many questions as possible about Maximilian I's life in order to achieve social ranks, from beggar to bourgeoisie to nobility. Lena presses the button on her OD to connect to the large display. When the next question starts, Lena selects an answer on her OD, and her parents see a bubble flying to the chosen answer on the large display. Olivia and Peter follow Lena with their ODs so that they can answer all the questions together. They have lively discussions about each choice.

Lena sees in the app that visitors can create their legends *Once upon a time...* in the fourth section (Figure 5.2 (4.3)). It seems that only one person can interact directly with the touch display. However, Lena does not know how to use the display. She wants to try but another visitor, Christoph, wants to interact with the display as well. Olivia and Peter end the following argument.

Lena uses the waiting time to explore the timeline visualization in the app. She notices that all of the presented exhibits are from the same epoch. The Sunthaym panels were created at the time of the legend of the monastery of Klosterneuburg. She also notes that she can build her own coat of arms using the app. Already when exploring the AR at the accounting book and playing the quiz, Lena collects special items. To get the next item, she has to explore the *Babenberg Family Tree* to find Friedrich II.

Shortly before the end of the exhibition, the family arrive at a large printed family tree (Figure 5.2 (5.3)). It is extended with a projection that displays how visitors should interact with the touch displays in front of the family tree to find out more about the Babenberg family. From school, Lena knows that Leopold III, the patron saint of Lower Austria, is a Babenberg. During the exhibition, she has already learned more about Saint Leopold III. She sees in the app that she has to put her OD on top of the wooden frame of the touch display. The display automatically logs on and welcomes Lena. Now, she starts out to find Friedrich II. The timeline on the touch displays shows the life trajectories of the Babenberg men and women, starting with the already known Leopold III. Lena sees that Leopold married Agnes and had many children. When selecting a person, she can read details about this person on the touch display and notices a hint that there is more information available on the projection which shows, for example, the Babenberg dominion growing. When she reaches the end of the timeline, she finds Friedrich II. He had no children, so he was the last Babenberg. Finally, Lena can create her very own coat of arms. Now, they can leave the exhibition. Her parents have already asked her to finish her exploration.

5.5 Requirements

Based on the mentioned own research and the described sample visit, we defined three requirements for our MDE:

(R1) OD integration: The visitors' device (smartphone or tablet with iOS as well as Android OS) should be used without requiring any hardware adaption.

(R2) Location tracking: To enable the experience of transition previously described, the MDE needs to know robustly in which room and at which exhibit the visitors and their devices currently are.

(R3) Guidance: To prevent a misunderstanding of the exhibits, information about how to use and interact with the interactive exhibits must be given.

5.6 Technical Infrastructure

We developed the architecture of the MDE in a four-day technical workshop with experts in the fields of mobile and multi-touch development as well as system architecture. We used the requirements and the sample visit as the basis.

The architecture consists of a server, called Guide of Devices (GoD), and various clients (see Figure 5.3). In contrast to Dini et al. (2007), we decided to use client-server architecture. Each client must communicate with the GoD. Therefore, Wi-Fi was accessible throughout the museum. To enable robust location tracking, selected exhibits were equipped with a Bluetooth beacon (Figure 5.2 colored in black). This concept is similar to the one developed by Ghiani et al. (2009), replacing RFID tags. Bluetooth is widely used in modern smartphones. We used the Bluetooth Low Energy broadcast topology which supports localized information sharing (Bluetooth SIG, Inc, 2017). Each time the OD recognizes a new Bluetooth beacon, the OD registers its new location at the GoD (addressing requirement R2).

5.6.1 GoD

The GoD processes all requests and state changes in our MDE and therefore needs to know the status and position of every device registered in the system. It consists of three major parts:

Web server. The web server is the server-side endpoint for all clients and therefore handles all requests and state changes. Communication between the GoD and the clients is via WebSockets, which allows the GoD to send relevant state changes to

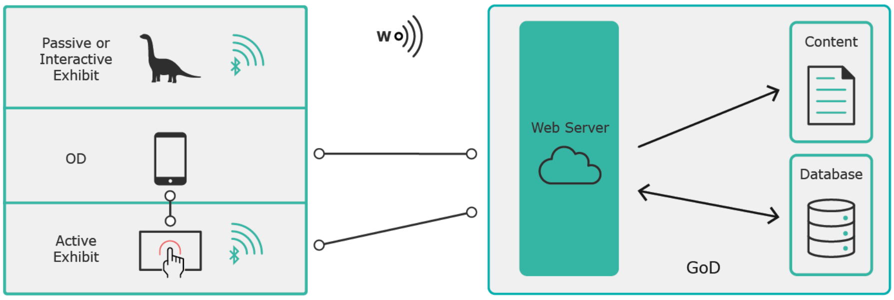


Figure 5.3: Our MDE architecture. The server (GoD) and clients (passive or interactive exhibits, ODs, active exhibits). The GoD includes a web server that manages the content and accesses the database. It communicates with the clients through a WebSockets connection. Exhibits are equipped with a Bluetooth beacon. Wi-Fi is accessible throughout the museum (W). Illustration by S. El Aeraky & K. Blumenstein.

all corresponding devices. The web server manages the content and data stored in the database.

Database. All device-specific data (e.g., status, position, addresses) are stored in an SQL database. On the one hand, the system stores all necessary data of the ODs (e.g., activities such as current location). On the other hand, the system saves the data of the exhibits (e.g., exhibit type, location of contents).

Content. The GoD manages all contents required for the various exhibits. Each time the client application needs content for an interactive exhibit, it sends a request to the web server. The web server replies with the corresponding content package.

5.6.2 Own Device

Addressing requirement R1, all visitors use their own devices to interact with the various exhibits. The OD app is the interface between the visitor and the GoD and contains the various views needed for active, passive, and interactive exhibits. Therefore, we developed the application *The Emperor's App* using web technologies (HTML, CSS, Angular (JavaScript)) as an interface between the visitor and the GoD. Since we used Bluetooth tags to trigger the location of the exhibits, we packaged the web content in a native application for iOS and Android[5].

The OD registers its unique identifier at the server when starting the app for the first time. As a response, the OD receives the latest lookup table. The lookup table contains a list of all exhibits with their corresponding information (e.g., beacon's identifier, exhibit's position, IP address, content location). When a Bluetooth beacon is detected, the OD gets the unique identifier, which can be resolved through the lookup table. In this way,

[5]The application was available in the Google Play and App Stores (http://meeteux.fhstp.ac.at/app/).

the OD knows all relevant information about the exhibit (e.g., how to contact it, the location of the content).

5.6.3 Active Exhibit

ODs can interact directly with an active exhibit. In our exhibition, the *Weißkunig Quiz* is an example of such an exhibit. Similar to Ghiani et al. (2009), we decided to assign different states to exhibits. In our MDE concept, active exhibits can have two kinds of states: *atExhibit* and *onExhibit*.

After registering the new location at the GoD (*atExhibit*) and checking whether the exhibit's status is free, the visitor will be guided through the initial interactions (R3). In the case of the *Weißkunig Quiz*, several visitors can join the exhibit to answer questions. When tapping the join button, the OD sends information to the GoD. The GoD updates the status of the exhibit. The OD opens the socket connection to the exhibit and sends all relevant data. From now on, the exhibit can communicate directly with the OD. Once the connection is established, the OD registers its new location (*onExhibit*) at the GoD (R2).

5.6.4 Interactive Exhibits

In contrast to active exhibits, the direct connection to an OD is not necessary for interactive exhibits. In the sample visit (Chapter 5.4), we mentioned two exhibits of this kind: *Once upon a time...*[6] and the *Babenberg Family Tree*[7].

Similar to active exhibits, when entering the detail page of an interactive exhibit, the OD registers the new location at the GoD (*atExhibit*), and the GoD returns the exhibit's status. If it is free, the visitor is guided through the first interactions (R3). We used Bluetooth beacons to determine the location where the OD has to be placed. The connection could only be established when the OD was quite close to the beacon. The visitors have to tap the "join" button and place their OD at the beacon. When the OD recognizes the corresponding beacon, the OD sends a join message to the GoD. The GoD updates the status of the exhibit and sends the join message with relevant data (e.g., user name and selected language) of the user to the interactive exhibit. If the interactive exhibit returns with success, the OD registers its new location (*onExhibit*) with the GoD (R2).

[6] The aim of the game *Once upon a time...* was to recreate the founding legend of the monastery Klosterneuburg. Visitors slipped into the role of a character on the touch screen and answered questions: Where am I - in a forest, by a river, in America? What else is here - dogs, birds, a wild boar, a horse? What am I doing here? Every decision led to changes on the drawn theatre stage and brought the chosen character either closer to the creation of a legend or to an end without a legend.

[7] With the installation *Babenberg Family Tree*, we brought a reproduction of the original painting to the exhibition on the ground floor. We extended this reproduction by an interactive projection: Using two touch displays in front of the projection, visitors were able to select a person on a time-oriented visualization of the Babenberg family tree. Detailed information about this person was then displayed on one side of the projection and could be assigned to the next relatives in the printed "main bloodline" of the Babenberg. This installation is described in more detail in Part III.

5.6.5 Passive Exhibit

Passive exhibits, such as the accounting book (Figure 5.2 (1.4)) or the painting of Saint Leopold (Figure 5.2 (2.9)), are exhibits with which the OD cannot interact directly. These types of exhibits only have the *atExhibit* state. Once the exhibit is identified, the OD sends a request to the GoD to register its new location (*atExhibit*) (R2) and to download the corresponding content package. The OD then displays the content of the exhibit. However, we had several options for what visitors could do. As described in the sample visit (Chapter 5.4), visitors were able to explore the accounting book and two other exhibits through AR.

5.7 Summary

In the previous sections, we described the MEETeUX research project (Chapter 5.1) which provides the environment for the two design studies that will follow in the next parts of this thesis. We used the goal-directed design (Cooper et al., 2014) to define personas and usage scenarios. We adapted a previously developed fictitious usage scenario based on the exhibition in focus (Chapter 5.4) and defined requirements (Chapter 5.5). Using these tools, we developed the architecture for our MDE (Chapter 5.6). In this way, we developed the necessary environment for the design studies which focus on data visualization.

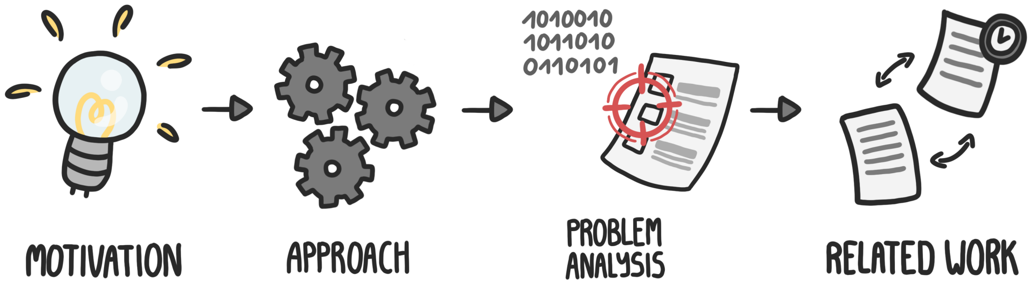
These design studies are the second step to validate our Design Space (Chapter 3). The first design study (Part II) focuses on a situated data visualization on the ODs and acts as a guide through the exhibition. The second design study (Part III) presents the interactive exhibit *Babenberg family tree* - a reproduction of the original painting as an embedded multi-device visualization. In Part IV, we apply the results of these design studies to our Design Space and discuss the descriptive, evaluative, and generative power (Beaudouin-Lafon, 2004) of our Design Space.

Part II

Design Study 1: Visualizing Historical Data on Mobile Devices

CHAPTER 6

Motivation, Background & Related Work



This chapter starts with the general motivation for the first design study about visualizing historical data on mobile devices in a museum (Chapter 6.1). We explain our approach (Chapter 6.2) and the preconditions (Chapter 6.3) and continue presenting related work according to mobile devices in museums, timeline visualization, and information visualization (InfoVis) on mobile devices in museums (Chapter 6.4).

Figure 6.1: Museum setting showing the visitor using the mobile application with visualization (a), the physical object in the museum (b), and Bluetooth beacons at exhibits telling the app where the user is located (c). Illustration by M. Boucher.

6.1 Motivation

Most exhibition objects in museums are passive and silent, i.e., the objects themselves do not provide any additional information or recommendations. This is why the artifacts are often augmented through short textual descriptions or explanations by a guide. However, there are commonly more data available (e.g., knowledge of curators or information in databases and documents) than what can be written on a small plate or told in a short time. Using mobile devices to convey this extra information has proven effective in several research projects (Boiano et al., 2012; Othman et al., 2015), and they have even more potential. Smartphone apps promote the museum, build up visitors' active participation, and enable them to access the content even outside of the exhibition (Tomiuc, 2014). By including games within mobile apps, engagement with both children and adults can be increased even further (Yiannoutsou et al., 2009).

In Austria, many museums enable their visitors to download additional information to their smartphones (e.g., Mumok Vienna (NOUS Knowledge Management, 2017), Haus des Meeres - Aqua Terra Zoo Vienna (Artware Multimedia GmbH, 2013)). However, this content is often identical to that of the exhibition. Besides, while most museum apps do offer maps and lists to assist users in navigation (Economou and Meintani, 2011), the apps are not location-aware, and visitors still have to select the objects of interest themselves.

Providing a friendly and efficient user interface is crucial when trying to convey the vast amount of information behind an exhibition, so that an app can also reach less experienced visitors and therefore more users in general (Palumbo et al., 2013). We believe this can be achieved through Information Visualization (InfoVis) methods. While there is much research on human-computer interaction in museums (Hornecker and Ciolfi, 2019), the use of interactive data visualization in museums is relatively uncommon (Isenberg et al., 2013; Li et al., 2012). Our research aims at introducing the perspective of InfoVis to the visitors' mobile devices and addresses the gaps *Missing Mobile Visualization for Museum* and *Full Spectrum of Representation Techniques Is Not Used* identified in Chapter 4.3.

Therefore, we conducted a design study in order to identify a suitable visualization for a location-aware mobile application that guides visitors through a museum exhibition (see Figure 6.1). The study consisted of two stages: First, we explored three different visualization concepts and evaluated them in a lab test. In the second stage, we built upon the results of the first stage, developed variations of the preferred visualization concept, and evaluated them in both a lab and the actual museum setting.

The main contributions of this design study are:

1. the design of situated, mobile visualization concepts, their prototypical implementation using web technologies and application in a real museum setting (Chapter 7.1 and Chapter 8.1),

2. the results of two consecutive comparative studies (Chapter 7 and Chapter 8), as well as

3. a set of general lessons learned and implications about visualization & interaction and the design process grounded on insights derived from the study process (Chapter 9).

6.2 Approach

We followed a design process with two iterations. First, we developed three basic visualization concepts and implemented them as clickable mockups for evaluation (Iteration 1, Chapter 7). Based on the chosen timeline concept, we noticed there were multiple options for visualizing the data. Therefore, we conceived three concepts which were developed as fully functional prototypes and assessed (Iteration 2, Chapter 8). Figure 6.2 illustrates the timeline of the iterative development phases.

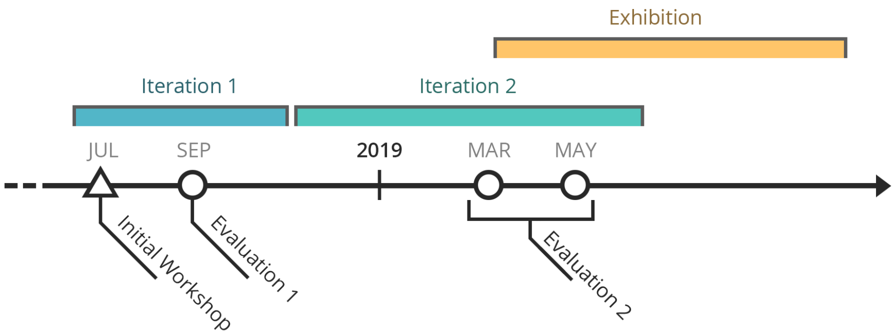


Figure 6.2: Timeline of the development phases from July 2018 to November 2019. Illustration by M. Boucher & K. Blumenstein.

The author of this thesis developed the design concepts together with a second computer scientist, both being experts in mobile development with knowledge in HCI and InfoVis. The two of them received constant feedback within the project team with three experts in

InfoVis and HCI and one computer scientist with knowledge about using digital artifacts to enhance museum visits.

We also integrated domain experts into the design loop and performed an initial workshop with the five exhibition curators with a background in history and as cultural mediators. In this workshop, we got to know the exhibition concept, discussed existing data, and defined the requirements. Furthermore, we brainstormed about what the visualization could look like - one of the ideas was a timeline that looked like a newspaper. With that knowledge, we started the development of the concepts for Iteration 1. We got back with the ideas to the curators in one of our monthly workshops with them in the course of preparing the entire interactive exhibition. Thus, we regularly discussed the progress of the visualization design and specified the underlying data.

6.3 Problem Analysis

Based on the results of the initial workshop with the exhibition curators, we defined data and requirements for the visualization.

Data Overview

The data contained a title, time (year(s)), a detailed description in text form, images, and additional interactive components (e.g., AR or a single choice game). The temporal dimension was not visible in the exhibition except on the exhibit labels which showed title, short description, and year. Therefore, including time in the visualization was of interest for the curators and ourselves.

In total, 27 exhibits were planned for the exhibition. Because of the storytelling aspects, the curators decided not to integrate all exhibits into the application. Thus, the exhibits within the app were reduced to 13. These exhibits were divided into six content-related sections.

Requirements for Visualization

Together with the curators, we defined requirements for our visualization concepts:

RQ1 The visualization should function as a guide through the exhibition. Thus, the order of the individual exhibits within the museum has to be shown.

RQ2 Depending on the visitor's location, exhibits should appear dynamically. The focus should be on the closest exhibit.

RQ3 To visualize the time dependency within the exhibition, exhibits appear chronologically within each section.

RQ4 Complementary information is shown for the selected exhibit, thus providing the visitors with additional information.

Based on the data and requirements, we focus on time-oriented data visualization for a location-aware mobile application in a museum. Next, we address related work for the addressed areas of interest.

6.4 Related Work

This section covers related work in three areas. First, we summarize the use of mobile devices in museums. Additionally, we take a closer look at mobile devices in museums, timeline visualization, and InfoVis in museums.

Mobile Devices in Museums

In the 1950s, Acoustiguide (2014) introduced the first audio guides with mobile devices in museums. Around 40 years later, first museum applications using PDAs and Pocket PCs were documented. E.g., HyperAudio (Petrelli and Not, 2005) is an early mobile guide based on a PDA with additional infrared sensors developed in the late 1990s. HyperAudio displayed hypermedia pages with an audio channel depending on the visitor's location in the museum. Several other visitor guides followed (e.g., Cardoso et al., 2019; Damala et al., 2005; Ghiani et al., 2008a; Othman et al., 2015).

Economou and Meintani (2011) evaluated museum applications for mobile phones. Most of them function as guided tours and representations of exhibitions, which is why maps or lists are often integrated to allow visitors to navigate according to the spatial layout or the chronological or alphabetical order of exhibits. In addition to functioning as guides, mobile phones are used to augment exhibits or exhibition spaces. Luna et al. (2019) analyzed Augmented Reality-integrating heritage applications in Europe. Most of the 35 studied apps (23) used AR to reconstruct spaces and buildings. Interestingly, fewer apps (10) extended exhibits. Research literature proposes AR to extend paintings (Damala et al., 2008) or to complete broken statues or show them in their original colors (Keil et al., 2013).

Mobile devices have also been integrated into MDEs. Such MDEs are often studied in the context of games (Jimenez and Lyons, 2011; Van Dijk et al., 2012) and as a combination of guides and games (Dini et al., 2007; Ghiani et al., 2009). Ghiani et al. (2009) extended large screens by combining a mobile guide with games. In contrast to the traditional way of using the mobile phone as the mobile device in an MDE, Banerjee et al. (2018) presented an MDE embedding smartwatches. The watch functioned as a device for notifications and as a remote control for interactive exhibits.

Timeline Visualization

Using time-based approaches (Aigner et al., 2011) to visualize data dates back to the 18th century. Already in 1765, John Priestley used timelines to visualize the lifespans of famous people for his *Chart of Biography* (Priesley, 1765). Khulusi et al. (2019) created an interactive version of Priestley's chart with data of musicians. Such timelines were also used to visualize personal histories based on medical records (Plaisant et al., 1996) and interactions of movie characters (Munroe, 2009). More recent research explores timelines in combination with storytelling (Brehmer et al., 2017).

Timelines are also of interest in researching visualization on mobile devices. Brehmer et al., on the one hand, examined data ranges in a time-oriented way on mobile phones (Brehmer et al., 2019) and, on the other hand, small multiples for trend visualization (Brehmer et al., 2020).

InfoVis on Mobile Devices & in Museums

In 2006, Chittaro (2006) published an article about visualizing information on mobile devices. The main conclusion was that "visualization applications developed for desktop computers do not scale well to mobile devices." The arguments mainly followed the lines of the smaller size, lower resolution, different aspect ratio, and less powerful hardware. Over the years, the performance of smartphones has been enhanced considerably. However, a survey article by Isenberg and Isenberg (2013) seven years later showed that smartphones had only been used in 6% of the 100 analyzed research projects, although the user base of smartphones had been continuously growing during these years. In recent years, visualization on mobile devices has attracted more and more attention in research (e.g., Blumenstein et al., 2016; Brehmer et al., 2019; Choe et al., 2019; Lee et al., 2018; Watson and Setlur, 2015) and practice (e.g., Ros and Bocoup, 2016; Sadowski, 2018).

A number of research works focused on tablets as target devices. Baur et al. (2012) presented TouchWave (touchable stacked graphs). Drucker et al. (2013) showed that users preferred the touch-centric fluid interface over non-touch-centric WIMP (window, icon, menus, and pointer). Jo et al. (2017) leveraged pen and touch interaction in TouchPivot, tailored towards beginners. Sadana and Stasko (2016) implemented multiple coordinated views for tablets. Later research on tablets explores details-on-demand techniques for interactive visual exploration (Subramonyam and Adar, 2019) or proposes consistent interaction across different types of visualization (Srinivasan et al., 2020). Compared to research on tablet devices, research on smartphones is underrepresented (Blumenstein et al., 2016). Besides, Hoffswell et al. (2020) proposed design guidelines for responsive visualization addressing news visualization.

Previously, visualization research used to heavily focus on expert users (e.g., Pousman et al., 2007). When designing InfoVis for museum visitors, however, users of the visualization are not domain experts (Block et al., 2012). Such casual users use visualizations for extrinsic and entertainment goals as well as learning or utility purposes (Sprague and Tory, 2012). Research by Börner et al. (2016) revealed a rather low level of data visualization literacy among science museum visitors. A promising fact, however, is that participants showed an interest in the presented visualization. In 2012, the utilization of casual InfoVis in museums was described as "a rudiment of utopia in the cultural organization" (Li et al., 2012). However, some applications show that data visualization fits very well into the museum space. Hinrichs et al. (2008) demonstrated the potential and challenges of such applications with InfoVis on a large touch display. Other examples of visualization in museums included tools with which visitors were able to explore scientific data (Ma et al., 2012), or a visualization that showed the area around Hamburg through space and time from the Middle Ages to the present (ART + COM Studios, 2012). The target device of those applications was a horizontal touch display (tabletop).

Rogers et al. (2014) performed a comparison of in-situ and remote exploration of museum collections through three visualizations (Choropleth map, bar graph, and list of artifacts) on tablets. Results showed that a keyword search was mostly likely to be used rather than visualization filters. One reason for this might be that the app was not implemented as location-aware, which is why it did not react to the visitors' location, and visitors had to figure out on their own which exhibit was next to them.

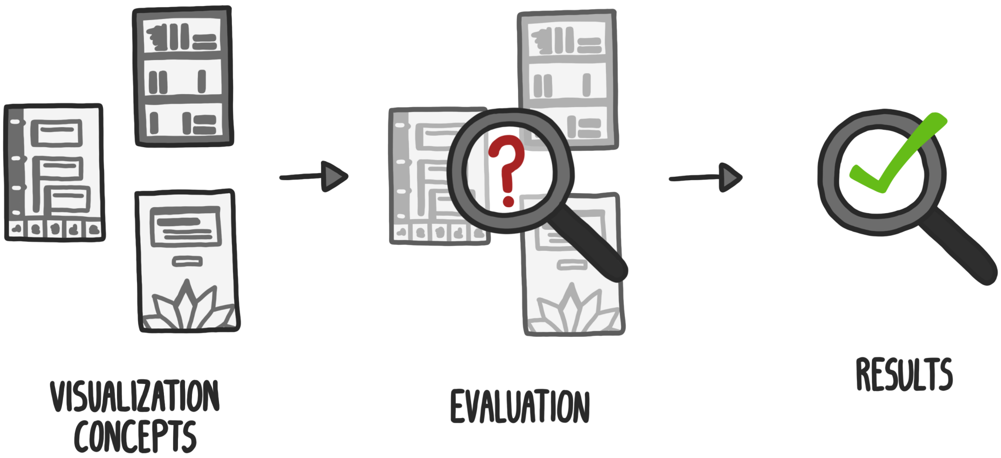
6.5 Summary

Currently, there is hardly any focus on InfoVis on mobile devices (esp. smartphones) in museums, which was also a result of our state-of-the art research (Chapter 4.3). Nevertheless, museums have utilized mobile applications as an additional way of extending visits. Therefore, introducing InfoVis to this area seems a more promising approach for enhancing the design possibilities for navigation through exhibits.

Next, we describe the visualization concepts and their comparative evaluation for Iteration 1 in detail (Chapter 7).

CHAPTER 7

Iteration 1: Visualization Concepts



This chapter describes the first iteration of our design study about visualizing historical data on mobile devices in detail. First, we explain the visualization concepts and why they were chosen (Chapter 7.1). Then, we address the comparative evaluation of the concepts (Chapter 7.2) and the results (Chapter 7.3). All materials used, such as the interview guideline and tasks, are included in Appendix C. A video showing the visualizations in action can be downloaded at https://phaidra.fhstp.ac.at/view/o:4085.

Since we did not want to settle on the first idea of a newspaper-like timeline, we conducted a brainstorming session with three experts in the fields of mobile, HCI, and InfoVis. The aim of this session was to generate a number of alternative visualization concepts. We combined basic InfoVis methods (e.g., overview first and then details on demand (Shneiderman, 1996)) and mobile guidelines (e.g., screen size limitation, vertical scrolling, occlusion and fat finger problem (Chittaro, 2006; Schwab et al., 2018; Wigdor et al., 2007)) to propose different visualization options. For presenting time-oriented information, we selected three out of five representation aspects as described by Brehmer et al. (2017) (linear, grid, and radial). We designed a conventional linear timeline (*Timeline*) and a radial approach that is optimized to take advantage of mobile screen size (*Timeflower*). Since our data are also historical, which is often connected to documents and books, we also created a grid visualization based on a bookshelf as a metaphor (*Bookshelf*).

7.1 Visualization Concepts

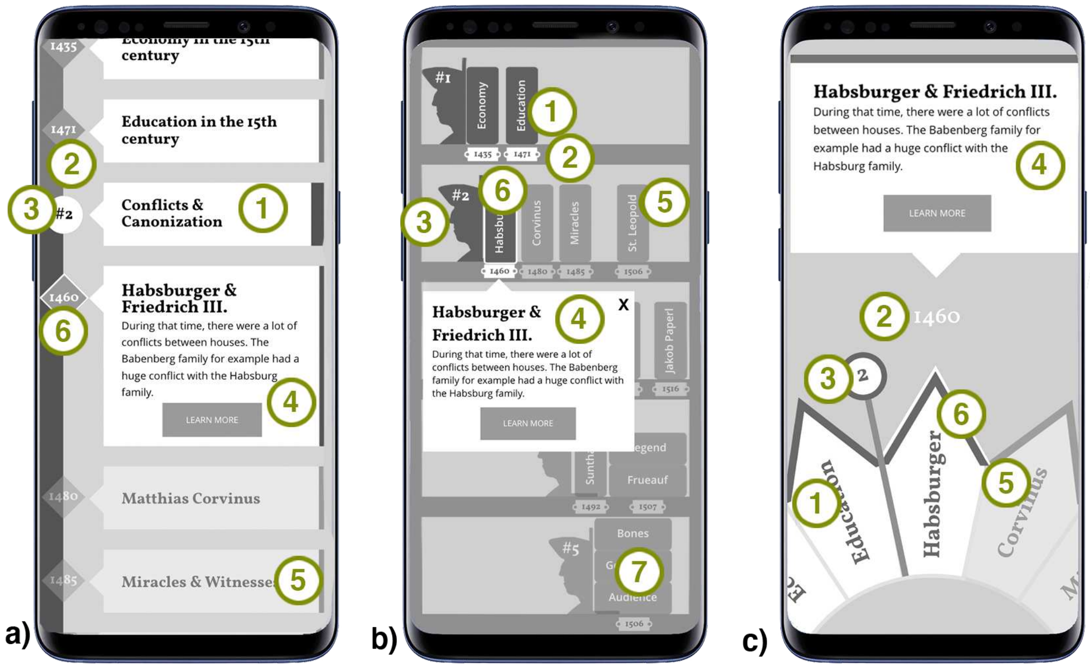


Figure 7.1: Three design concepts for visualizing historical data on a mobile device: Timeline (a), Bookshelf (b), and Timeflower (c).

In *Timeline*, data are represented as a linear vertical timeline (Figure 7.1 (a)). A box represents each exhibit containing its title (Figure 7.1 (a) 1) and is anchored to a year on the timeline (Figure 7.1 (a) 2). If a museum visitor has not yet passed an exhibit, it is displayed as inactive (Figure 7.1 (a) 5). Addressing RQ2, an exhibit is activated on the timeline whenever visitors walk by. Besides, it automatically moves to the center of the screen. The year of the closest exhibit is marked with a border (Figure 7.1 (a) 6).

If the visitor selects an exhibit by tapping on the box, a larger box appears containing additional text (Figure 7.1 (a) 4, RQ4). A section-introduction element introduces each section (Figure 7.1 (a) 3) which, in contrast to regular exhibits, features a different icon and starts a new timeline instead of displaying a year.

The *Bookshelf* visualization shows the data in a bookshelf-like grid layout in which each rack represents one section of the exhibit (Figure 7.1 (b)). Bookshelves were used as a metaphor in visualization before (e.g., Aslan et al. (2013); Thudt et al. (2012)). In contrast, we intended to visualize a real bookshelf. Each book corresponds to one exhibition object and shows a keyword on its back (Figure 7.1 (b) 1). Labels on the underlying racks show the year of the exhibits (Figure 7.1 (b) 2). Book holders represent section introductions (Figure 7.1 (b) 3). While the racks (sections) are aligned vertically, the horizontal alignment of the books shows the chronological order of the exhibits (RQ1, RQ3). If the years of multiple exhibits are the same, the books are stacked on top of each other (Figure 7.1 (b) 7). Once again, the books are marked as inactive until the visitor has passed the corresponding exhibit. The book which represents the closest exhibit is shown with a border (Figure 7.1 (b) 6). Its rack scrolls to the middle of the screen upon activation (RQ2). Tapping on the book reveals detailed information as an overlay (Figure 7.1 (b) 4, RQ4).

Timeflower was inspired by People Garden (Xiong and Donath, 1999) which is a graphical representation of users based on their past interactions. The entire content of the exhibition is represented by a flower-like structure (Figure 7.1 (c)) in which each exhibit is a petal (Figure 7.1 (c) 1). Stamens mark section introductions (Figure 7.1 (c) 3). By swiping across the screen, the flower can be rotated. While the flower takes up the lower half of the screen, an information box is displayed on the upper half (Figure 7.1 (c) 4, RQ3). This box contains the title and a teaser text of the exhibit petal that is currently facing upwards. Between the box and the petal, the year of the corresponding exhibit is shown (Figure 7.1 (c) 2). When visitors pass an exhibit, the flower automatically rotates so that the corresponding petal is in the middle of the screen, and its information is displayed. An additional border marks the petal that represents the closest exhibit (Figure 7.1 (c) 6, RQ2).

Our three concepts address the defined requirements. The order of the exhibits in all three concepts represents the path through the museum (RQ1). This order also represents a chronological order within each section (RQ3). As *Timeline* and *Timeflower* have a sequential scale, we do not visualize the period in between the exhibits. *Bookshelf*, on the other hand, visualizes such data as a chronological scale. To address RQ3, we activate exhibits that are close to the visitors, center and highlight them in all three concepts. Besides, we show additional information for selected exhibits (RQ4). However, our three designs have different strengths and weaknesses. *Timeline* has the look and feel of a news app, which is well known. The vertical scrolling is familiar to the user (Buchanan et al., 2001). Yet, it is a classic approach that might offer the least fun experience. *Bookshelf* provides a good overview and looks well structured. Its weakness is the covering of parts when showing detailed information. The strength of *Timeflower* is the excellent mixture between overview and detail, but it is less known for presenting data and uses vertical text orientation, which could influence readability.

7.2 Evaluation

As the three designs are quite different in their approaches, we conducted a comparative evaluation of clickable mockups to see which concept was the easiest to understand and use. To focus on the different design concepts, we added neither the location-aware aspect nor coloring in this first evaluation step. The evaluation was counter-balanced with a within-subject design. We selected four tasks to find out 1) how participants interpret our designs, 2) whether it is possible for them to navigate within the prototype, 3) find additional information, and 4) get back to the overview page. During these tasks, participants were asked to think aloud. Afterward, they answered three post-task questions about 1) the comprehensibility of the navigation, 2) the comprehensibility of changing between exhibition objects, and 3) the ease of use of the visualization. Once all three concepts had been tested, users were requested to fill in a post-study questionnaire in order to directly compare the concepts. All questions were presented as a seven-point Likert scale varying from negative to positive scores.

Subjects

Twenty-four persons (P) participated in the assessment (13 female and 11 male), with an age range of 19 to 77 years ($M = 41.6$, $SD = 14.9$). Seventeen participants used Android as the operating system, while the others used iOS. Only one user reported not having experience using a smartphone.

Data Analysis

Data were analyzed with R. When distributions were not Gaussian (according to the Shapiro-Wilks test), the effect of the three designs on the participants' scores was evaluated using the non-parametric Friedman test with posthoc Wilcoxon analyses (paired samples).

7.3 Results

When performing the assigned tasks, the design did not affect user performance. Participants reached correct results in 79% ($SD = 23.2$) of cases with the *Timeline* design, in 78% ($SD = 21.2$) of cases with *Bookshelf*, and in 74% ($SD = 23.0$) of cases with *Timeflower*. However, results regarding user experience are in contrast to these findings. Figure 7.2 and Table 7.1 summarize the results for the post-task and post-study questionnaires.

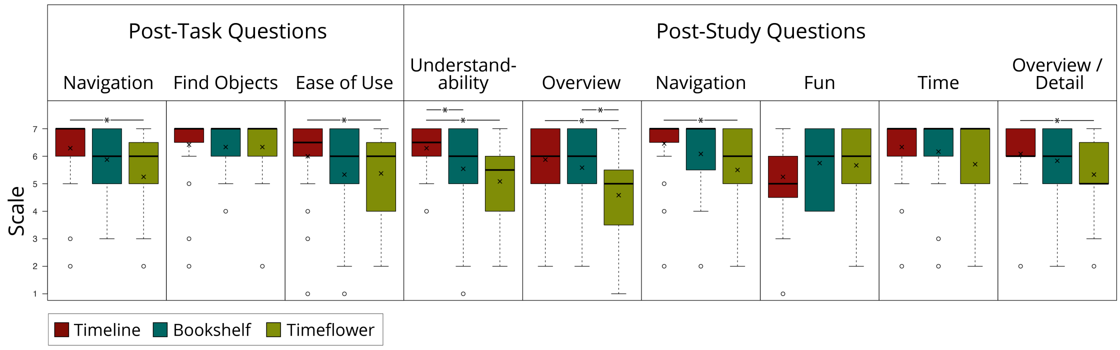


Figure 7.2: Iteration 1. Scores from post-task and post-study questionnaires across designs. The y axis maps the Likert scale, with 1 being on the negative and 7 being on the positive end of the scale.

Table 7.1: Iteration 1. Means and standard deviation of questionnaire scores.

		Timeline	**Bookshelf**	**Timeflower**
Post-Task Questions	Navigation	6.29 (*SD*: 1.30)	5.87 (*SD*: 1.22)	5.25 (*SD*: 1.67)
	Find Objects	6.41 (*SD*: 1.31)	6.33 (*SD*: 0.96)	6.33 (*SD*: 1.20)
	Ease of Use	6.00 (*SD*: 1.50)	5.33 (*SD*: 1.83)	5.37 (*SD*: 1.52)
Post-Study Questions	Understandability	6.29 (*SD*: 0.90)	5.54 (*SD*: 1.61)	5.08 (*SD*: 1.66)
	Overview	5.87 (*SD*: 1.29)	5.58 (*SD*: 1.74)	4.58 (*SD*: 1.55)
	Navigation	6.45 (*SD*: 1.21)	6.08 (*SD*: 1.52)	5.50 (*SD*: 1.61)
	Fun	5.25 (*SD*: 1.45)	5.75 (*SD*: 1.29)	5.66 (*SD*: 1.65)
	Time	6.33 (*SD*: 1.23)	6.16 (*SD*: 1.34)	5.70 (*SD*: 1.80)
	Overview / Detail	6.08 (*SD*: 1.13)	5.83 (*SD*: 1.23)	5.33 (*SD*: 1.34)

Post-Task Questions

The design had an effect on the comprehensibility of the navigation ($\chi^2(2) = 9.30$, $p < .01$). Posthoc tests showed that *Timeline* provided an easier navigation than *Timeflower* ($p < .01$). In addition, there was an effect of the design on the ease of use of the visualization ($\chi^2(2) = 6.03$, $p < .05$) where *Timeline* also supported a better usage than *Timeflower* ($p < .05$). However, designs did not differ in the ratings for comprehensibility when changing between exhibition objects.

Post-Study Questions

The design also had an effect on the understandability rating of the visualization ($\chi^2(2) = 9.95$, $p < .01$). The *Timeline* design was assessed as more understandable than both *Bookshelf* ($p < .05$) and *Timeflower* ($p < .01$). In addition, the design affected the quality of the overview offered by the visualization ($\chi^2(2) = 11.05$, $p < .01$). This time, *Timeflower* was judged to be less suitable for overview compared to both *Timeline* ($p < .01$) and *Bookshelf* ($p < .05$). Both results seem to be related to the responsiveness of

Timeflower.

The design also had an effect on how easy it was to navigate through the visualization ($\chi^2(2) = 11.39$, $p < .01$). Again, *Timeline* was rated as supporting navigation better than *Timeflower* ($p < .01$). In addition, regarding the combination between overview and detailed information, there was also a difference between designs ($\chi^2(2) = 6.11$, $p < .05$). *Timeline* offered a better balance between overview and detailed information than *Timeflower* ($p < .05$).

User Experience

Qualitative results showed that the idea behind *Timeline* was received well. Comments such as *"one can scroll, and there are exhibits"* (P2), *"I would expect it when I download a museum app"* (P7), and *"exhibition topic with historical order of objects"* (P9) documented this fact. For *Bookshelf*, we recognized two different opinions within the comments of the participants: *"overloaded, do not know where to look"* (P10) vs. *"well structured and numbered"* (P18). *Timeflower* was hardly recognized as a flower. Participants recognized, e.g., a crown, a sun, or arrows. The most critical issue design-wise referred to the sectioning; in each respective design, 14 (for *Timeline* and *Bookshelf*) and 18 (for *Timeflower*) participants could not imagine what the subdivision meant.

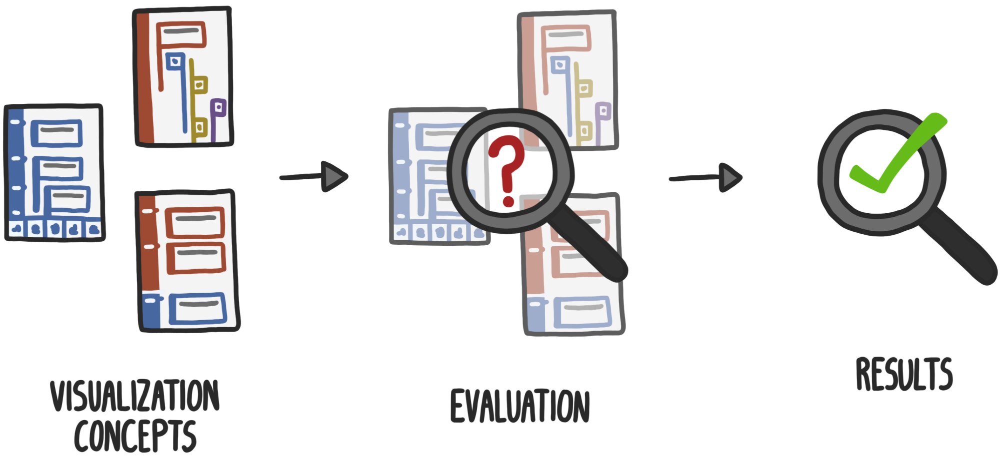
7.4 Summary

This chapter described the design and evaluation of three basic visualization concepts for presenting historical data on mobile phones. Combining the results of post-task and post-study questionnaire as well as user experience, the linear *Timeline* visualization is the best evaluated concept. Participants rated the concept as the easiest to understand and received the idea well when describing what they saw.

In Iteration 2, we therefore developed the linear concept further, which is described in Chapter 8. We chose three linear concepts and performed an additional comparative evaluation.

CHAPTER 8

Iteration 2: Linear Timelines



This chapter describes the second iteration of our design study about visualizing historical data on mobile devices in detail. First, we explain the linear timeline concepts and why they were chosen (Chapter 8.1). Then, we address the comparative evaluation of the concepts (Chapter 8.2) and the results (Chapter 8.3). All materials used, such as the interview guideline and tasks, are included in Appendix D. A video showing the visualizations in action can be downloaded at https://phaidra.fhstp.ac.at/view/o:4085.

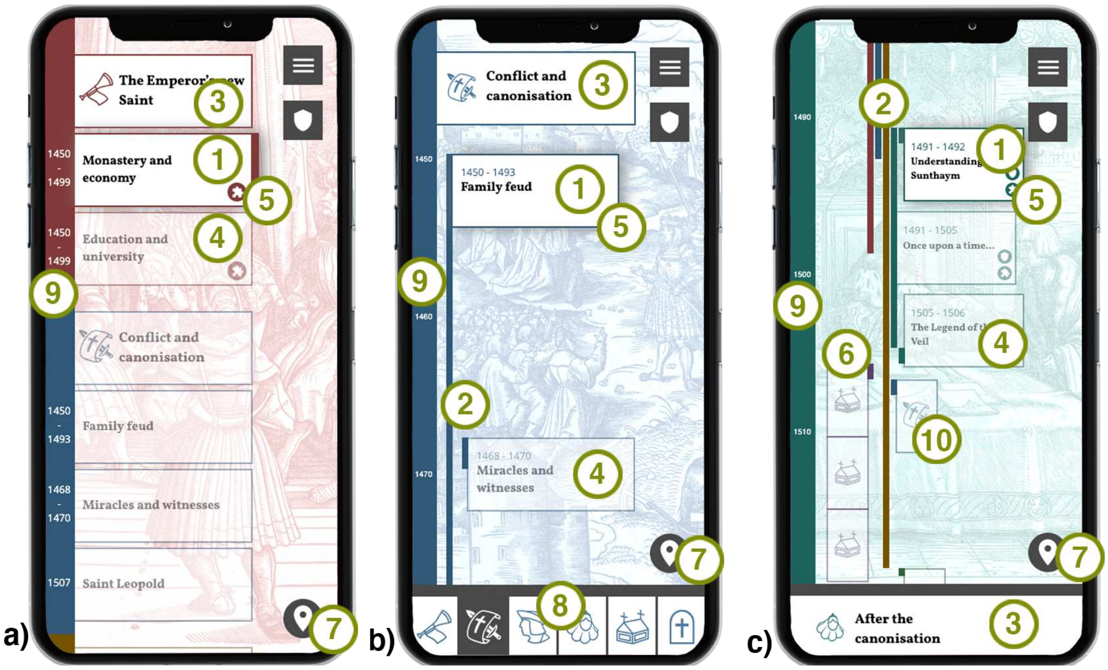


Figure 8.1: Timeline visualizations showing different areas of the exhibition: Stack-based (a), Section-based (b), and All-in-one (c) visualization.

Based on the results of the first evaluation, in which the *Timeline* concept received the better overall rating, we developed the linear concept further. Since we had to visualize time and duration for six different sections, we noticed different options concerning scale and layout (Brehmer et al., 2017). First, we reproduced the same timeline concept which focused on the exhibits' order. Therefore, such a visualization displayed the different sections consecutively (*Stack-based*, Figure 8.1 (a)). In general, stacking items is common for mobile screens. However, it means having stacked timelines as well, which corresponds to a faceted layout (Brehmer et al., 2017). To avoid a very long list of six chronological timelines, a sequential scale was chosen, which means that distances between exhibits do not correspond to chronological distances (Brehmer et al., 2017). In our second approach, we used pagination (*Section-based*, Figure 8.1 (b)) to overcome the stacking (faceted layout). Thus, we could use a chronological scale to visualize the exhibits. Alternatively, we also implemented a unified option prioritizing time over exhibits' order by including all exhibits in one timeline (*All-in-one*, Figure 8.1 (c)) with a chronological scale.

8.1 Visualization Concepts

In all three visualizations, exhibits are represented as cards with a title and the exhibit's time frame either on the card (Figure 8.1 (b, c) 1) or on the timeline next to it (Figure 8.1 (a) 1). The card representing the exhibit closest to the visitors is highlighted (Figure 8.1 (a, b, c) 5, RQ2), and a location button can be used to scroll to the corresponding card (Figure 8.1 (a, b, c) 7). Inactive cards represent exhibits visitors have yet to unlock by walking by them and are indicated by higher transparency (Figure 8.1 (a, b, c) 4). Once an exhibit is unlocked, the visualization scrolls to the corresponding object card (RQ2). In case this exhibit is in a different section, both the section color and the background image change accordingly. In all three visualization prototypes, clicking on a card opens the exhibit's detail page showing detailed descriptions in the form of text, images, and/or additional interactive components (RQ4). In both *Stack-based* and *Section-based* visualization, the current exhibit's section is displayed on section introduction cards showing its title and icon (Figure 8.1 (a, b) 3). In the *All-in-one* visualization, this information is shown as a footer instead (Figure 8.1 (c) 3).

In the *Stack-based* visualization (Figure 8.1 (a)), a timeline is divided into sections. Whenever visitors walk into a new section, the timeline's color as well as the background color and image change. Within these colored sections, the objects are listed chronologically, but the time axis jumps between years according to the sequence of the displayed objects (Figure 8.1 (a) 9).

The *Section-based* visualization shows each section as a page. For navigation through these pages, we positioned a navigation bar at the bottom (Figure 8.1 (b) 8). The time frame of the time axis (Figure 8.1 (a) 9) remains the same through all sections. The coloring of this axis is based on the section's color. Objects within the sections are listed chronologically. Timelines (Tufte, 2007) on the left side of the object's cards indicate the temporal assignment as their height is determined by the start and end years the exhibit is assigned to (Figure 8.1 (b) 2).

The *All-in-one* visualization shows one time axis (Figure 8.1 (a) 9) integrating all exhibits. Within each section, exhibits still appear based on the order in the exhibition. To differentiate between the exhibition's sections, each card is connected to a timeline showing the temporal assignment (Figure 8.1 (c) 2). The timelines are colored according to the section they belong to. Whenever a visitor is located in a section, the background color and the image change accordingly. In addition, all cards which belong to this section are shown in full size (Figure 8.1 (c) 1). The other cards are reduced to a small card showing the dedicated section icon (Figure 8.1 (c) 10) such as a fisheye (Furnas, 1986). In case exhibits are allocated to the same year or time frame, their cards are shown as aggregated (Figure 8.1 (c) 6).

Our three visualizations are well suited for getting to know the time the exhibits are related to (RQ3). Nevertheless, these visualizations have different strengths and weaknesses. The *Stack-based* visualization is a simple and straightforward concept, backed by Iteration 1. However, the focus is on the exhibits' order within the exhibition rather than on time (RQ1). The *Section-based* visualization tries to solve this by displaying each section on demand. In this way, it is possible to compare the time between objects of different sections, as the time axis stays in the same position. On the other hand, it might present too much white space, as exhibits in each section are spread over different years of the same time axis. The focus of the *All-in-one* visualization is on the chronological order (RQ3) rather than the exhibits' order within the exhibition (RQ1). Its strengths are the overview of all exhibition objects and the ease of comparing the time of exhibits. However, such a concept might be overwhelming for first-time users.

8.2 Evaluation

To evaluate which visualization is the easiest to understand and provides the best experience, we once again prepared a counter-balanced evaluation within-subject design. This evaluation was performed both in the lab and museum settings. Therefore, we implemented the three visualizations with web technologies (HTML, CSS, Javascript, and D3 (Bostock et al., 2011)). As we used Bluetooth tags to trigger the location of the exhibits, we wrapped the web content in a native application for iOS and Android. All subjects were provided with prepared iPhone devices (iPhone 7 and 8) to ensure that different devices did not influence results. The three tasks were the same for all visualizations: 1) Describe the visualization. 2) Which year(s) is/are assigned to the last object you activated? 3) Show us two objects which are linked in the same year(s). After each visualization, participants answered three questions about 1) the ease of use, 2) the comprehensibility of the temporal assignment, and 3) the ease of comparing the time between exhibits. When all three visualizations were tested and rated, the users completed an additional questionnaire in which the visualizations were directly compared. For both the post-task and the post-study questions, we used a seven-point Likert scale with varying scores from negative to positive.

We used the same process for both the lab and the museum settings. Each visualization was tested in two sections (two exhibits in the first section, one exhibit in the second section). For the lab setting, we prepared a path comparable to the museum setting with five sections. Additionally, the test in the museum setting was carried out at a time when there were hardly any visitors in the museum so that we could reduce distractions.

Subjects

A total of thirty-six persons participated in the assessment. The evaluation was conducted in two different locations: first, with 24 participants (14 female and 10 male, age range 20 to 56 years ($M = 32.8$, $SD = 11.2$)) in a lab setting. The second location was in the field, testing 12 users (6 female and 6 male, 11 and 12 years old ($M = 11.8$, $SD = 0.6$)) in the actual exhibition.

In the pre-questionnaire, 25 (museum: nine) participants reported their daily smartphone usage time to be 61 minutes and more, while six (museum: two) participants reported 30 to 45 minutes of daily usage time, three participants in the lab setting said they used it for 45 to 60 minutes, and 15 to 30 minutes (museum) and 10 to 15 minutes (lab) were each reported once. Participants were also asked to rate their data visualization experience on a seven-point Likert scale (low to high), resulting in a mean of 4.0 ($SD = 1.4$) for participants in the lab setting, and 2.3 ($SD = 1.7$) in the museum setting.

Data Analysis

The same methods from Iteration 1 were applied. There were no significant differences between the assessed treatments. Following an exploratory analysis (Tukey, 1977), Pearson tests were also performed for testing the correlation between the users' scores and their demographics: gender (male, female), age group (child & adolescent (under 18, n = 12), young adult (18 to 30, n = 13), middle- and old-aged person (above 30, n = 11)), smartphone usage, data visualization experience, setting group (lab vs. museum), and condition type (order of design during the test). After detecting significant correlations, a factorial analysis was adopted with a factorial ANOVA test and Tukey test for posthoc analysis.

8.3 Results

When performing the tasks, participants reached correct results in 68% of cases with *Stack-based* (SD = 32.0) and *Section-based* design (SD = 33.1), and in 78% (SD = 33.7) of cases with *All-in-one* design. These findings reflect the overall results regarding user experience. Figure 8.2 shows the aggregated results for the post-task and post-study questionnaires. Table 8.1 and Table 8.2 summarize means and standard deviation as well as relevant scores for correlation tests.

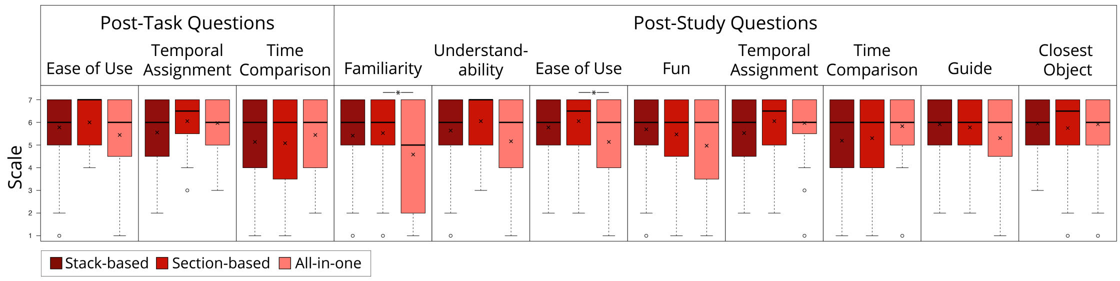


Figure 8.2: Iteration 2. Scores from post-task and post-study questionnaires across visualization. The y axis maps the Likert scale, with 1 being on the negative and 7 being on the positive end of the scale.

Post-Task Questions

The ANOVA test reported a significant effect ($F(1{,}102) = 4.44$, $p = .04$) of the setting group (lab vs. museum) on the ease of use. Ease of use was rated significantly better ($p = .04$) by the museum group than the lab group. Additionally, there was a significant effect ($F(1{,}102) = 16.11$, $p < .001$) of the setting group on the ease of use of the time comparison task, which was rated better ($p < .001$) by the museum group than the lab group.

Age groups had an effect on comparing the time ($F(2{,}99) = 8.76$, $p = < .001$). Young adults as well as middle- & old-aged adults rated significantly lower ($p < .01$ & $p < .001$)

Table 8.1: Iteration 2. Means and standard deviation (SD) of questionnaire scores.

		Lab Group	Museum Group	Stack-based	Section-based	All-in-one	Child & Adolescent	Young Adult	Middle & Old Aged
Post-Task Questions	Ease of Use	5.51 (*SD*: 1.65)	6.19 (*SD*: 1.40)	5.78 (*SD*: 1.55)	6.00 (*SD*: 1.29)	5.44 (*SD*: 1.89)	6.19 (*SD*: 1,39)	5.59 (*SD*: 1.46)	5.42 (*SD*: 1.87)
	Time	5.75 (*SD*: 1.33)	6.08 (*SD*: 1.27)	5.56 (*SD*: 1.50)	6.06 (*SD*: 1.19)	5.97 (*SD*: 1.21)	6.08 (*SD*: 1.27)	6.00 (*SD*: 1.21)	5.45 (*SD*: 1.42)
	Time Comparison	4.75 (*SD*: 1.91)	6.17 (*SD*: 1.25)	5.13 (*SD*: 1.91)	5.08 (*SD*: 1.95)	5.44 (*SD*: 1.68)	6.17 (*SD*: 1.25)	4.90 (*SD*: 1.96)	4.58 (*SD*: 1.87)
Post-Study Questions	Familiarity	4.78 (*SD*: 1.97)	5.97 (*SD*: 1.23)	5.42 (*SD*: 1.56)	5.53 (*SD*: 1.56)	4.58 (*SD*: 2.23)	5.97 (*SD*: 1.23)	5.00 (*SD*: 1.73)	4.52 (*SD*: 2.22)
	Understand-ability	5.28 (*SD*: 1.80)	6.31 (*SD*: 1.21)	5.64 (*SD*: 1.66)	6.06 (*SD*: 1.24)	5.17 (*SD*: 2.02)	6.31 (*SD*: 1.21)	5.31 (*SD*: 1.56)	5.24 (*SD*: 2.08)
	Ease of Use	5.31 (*SD*: 1.82)	6.36 (*SD*: 0.90)	5.78 (*SD*: 1.49)	6.06 (*SD*: 1.22)	5.14 (*SD*: 2.03)	6.36 (*SD*: 0.90)	5.44 (*SD*: 1.82)	5.15 (*SD*: 1.84)
	Fun	4.89 (*SD*: 1.92)	6.36 (*SD*: 0.93)	5.69 (*SD*: 1.43)	5.47 (*SD*: 1.66)	4.97 (*SD*: 2.17)	6.36 (*SD*: 0.93)	4.85 (*SD*: 1.83)	4.94 (*SD*: 2.05)
	Time	5.65 (*SD*: 1.49)	6.25 (*SD*: 1.02)	5.53 (*SD*: 1.48)	6.06 (*SD*: 1.24)	5.97 (*SD*: 1.38)	6.25 (*SD*: 1.02)	5.92 (*SD*: 1.33)	5.33 (*SD*: 1.63)
	Time Comparison	4.97 (*SD*: 1.82)	6.39 (*SD*: 1.02)	5.19 (*SD*: 1.75)	5.31 (*SD*: 2.00)	5.83 (*SD*: 1.36)	6.39 (*SD*: 1.02)	4.95 (*SD*: 1.89)	5.00 (*SD*: 1.77)
	Guide	5.21 (*SD*: 1.72)	6.58 (*SD*: 0.77)	5.92 (*SD*: 1.30)	5.78 (*SD*: 1.51)	5.31 (*SD*: 1.92)	6.58 (*SD*: 0.77)	5.18 (*SD*: 1.75)	5.24 (*SD*: 1.71)
	Closest Object	5.64 (*SD*: 1.51)	6.33 (*SD*: 1.12)	5.94 (*SD*: 1.22)	5.75 (*SD*: 1.61)	5.91 (*SD*: 1.46)	6.33 (*SD*: 1.12)	5.74 (*SD*: 1.57)	5.12 (*SD*: 1.46)

Table 8.2: Iteration 2. Correlation coefficients of questionnaire scores (*df*=106). Significant values are shown in boldface.

		Age Group	Setting Group	Data Visualization Experience
Post-Task Questions	Ease of Use	**-.20**	**.20**	**-.19**
	Time	**-.19**	.12	-.001
	Time Comparison	**-.35**	**.36**	**-.21**
Post-Study Questions	Familiarity	**-.32**	**.31**	-.15
	Understandability	**-.26**	**.29**	-.19
	Ease of Use	**-.30**	**.30**	**-.26**
	Fun	**-.32**	**.39**	-.15
	Time	**-.27**	**.21**	-.08
	Time Comparison	**-.33**	**.39**	**-.24**
	Guide	**-.34**	**.41**	**-.26**
	Closest Object	**-.23**	**.23**	-.14

than children & adolescents.

The ANOVA tests showed a significant correlation ($F(6{,}87) = 2.62$, $p = .02$) between data visualization experience and comparing the time. Participants with medium experience ($M = 4.48$, $SD = 2.01$) rated significantly lower ($p = .02$) than participants with the lowest experience ($M = 6.33$, $SD = 1.28$).

Post-Study Questions

Correlation tests revealed positive correlations between setting groups and each of the post-task questions. For familiarity, ANOVA revealed a significant difference between designs ($F(2{,}102) = 3.29$, $p = .04$). Participants had more fun with the *Section-based* visualization than with the *All-in-one* visualization ($p < .001$). There was also a significant difference between setting groups ($F(1{,}102) = 11.73$, $p < .001$). The museum group provided significantly better ratings than the lab group ($p < .001$). We found the same significant differences for understandability ($F(1{,}102) = 9.83$, $p < .01$), fun ($F(1{,}102) = 19.25$, $p < .001$), temporal assignment ($F(1{,}102) = 4.64$, $p = .03$), comparing the time ($F(1{,}102) = 18.75$, $p < .001$), suitability as guide ($F(1{,}102) = 20.97$, $p < .001$), noticing the closest object ($F(1{,}102) = 5.76$, $p = .02$), and ease of use ($F(1{,}102) = 11.22$, $p = .001$). In terms of ease of use, ANOVA also reported a significant difference between designs ($F(2{,}102) = 3.34$, $p = .04$). Again, the *Section-based* visualization was easier to use than the *All-in-one* visualization ($p = .04$).

ANOVA reported a significant difference in familiarity between designs ($F(2{,}99) = 3.28$, $p = .04$) and between age groups ($F(2{,}99) = 3.28$, $p = .04$). On the one hand, the posthoc test showed a marginally significant difference ($p = .05$) that the *Section-based* visualization was more familiar than the *All-in-one* visualization. On the other hand, young adults as well as middle- & old-aged adults rated significantly lower ($p = .04$ & $p < .01$) than children & adolescents. In terms of understandability, we found a significant difference based on age groups ($F(2{,}99) = 5.28$, $p < .01$). Again, the posthoc test showed that young adults as well as middle- & old-aged adults gave significantly fewer points ($p = .02$ & $p = .01$) than children & adolescents. Additionally, there was an effect on interaction between designs and age groups ($F(4{,}99) = 3.04$, $p = .02$). For middle- & old-aged adults, the *Section-based* design was more understandable than the *Stack-based* design ($p = .04$). Design proved to have a significant effect ($F(2{,}102) = 3.38$, $p = .04$) on the ease of use. The *Section-based* design was easier to use than the *All-in-one* design ($p = .03$). Additionally, ease of use ($F(2{,}99) = 5.99$, $p < .01$) as well as fun ($F(2{,}99) = 9.80$, $p < .001$), comparing the time ($F(2{,}99) = 9.64$, $p < .001$), and suitability as a guide ($F(2{,}99) = 10.38$, $p < .001$) showed effects with age groups. Young adults as well as middle- & old-aged adults rated significantly lower than children & adolescents. For the temporal assignment, we also found significant differences between age groups ($F(2{,}99) = 4.05$, $p = .02$). This time, only middle- & old-aged adults rated significantly lower ($p = .16$) than children & adolescents.

ANOVA showed a significant difference between designs ($F(2{,}102) = 3.93$, $p = .04$).

Also, in combination with data visualization experience, participants reported that the *Section-based* visualization was easier to use than the *All-in-one* visualization ($p = .03$). Data visualization experience had an effect on comparing times ($F(6{,}87) = 2.26$, $p < .05$) and on suitability as a guide ($F(6{,}87) = 2.64$, $p = .02$). Participants with the lowest data visualization experience ($M = 6.61$, $SD = 1.04$) gave significantly ($p = .03$) more points than participants with data visualization experience three ($M = 5.10$, $SD = 1.84$).

User Experience

Qualitative results show that the general "timeline" concept is received well. However, both qualitative and quantitative results show that user opinions on the different designs diverge considerably. The *Stack-based* design is properly recognized as *"multiple stacked timelines"* (P2). Participants describe it as *"clear"* (P5, P15, P28) or *"looking ordered"* (P29). At the same time, others called it *"not clear"* (P11), *"overwhelming"* (P10), or found the time *"completely messy"* (P20). The *Section-based* design is described as a *"vertical timeline with multiple parallel timelines"* (P2) which *"feels like a conventional app layout"* (P9). Comments regarding this visualization were that it was *"irritating"* (P17) or *"cool, but hard to understand"* (P26). P8 reported that it took her *"longer to do something, but with the sections, it is straightforward"*. P6 states that *"the comparison is not possible"*. However, she had given the correct answer in the comparison task. The *All-in-one* design is described as *"multiple timelines side by side with colors and icons"* (P2). Judging from the comments, it seems to cause the most diverging opinions. On the one hand, *All-in-one* is praised for providing *"a good overview"* (P3), for being *"easy to understand"* (P31), *"well organized"* (P33), and for having *"a clean layout"* (P24). On the other hand, participants' comments included remarks such as *"loose orientation"* (P7), *"totally overwhelming"* (P10), *"looks more confusing"* (P20), *"overloaded"*, or *"very complicated"* (P25, P26). Overall, participants liked the section coloring which supported guidance within the exhibition.

8.4 Summary

This chapter described Iteration 2 for designing and evaluating three linear timeline concepts to present historical data on mobile phones. Qualitative results showed that participants performed slightly better with the *All-in-one* design. On the other hand, the *Stack-based* and *Section-based* designs yielded close and slightly better scores than the *All-in-one* design in quantitative results. However, middle- & old-aged adults in particular rated the *Section-based* visualization as more understandable. We decided, therefore, to implement the *Section-based* approach into the application for the own devices (see Chapter 5.6.2).

Next, we reflect on our results of both iterations and derive implications for future studies on visualizing historical data on mobile devices.

CHAPTER 9

Reflection & Lessons Learned

Following the design study methodology by Sedlmair et al. (2012), we next reflect on visualization & interaction and the design process of our design study and derive implications.

9.1 Visualization & Interaction

Choosing Familiar and Linear Visualization Techniques

Our results show that the general public may lean towards more familiar and linear visualization techniques. Börner et al. (2016) already stated the importance of familiarity for visitors with low data literacy. In Iteration 1, participants were able to perform the tasks well with all three designs, although the user experience with the designs was different. Based on the users' ratings, there was no difference between designs regarding their ability to display content about exhibits (Find Objects). However, participants rated *Timeflower* as the least preferred approach regarding navigation and ease of use. *Timeflower* was functional and met the system requirement of focusing mainly on the current exhibit, which was shown by the scores it got for the overview. Nevertheless, it was also a somewhat unfamiliar technique and metaphor. Whenever users were unable to identify which object *Timeflower* represented, they were not able to see its affordance, which negatively influenced usability. The *Bookshelf* and *Timeline* designs, on the other hand, were more apparent and more familiar to the users, yielding close scores in many aspects such as navigation and overview. However, participants rated *Bookshelf* as significantly less understandable than *Timeline*. Even when the meaning of the metaphor of *Bookshelf* was clear, *Timeline* shows objects in a straightforward and functional manner. *Timeline* also reflects the same visual metaphor found in news feeds and social media (e.g., card-based layout). This is why we chose *Timeline* as the basis for Iteration 2. With three versions of a linear timeline in Iteration 2, users were again able to perform the tasks well with all three designs with no significant differences in performance and user experience.

In future projects, we will choose a familiar and linear visualization technique when designing for casual users and mobile devices.

Clickable Mockups Are Not Always the Optimal Choice

In Iteration 1, we produced medium-fidelity clickable mockups as we wanted to make use of the real physical device (Hartson and Pyla, 2018). Nevertheless, we noticed that there might be an effect of the static mockup setup, particularly on the *Timeflower* assessment. The design of *Timeflower* included a wheel interaction not present in the other designs. Missing interaction elements (e.g., a smooth spinning of *Timeflower*) may influence the perception of the visualization representation, especially when comparing familiar (*Timeline* or *Bookshelf*) with non-familiar techniques (*Timeflower*). Therefore, we conclude that click dummies are not always ideal for comparing different visualization techniques.

In future projects, interaction should be the primary key when deciding on prototype fidelity. If the interaction varies between designs, all interactions must be implemented as they should work in the final version (i.e., with higher fidelity). Otherwise, it is possible to use lower-fidelity prototypes and simulate interactions (e.g., with a wizard-of-oz technique (White and Lutters, 2003)).

Age vs. Design Alternatives

Different age groups responded differently to the assessed prototypes. The *Stack-based* and *Section-based* visualization yielded close scores, but the *Section-based* design was shown to be easier to use for older users (middle- & old-aged adults). Finally, we consistently observed the prevalence of older visitors despite our museum partner reporting its target group as people from a wide age range.

In such a scenario, considering only the differences between age groups, the final design should follow a *Section-based* implementation. However, both *Stack-* and *Section-based* visualizations were shown to be suitable.

9.2 Design Process

Combining Quantitative Scores and Qualitative Feedback

In our studies, we wanted to perform a comparative evaluation but still consider the user's experience at the same time. That is why we selected a combination of a task-based method and structured Likert-scale questions, which could work even in the real museum setting and had been used before (e.g., Jimenez and Lyons, 2011). This allowed us to adequately observe when the performance of the users differed from their perceived performance. With a mixed-method approach, we were able to search for statistical effects between the designs. Also, asking participants about the motivation for their ratings provided us with additional qualitative information, which could be combined with the ratings. Quantitative data was also used to support the interpretation of qualitative data (Creswell and Creswell, 2018). Therefore, in future comparative studies, we will once again prefer such a mixed-method approach whenever feasible.

Choosing Participants with Different Profiles

Correlation tests in Iteration 2 revealed that participants who reported having more experience with data visualization consistently rated their experience lower than those with less data visualization experience. Therefore, more experienced participants might be more analytical than less experienced users.

Regarding the age of our participants, we were unable to determine a correlation between smartphone usage and age. However, our youngest age group (children & adolescents) consistently rated their experience higher than the older participants. The younger ones are surrounded by technology (Burns and Gottschalk, 2019) and use it frequently (Bitkom Research, 2019). Hence, they might have shown a higher motivation to use their smartphone within the museum and a different perspective when rating the designs.

Visually impaired people are an underrepresented target group in visualization research (Grinstein, 2016). Although accessibility was not in the focus of our study, we have provided each element with the required ARIA[1] labels enabling users to read all visualization elements via screen reader. We observed a blind person using the *Section-based* visualization (final version). Accessing an exhibit in the middle of the timeline was a main issue, as users had to go through all previous exhibits in the timeline to reach the desired item every time the screen was reloaded. To solve this problem, we had to add anchor points to jump to exhibits directly.

As casual users differ in visualization literacy (cf. Pousman et al., 2007), motivations in using technology, and limitations, there is a need for future studies to select participants with different profiles, especially when targeting casual users.

Weighing up Lab Against Museum Settings

In Iteration 2, we tested our location-aware visualization in two different settings. The lab provided a controlled setting aiming at high internal validity. Besides, we wanted to address the lack of knowledge about the context of usage (Blumenstein et al., 2016) through additional testing in the museum. In our study, the two questions focusing on the location-aware aspect (noticing the closest object & suitability as a guide) were rated significantly higher by the museum group. Which might indicate a clear benefit in using the real exhibition setting. However, the museum group was the same as the youngest age group. Therefore, we cannot differentiate between the effects of age group and test setting. Performing a comparative study in a running exhibition environment meant a lot of effort. That is why we used a school class. On the other hand, in such classes, the population is far too homogeneous, with participants presenting similar profiles.

For future studies, we plan to perform comparative evaluations in the controlled lab setting, and only observations and functional tests in the museum.

9.3 Summary

Following the design study approach (Sedlmair et al., 2012), we first characterized the problem (Chapter 6.3). We then developed three basic visualization concepts and performed a comparative evaluation with clickable mockups in a lab setting. We determined that the linear *Timeline* approach was the most suitable visualization for a location-aware application to present historical data in a museum (Chapter 7). As a second step, we developed functional prototypes for three timeline approaches and performed an additional comparative evaluation in a lab and a museum setting (Chapter 8). Results indicated that the *Section-based* approach was the most suitable for middle- & old-aged visitors. As we observed the presence of mainly older visitors in the museum, we decided to implement this approach into the companion app *The Emperor's New Saint* (see Chapter 5.6.2).

With the presented first design study, we addressed two gaps identified in Chapter 4.3:

[1] ARIA stands for Accessible Rich Internet Applications (Diggs et al., 2017).

Missing Mobile Visualization for Museums. In this design study, participants from diverse knowledge backgrounds tested and compared visualization techniques for presenting historical data in a time-oriented way on smartphones. Based on the results, we integrated the most suitable visualization technique into a location-aware application that reacts to the exhibits next to the visitor via Bluetooth beacons. This mobile visualization guided the visitors through the exhibition and thus provided additional information at the dedicated locations.

Full Spectrum of Representation Techniques Is Not Used. During the two iterations, we tested different representation techniques. Within the first Iteration, *Timeline* can be categorized as a diagram, *Bookshelf* as a graph (plot), and *Time-flower* as another chart. When we focused on the linear timeline design in Iteration 2, we developed graphs (plot) further through the *Section-based* and *All-in-one* designs and a diagram with the *Stack-based* visualization.

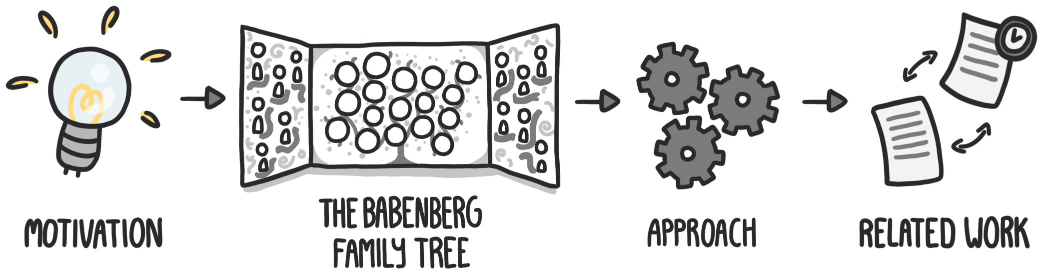
Next, we present the second design study (Part III) describing the interactive exhibit *Babenberg family tree* - a reproduction of the original painting as an embedded multi-device visualization. In Part IV, we apply our design studies to our Design Space and discuss the descriptive, evaluative, and generative power (Beaudouin-Lafon, 2004) of our Design Space in relation to the first (Part II) and second design studies (Part III).

Part III

Design Study 2: Babenberg GenVis – Interactive, Multi-Device Visualization of a Historical Genealogy Painting

CHAPTER 10

Motivation, Background, & Related Work



This chapter starts with the general motivation for the second design study about extending a genealogy painting with multi-device visualization (Chapter 10.1). We describe the original painting (Chapter 10.2) and our approach (Chapter 10.3) and continue presenting related work according to genealogical and time-line visualization, InfoVis in museums, and multi-device visualization (Chapter 10.4).

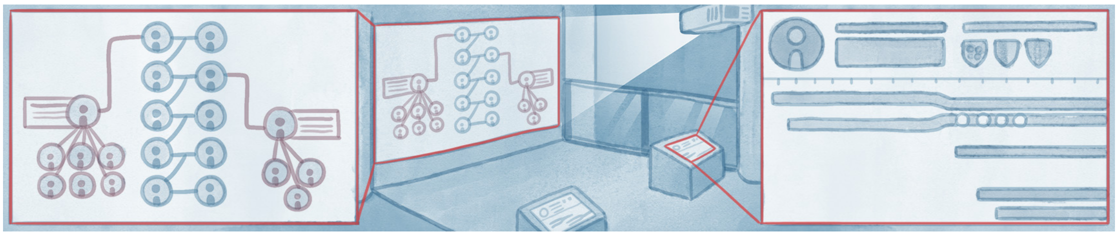


Figure 10.1: Overview of Babenberg GenVis: collaborative, interactive visualization of a historical genealogy tree that spans two multi-touch displays and a wall-projected display. In the center, the layout of the exhibit space is shown. Two touch displays are positioned in front of a print, which is augmented through a projection. The print (left) presents the main lineage of the Babenberg family, starting with Leopold III. Through augmentation (highlighted in red), the printing is extended with additional information of persons selected on the touch displays. With the touch displays (right), visitors can explore the genealogy of the Babenberg family with a time-oriented visualization.

10.1 Motivation

For centuries, museums have followed the traditional model of displaying exhibits with additional information panels next to them. When novel devices such as multi-touch tables emerged, they quickly found their way into exhibitions. Today, many museums feature some kind of interactive elements, such as multi-touch tables, hands-on interactive installations, or digital augmentations of exhibits (Chu et al., 2015; Clarke and Hornecker, 2013; Schmitt et al., 2010; Skowronski et al., 2018). Their main advantages are that they make content more attractive to younger generations of visitors, offer knowledge transfer methods beyond traditional text reading, and contribute to a more engaging museum experience (Skowronski et al., 2018).

Nevertheless, when trying to incorporate such interactive elements into an exhibition, there are several challenges: Exhibits (e.g., antique objects) might require special handling or environmental conditions, which reduces the possibilities of digitally augmenting them. Thus, designing interactive content requires intensive collaboration with curators and/or facility managers, as both architectural and conservational demands might require compromises due to restrictions in infrastructure (e.g., access to electricity or Wi-Fi), space, or design (Hornecker and Ciolfi, 2019). Also, museum visitors differ in age, interests, experience with technology, and social and cultural background (Hinrichs et al., 2013; Screven, 1999). Previously, visualization research has mainly focused on expert users (Pousman et al., 2007). Museum visitors, however, are casual users (Block et al., 2012), who use visualizations for extrinsic and entertainment goals as well as learning or utility purposes (Sprague and Tory, 2012).

While there is much research on human-computer interaction in museums (Hornecker and Ciolfi, 2019), the use of interactive data visualization in museums is relatively uncommon (Isenberg et al., 2013; Li et al., 2012). However, it could allow curators to visualize, e.g., known data which otherwise could not be shown, or more recent data which were not known when the object in question was made. Although aimed at casual users, multi-device scenarios lack in-the-wild research, especially those with InfoVis for museums (Brudy et al., 2019; Isenberg et al., 2010). In Chapter 4.3, we additionally found the following gaps that are addressed with this design study: *Multi-device Ecologies Integrating Visualization Are Rare*, *Physical Artifacts Are Not Often Linked to Visualization*, and the *Full Spectrum of Representation Techniques Is Not Used*. To deal with these issues, we developed a suitable visualization concept for a multi-device application extending a historical genealogy painting for a museum exhibition - the *Babenberg GenVis* (see Figure 10.1).

The study consists of three iterations: First, we developed a functional prototype and evaluated it with a task-based usability test in a lab setting. In the second iteration, we implemented the entire installation in a museum and used a mixed-method approach (observation combined with interviews) for evaluation in the wild. For our final iteration, we built upon the results, improved the prototype, and finally evaluated again with observation, log data, and reflection interviews.

The main contributions of this design study are:

1. a problem characterization with data and task abstractions (Chapter 10.2 and Chapter 11.2),
2. the iterative design of a multi-device visualization concept, its prototypical implementation using web technologies, and its application in a real museum setting (Chapter 12, Chapter 13, and Chapter 14),
3. the results of three evaluation rounds (Chapter 12, Chapter 13, and Chapter 14), and
4. a set of general lessons learned and implications that are based on insights gained during the process (Chapter 15).

10.2 The Babenberg Family Tree

The original painting of the family tree (1489-1492 by Hans Part) is a triptych whose middle shows a family tree with 27 male family members, starting with Leopold I and ending with Friedrich II (see Figure 10.2). The connections between the family members are visualized through leaves and branches. However, since the branches are interwoven, it is not possible to see the relations between them (e.g., to see whether someone is a son or a brother).

On the left and right wing, 46 female family members are painted side by side without any visible connection to the men. The painting is based on the genealogy research of Ladislaus Sunthaym and shows 73 people in total.

Figure 10.2: The original painting of the genealogy of the Babenberg family. Photographed by M. Seidl in 2017.

10.3 Approach

We followed a process of iterative design and evaluation (Nielsen, 1993) to address a particular domain problem by involving collaborators and users from the domain as other design studies (Sedlmair et al., 2012). Figure 10.3 illustrates the timeline of Babenberg Genvis's development and the iterative evaluation phases.

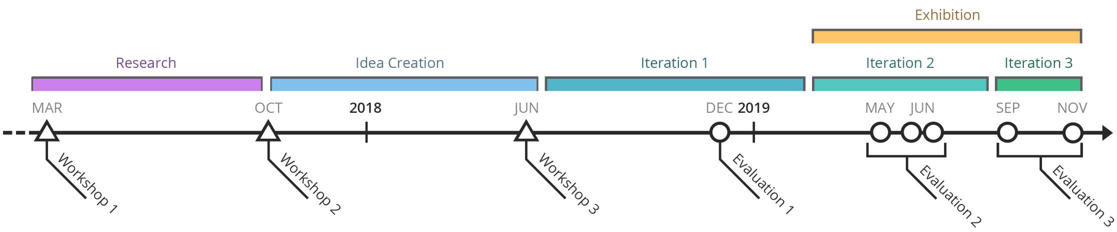


Figure 10.3: Timeline of Babenberg Genvis's development and evaluation phases from March 2017 to November 2019. Illustration by M. Boucher.

For this design study, we followed the approach described in Chapter 5.2. We started the research phase in March 2017 and the idea creation phase in October and carried out three workshops until June 2018. We first determined the actual state of demand in the sector and ended up with concrete ideas based on personas and scenarios.

To refine our concept ideas, we created paper prototypes, which allowed us to define the entire setup and address conceptual issues at an early stage (Dumas and Fox, 2009). Afterward, we developed a functional prototype, which was evaluated with a tasked-based usability test in a lab setting in December 2018 (Evaluation 1). The exhibition started in March 2019, which was the deadline for the implementation of the entire installation prototype in the museum. To validate our concept, we performed first evaluations in the wild in May and June 2019 with observations and interviews (Evaluation 2). Based on the results, we made adaptions to the design and performed an additional evaluation combining observations and log-data analysis (Evaluation 3). To reflect the installation in the museum, we performed reflection interviews at the end of the exhibition (November 2019) with two of the curators and two exhibition guides.

The entire MEETeUX project team consisted of 12 team members, including computer scientists, experts in HCI, and InfoVis and one computer scientist with knowledge of using digital artifacts to enhance museum visits. However, only four people were part of the core team in the design process of Babenberg GenVis: two computer scientists (including the author), one graphic designer, and one of the five exhibition curators (background in history and as cultural mediator) as domain experts. The core team got constant feedback from the project team. Also, feedback from the five exhibition curators was integrated into the design loop.

Next, we outline related work for the addressed areas of interest.

10.4 Related Work

This section covers related work about the use of genealogical and timeline visualization, InfoVis in museums, and multi-device visualization.

Genealogical and Timeline Visualization

Using time-based approaches (Aigner et al., 2011) to visualize data dates back to the 18th century. Already in 1765, John Priestley used timelines to visualize the lifespans of famous people for his *Chart of Biography* (Priesley, 1765). Khulusi et al. (2019) created an interactive version of Priestley's chart with data of musicians. Such timelines were also used to visualize personal histories based on medical records (Plaisant et al., 1996) and interactions of movie characters (Munroe, 2009). More recent research explores timelines in combination with storytelling (Brehmer et al., 2017).

On the other hand, visualization of genealogy (the study of families) is often used for research purposes, either by hobbyists researching their kinship or by professional genealogists (Mills, 2003). When we consider only parent-child relationships in genealogy, we talk about hierarchical data, which are often visualized as tree visualizations (Schulz, 2011). Integrating more complex relationships (marriages, divorces, and remarriages) by combining family trees builds a rather complex network (Kim et al., 2010).

Software is available to visualize conventional family trees (Genelines, 2020; GenoPro, 2019). However, it is in the interest of the research community to visualize more complex networks (Draper and Riesenfeld, 2008; McGuffin and Balakrishnan, 2005). TimeNets (Kim et al., 2010) presents an approach with improvements to traditional genealogy representations. It visualizes family kinship combined with timelines showing individual life events and thus expresses temporal attributes (e.g., birth, death, marriage dates) (Kim et al., 2010). Nevertheless, TimeNets has never been tested with casual users before.

InfoVis in Museums

Research by Börner et al. (2016) revealed a rather low level of data visualization literacy among science museum visitors. However, participants showed interest in the presented visualization. In 2012, the use of casual InfoVis in museums was described as "a rudiment of utopia in the cultural organization" (Li et al., 2012). Yet, existing applications prove that data visualization fits into the museum space very well. The Deep Tree exhibit (Block et al., 2012; Horn et al., 2016) is an example of visualizing hierarchical data as a tree of life visualization. Other examples of visualization in museums include tools that allow visitors to explore scientific data (Ma et al., 2012, 2015) or a visualization of the area around Hamburg through space and time from the Middle Ages to the present (ART + COM Studios, 2012). As in the latter example, spatial data are often visualized as maps (Rönneberg et al., 2014; Von Zadow et al., 2011) or in combination with the temporal dimension (Hsueh et al., 2016; Ress et al., 2018; Roberts et al., 2014). For most of the mentioned installations, the target device was a horizontal touch display (tabletop).

Roberts et al. (2018) assessed different digital labels on large touch displays mounted in front of the objects. The design focusing on visualizing a timeline was shown to be more effective in making visitors stop and interact than the original approach with text and images and the one with big question (not significant). These results underline the potential of using a time-oriented approach as a base for our implementation.

Multi-Device Ecologies

The implementation of MDEs with visualization is rare. Hinrichs et al. (2008) discuss the potential and challenges of such installations. Focusing on the temporal and contextual dimensions, visitors could explore the work of an artist through two linked visualizations. An additional, large wall projection made the actions performed on the touch display visible across the exhibition floor. Such setups make collaborative and social data exploration possible (Isenberg et al., 2010).

MDEs in museums are often combined with mobile devices. They are studied in the context of games (Jimenez and Lyons, 2011; Van Dijk et al., 2012) and as a combination of guides and games (Dini et al., 2007; Ghiani et al., 2009; Hope et al., 2009). Langner et al. (2018) also propose concepts for working with coordinated and multiple views across multiple mobile devices (smartphones and tablets). There is an increasing interest to combine these mobile devices for data exploration (Marquardt et al., 2018; Perelman et al., 2019; Zagermann et al., 2020).

A study by Brudy et al. (2019), including 510 research papers, shows the great interest in multi-/cross-device ecologies. Several researchers focus on technical aspects and propose frameworks (Frosini and Paternò, 2014) or toolkits (Hartmann et al., 2013; Marquardt et al., 2011) for setting up such settings. Application domains of MDEs range from crisis management (Prouzeau et al., 2018) to meetings (Horak et al., 2016) and public spaces (Bazo and Echtler, 2014; Winkler et al., 2014). Also, a focus on techniques to make multi-device data exploration happen can be recognized (Alsaiari et al., 2019; Badam et al., 2015; Gjerlufsen et al., 2011; Marquardt et al., 2018; Monroe and Dugan, 2015). Butscher et al. (2018), for example, created an immersive 3D parallel coordinates visualization of multidimensional data using Virtual Reality headset and a horizontal touch table. Homaeian et al. (2018) researched a combination of tablet and horizontal touch table to gain insights in the interaction techniques of direct touch and tablet-tilt on mixed-focus collaboration. Horak et al. (2019) present a more generalized view on interactive visualizations and MDEs.

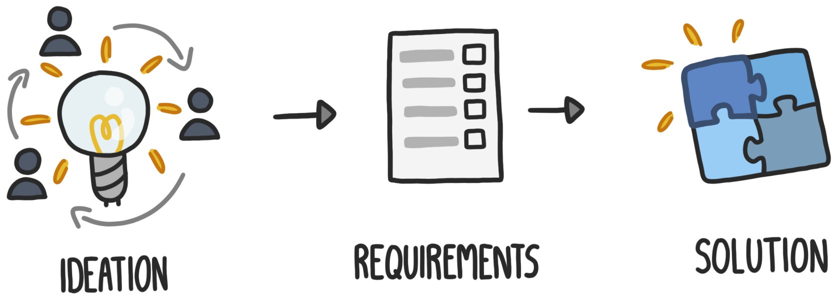
10.5 Summary

Current research in the field of multi-device visualization is mainly focused on technical aspects and working environments with expert users. As opposed to this, we focus on casual users (Pousman et al., 2007) in a "free-choice learning" environment (Falk et al., 2006), which means that visitors can choose what they are interested in. Our approach is to create a time-oriented concept to visualize genealogical data, building on TimeNets but ensuring it is understandable for museum visitors.

Next, we describe the ideation process, the preconditions and the final solution in detail (Chapter 11).

CHAPTER 11

Development of the Solution



In this chapter, we focus on the development of our solution. We describe the ideation process of developing the basic idea (Chapter 11.1), the preconditions (Chapter 11.2), and the final solution - Babenberg GenVis (Chapter 11.3).

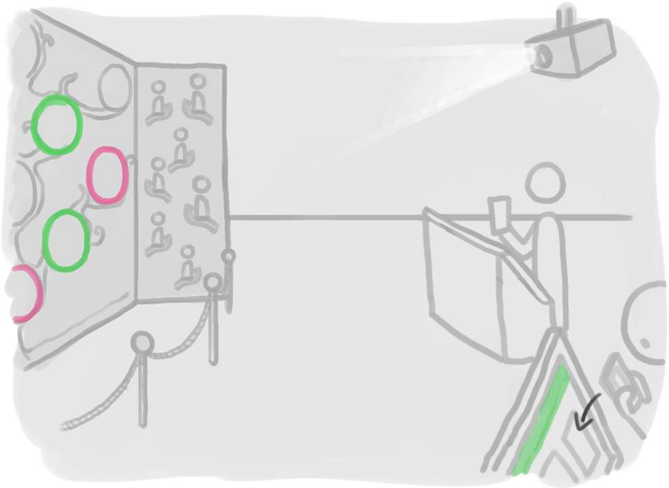


Figure 11.1: First scribble of a multi-device setting showing the projection on the original painting of the genealogy of the Babenberg family in combination with touch displays. Illustration by M. Boucher.

11.1 Ideation

For this design study, we were in line with the approach of the MEETeUX project (see Chapter 5.2). We conducted three workshop in the research and idea creation phase. The results of the first workshop were personas and scenarios (see Appendix A). Within the second workshop, we created ideas based on these personas and scenarios that were afterward reduced to the top five ideas. Based on the top five ideas, we worked in the third workshop on concrete ideas in relation to the exhibition context[1]. One suggestion was to extend the painting of the Babenberg family tree with a projection and touch displays (see Figure 11.1). With this idea in mind, we started to work with the five exhibition curators to gain a more in-depth knowledge of the exhibition's conditions and historical background information of the genealogy painting. We also specified the requirements and necessary data.

11.2 Problem Analysis

Based on the results of a workshop with the exhibition curators, we defined data and requirements for the visualization.

11.2.1 Data Overview

Genealogical data are, on the one hand, hierarchical when it comes to parent-child relationships (*consanguine* relations). On the other hand, those data are non-hierarchical

[1]For more details about the workshops see Chapter 5.2.

when we consider relationships through marriages (*conjugal* relations) combining family trees. Thus, genealogical data form a network of relationships (Kim et al., 2010).

Our genealogical data contained 73 persons (27 men, 46 women), which are shown in the original painting. More recent research (Pohl and Vacha, 1995) reveals that the Babenberg genealogy consists of 81 persons (29 men, 52 women). For each family member, the data contained the name, additional title, gender, and dates of birth, death, marriages, and divorces. Since some historical dates are not known precisely, we also had the information whether the years for birth, death, marriage, and divorces are exact or estimated. A description, the image from the original painting, information about the coats of arms of the respective person, and the persons' individual relationships to their spouses and children were also available. Additionally, maps exist showing the Babenberg dominion in 1156 and 1246, which were the two main points in the history of the dominion.

In summary, our goal was to develop a visualization concept for a complex data set combining genealogical with time-oriented data containing instants (e.g., dates of birth or marriage) and intervals (Aigner et al., 2011) (e.g., duration between birth and death date) as well as spatial and textual data.

11.2.2 Requirements

Based on the available data and the findings during our ideation process, we defined the following requirements for Babenberg GenVis:

RQ1 Visitors should gain deeper insights into Babenberg's genealogy. They should have the possibility to explore the genealogy on the touch displays through a time-based approach.

RQ2 As the original painting does not show the relations between men and women, these data should be provided through the installation.

RQ3 The projection on the printed canvas should be a form of projected augmented reality (Hornecker and Ciolfi, 2019). It should avoid the isolation of visitors and the need for mobile equipment (as opposed to using see-through augmented reality) (Ridel et al., 2014).

RQ4 The projection should become richer when people interact with both touch displays (scalable interaction (Snibbe and Raffle, 2009)).

RQ5 Based on advice by Block et al. (2015), our installation should target mainly couples and single users.

11.3 Solution

During the early discussions, together with the curators, we decided that the installation would be placed on the ground floor. Since it would have been impossible to move the wooden 8x4 meters painting from the upper floor to the place of the installation, we could not augment the original exhibit. The surface of the painting also proved to be too reflecting, and it was too detailed to display much information through a projection. Additionally, the space available for the installation was planned to be only 3.60x3 meters. Thus, we decided to use a smaller reproduction of the genealogy instead.

Projection

By only showing the direct bloodline of Leopold III, which ends with the last rightful heir of the Babenberg family, we were able to reduce the number of persons to be printed on the canvas to five men and five women. We presented the men together with their wives as a classic family tree, using excerpts of the original painting and adding the relation to each other through vines (see Figure 10.1 left, middle blue part). We placed the print in the middle of a white canvas so the right and left sides would provide space for the projection extensions (RQ3, RQ4). The contents of this space were controlled through the two touch displays. When selecting a person on one touch display, they were projected onto the corresponding side of the canvas and connected to the nearest relative in the central bloodline. Additional information, such as the relationship to this relative and the map showing their dominion, was displayed as well.

Touch Displays

We decided to use two touch displays in suitable sizes for two visitors standing side by side in front of them (RQ5). They also provided different options for group interaction (Isenberg et al., 2010). With two displays, we had separate individual spaces for exploration, and visitors interacting with different objects would not disturb each other.

The overall aim of the touch displays was to show the genealogy in a time-oriented way, starting with Leopold III (RQ1, RQ2). We researched time-oriented visualization techniques in the work by Aigner et al. (2011). In earlier research, timelines were used to present genealogical data (e.g., Kim et al., 2010; Plaisant et al., 1996; Rost, 2014), which suited our idea for Babenberg GenVis. We decided to base our visualization on the TimeNets solution (Kim et al., 2010).

The screen was divided into an information (upper area) and a visualization part (see Figure 10.1 right). In the visualization part, a person's life trajectory could be selected by tapping it. The information part showed details of the selected person: the image from the original painting and textual information such as name, additional title, and description, and the corresponding coats of arms. Each person who could be selected on the touch display by tapping the life trajectory had to have a direct connection to one of the printed persons - either they were the person themselves, or they were a direct descendant of one of the persons.

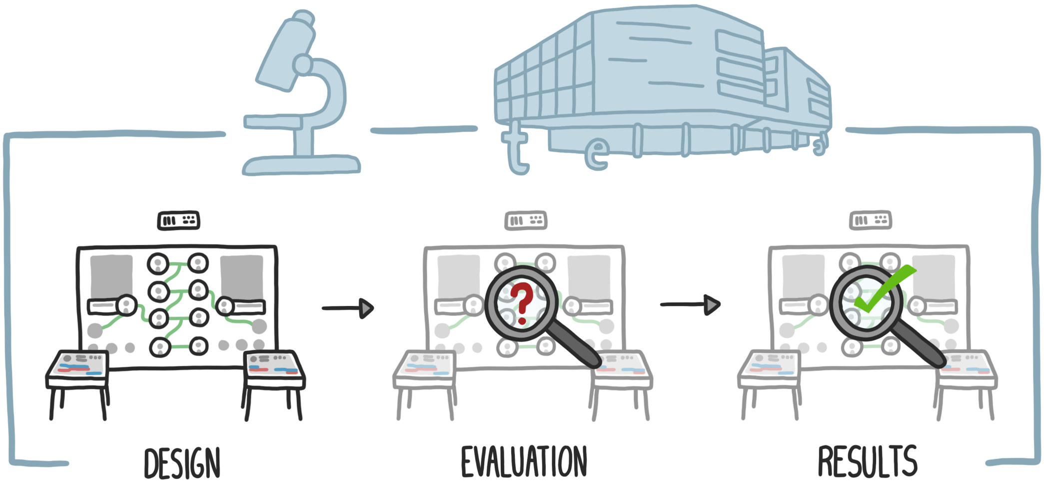
11.4 Summary

Based on the decision to reduce the people on the printed canvas to 5 men and 5 women, we could integrate additional 30 (16m, 24f) people in the timeline visualization. Through visualizing spouses and children of selected persons on the projection, visitors could browse additional 20 (14m, 6f) family members. 14 of them were mainly husbands of daughters who were not present in the original painting. In total, 60 members of the Babenberg family starting with Leopold III were shown in our multi-device visualization compared to 46 family members who are present in the painting.

The implementation of Babenberg GenVis was a 3-staged iterative process. Each stage was completed with an evaluation. In the following chapters, we describe the three iterations and the corresponding evaluations from with functional prototyping (Chapter 12) over going into the museum (Chapter 13) to the third and final iteration (Chapter 14).

CHAPTER 12

Iteration 1: Functional Prototypes



This chapters outlines the first iteration of the 3-staged process to develop Babenberg Genvis in detail. We first describe the visualization design of the projection and touch displays. Then, we address the evaluation of the functional prototype (Chapter 12.1) and its results (Chapter 12.2). All materials used, such as the interview guideline and tasks, are included in Appendix E.

As a first step after creating paper prototypes, we developed functional prototypes for both the touch displays and the projection to get a first impression of our solution. The prototype was developed with web technologies using HTML, CSS, and JavaScript in combination with the library D3 (Bostock et al., 2011). We stored the data locally in JSON files to reduce latency and improve responsiveness.

Projection

The projection (see Figure 12.1) was divided into three columns (left-side projection (1), printed middle (2), and right-side projection (3)) and three rows (map, general information about the selected person, and their relatives). In the course of the development, the printed part of the canvas was included in the projection as a background. This way, the connections to the relatives could be positioned approximately and later refined in the museum setting using the actual resolution of the projector.

Figure 12.1: Functional prototype of the projection (left side (1) and right side (3)) with the printing (2) integrated as a background image (highlighted with a blue shadow).

The historical person selected on a touch display could have the following connections to the printed lineage: 1) same person & same side, 2) same person & different side, 3) direct descendant & same side, and 4) direct descendant & different side. The vines themselves were assembled dynamically from different corner images as well as vertical and horizontal line elements. The general information about the selected person was displayed in the middle of the left and right columns. In addition to the circular image and the name, which were also displayed on the touch screens, we showed the birth and death dates as well as the information whether this date was estimated using the character ∼ before and a question mark after the date (see Figure 12.1).

For each of the historical persons in the timeline visualization on the touch displays, we showed spouses and children on the projection. This way, it was possible to display 20 additional people not included in the timeline. The data constellation revealed eight different display options depending on the number of spouses and children a person had. It posed another challenge of limited space (e.g., when we had to show one spouse with twelve children). We arranged the children in four columns and rows of three and used this as a base for the other options. Also, we prepared several options to connect spouses and children as traditional tree visualization: thin vines, vines behind images and text, and semi-transparent vines. As the viewing distance to the projection played a essential role, connections and final minimal size of elements could only be decided in the museum setting.

At the top, we presented maps showing the Babenberg dominion in 1156 or 1246. The decision was based on the death date of the selected person (before 1246 or after).

Touch Displays

The screen of the touch-display implementation was divided into two rows for detailed information and timeline visualization (see Figure 12.2). The information row was split into three columns for 1) the circular image, 2) name, title, and description, and 3) information on the coat of arms of the currently selected person.

As the existing TimeNets (Kim et al., 2010) visualization had been realized in 2009 with Adobe Flash, which is no longer up to date, we had to develop the visualization anew. In contrast to Kim et al. (2010), we decided on touch displays, which required adaptions of the height of the life trajectories. Since this challenge concerned only the height of the trajectories in our visualization (the width was always large enough), we decided to set the height to 40 pixels (stroke width) with an additional space between the trajectories of at least 20 pixels to make it possible for visitors to touch the trajectories precisely. This decision was based on the average humans finger size (Anthony T, 2012; Dandekar et al., 2003).

For implementing the interactive time-oriented visualization, we mainly used the line function of D3 (Bostock et al., 2011). In general, the drawn lines were defined through the birth and death dates. The dates were mapped to the x axis of our visualization, while the y axis was used to visualize relationships. Each line was assigned a start y position (calculated by multiplying the stroke width by 2.2) so that they were displayed below each other. As Kim et al. (2010), we used vertical proximity to visualize marriages and divorces. The x axis point at which the lines were the closest marked the date of a marriage or divorce. We differentiated between husbands (adding stroke width

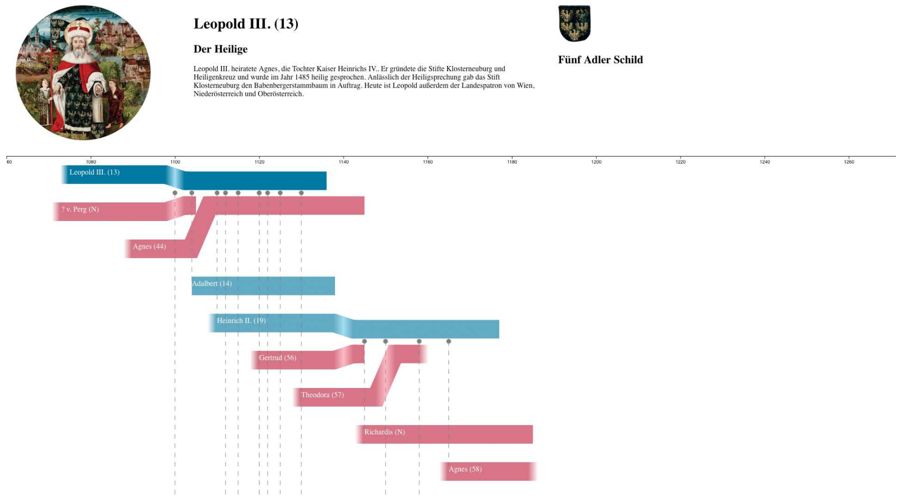


Figure 12.2: Functional prototype of touch displays showing the detailed information part (top) and the timeline visualization (bottom). The currently selected person is Leopold III.

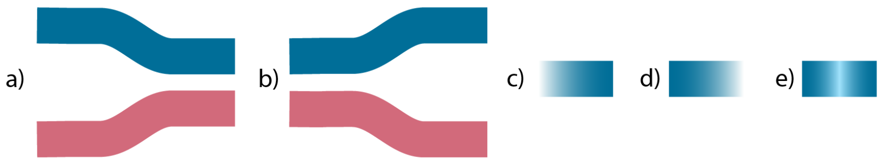


Figure 12.3: Timeline visualization shows the life trajectories of a man (blue) and a woman (red). For visualizing the date of a marriage (a) and divorces (b), we used vertical proximity. The proximity of the two nearby paths was reduced for marriages and increased for divorce. Estimated values are shown with a gradient. We use a gradient from white for estimated birth dates (c), to white for estimated death dates (d), and to white and back to the color for estimated dates of marriages and divorces (e).

divided by 3 pixels to the start y position) and wives (subtracting stroke width divided by 3 pixels from the start y position) when drawing the lines (see Figure 12.3 (a) and (b)). To visualize estimated values, we used a gradient from (birth) or to (death) white (see Figure 12.3 (c) and (d)). The x axis point with the fully saturated color marked the corresponding year. The estimated marriage or divorce date was shown through a gradient to white and back to the color (see Figure 12.3 (e)).

In addition to life trajectories, we drew droplines to connect children and parents. Droplines were used in Genelines (2020) and discussed by Kim et al. (2010). A small dot between the trajectories of the parents marks the birth date of a child (see Figure 12.2). To connect these dots (i.e., the children) with their respective lines, we used dashed lines. In contrast to Kim et al. (2010), we decided to color these droplines in light grey to reduce possible distraction for the user. The lines were placed in front of life trajectories. We use color-coding to differentiate between men (blue) and women (red). When selecting a person, the color becomes more saturated.

12.1 Evaluation

While early evaluations are necessary, initial prototypes of installations are often not ready for a “naturalistic user study in the wild” (Hornecker and Nicol, 2012). Therefore, we decided to first test a functional prototype of the touch display implementation only, since testing the projection itself and the combination with the touch displays required the actual museum setting, which was not available at this stage.

To test the timeline visualization, we conducted a task-based usability evaluation with the functional prototype in a lab setting (Lazar, 2017). The testing device was one of the dedicated 27-inch touch displays (Iiyama Pro ProLite TF2738MSC). To see whether potential visitors understood the main issue (the life trajectories showing relationships) and whether they were able to read the visualization (birth, marriage, death), they had to describe what they saw, select certain people, and answer questions such as when Leopold III was born.

After each task, participants answered a question about the easiness of the task. When all tasks were completed, participants filled out an additional questionnaire with three questions about 1) difficulty of the visualization, 2) understandability of the precise dates, and 3) understandability of the estimated dates. For both the post-task question and the post-study questionnaire, participants could answer on a seven-point Likert scale ranging from negative to positive scores.

Subjects

Six participants (two female and four male) aged 25 to 40 years ($M = 30$, $SD = 5.6$) participated in the assessment. Participants were asked to rate their data visualization ($M = 4.8$, $SD = 1$) and touch display experience ($M = 6.2$, $SD = 1.2$) on a seven-point Likert scale (low to high). None of them reported having visual impairments.

12.2 Results

Figure 12.4 and Table 12.1 summarize the results for the post-task and post-study questionnaires. When performing the assigned tasks, participants reached the correct results in 63.7% ($SD = 10.6$) of the cases. The task fulfillment of reading data points showed that all participants read the death date (precise) correctly. The birth date, which was an estimated date, was read correctly by one participant (used the term “around”). The others did not recognize this date as an estimation. For the marriage date, one participant had trouble finding it; another one could read the date correctly; the rest was close to but not entirely correct. Even though user performance was low, the participants' user experience was rated positively on average. The same pattern became visible for the task of selecting a specific daughter. Two out of six subjects selected her correctly. User performance when selecting the wife of a person was excellent (all participants selected the correct person). However, the user experience rating revealed that one person had not been sure about their selection.

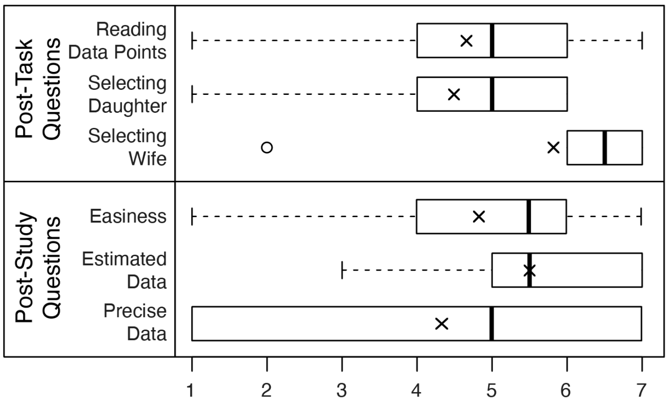


Figure 12.4: Evaluation 1. Scores from post-task and post-study questionnaires. The x axis maps the scale from 1 (negative) to 7 (positive).

Table 12.1: Evaluation 1. Means and standard deviations of scores from post-task and post-study questionnaires.

Post-Task Questions			**Post-Study Questions**		
Data Points	**Daughter**	**Wife**	**Easiness**	**Precise**	**Estimated**
4.7 (SD: 2.1)	4.5 (SD: 1.9)	5.8 (SD: 1.9)	4.8 (SD: 1.9)	5.5 (SD: 1.5)	4.3 (SD: 2.8)

Overall, the post-study questionnaire showed a positive rating. The understandability of estimated dates had the most divergent scores, which was also a point for discussion in the open questions. One participant wished to have the dates written in the textual description shown in the projection as well. In general, all participants understood the idea behind the visualization and color-coding. However, the evaluation revealed problems in reading the dates for birth, marriage, or death. The participants had difficulties with the gradient line ends - they were not sure whether the beginning, middle, or end of the gradient marked the estimated date. The test also revealed problems in noticing marriages as well as finding someone's child.

12.3 Summary

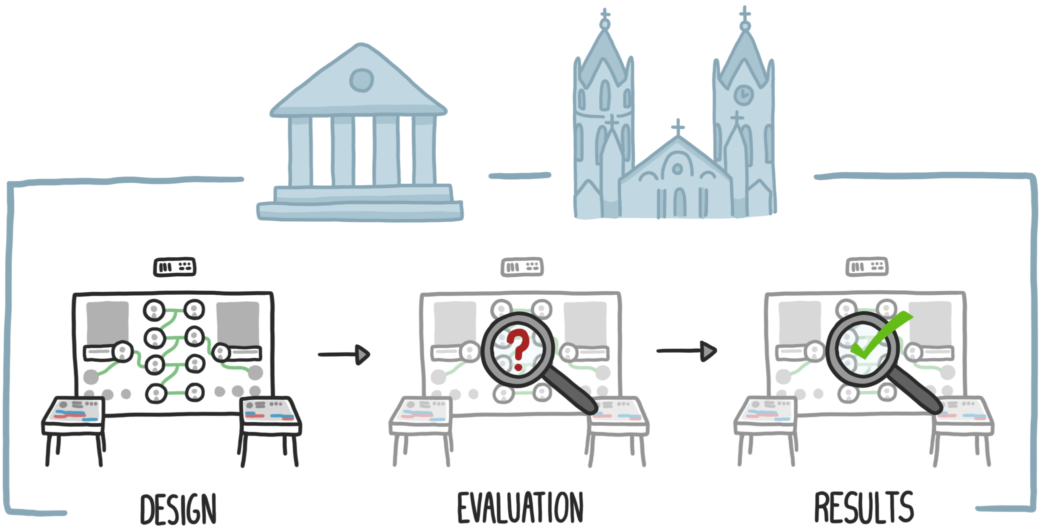
This chapter explained the first iteration of the development of Babenberg Genvis. We developed functional prototypes for projection and touch displays and performed an evaluation to test the visualization on the touch displays in a lab setting. The results indicate difficulties in reading the time-oriented visualization (parent-child connection or reading the dates for birth, marriage, or death). Therefore, we decided on the following changes:

- Use icons to help in understanding birth, death, and marriage dates and specify the position of that date.
- Connect children and parents more visibly. Make the dots touchable and/or scroll directly to the child.
- Better divide the x axis and life trajectories in terms of the visual display. Add more ticks to make it more readable.

Next, we describe the second iteration with the aim of implementing the installation into the museum (Chapter 13). We demonstrate how we addressed the mentioned changes and explain the conducted qualitative and quantitative evaluations and its results.

CHAPTER 13

Iteration 2: Into the Museum



This chapters describes the second iteration of the 3-staged process to develop Babenberg Genvis in detail. We first explain the changes made based on the results of the first iteration. Then, we address the evaluations performed in the museum with this version (Chapter 13.1) and its results (Chapter 13.2). All materials used, such as the interview guideline and tasks, are included in Appendix F.

When setting up the installation in the museum, we worked with the dedicated hardware setup for the first time. We used the Christie LHD720i projector with a Christie Zoom Lens (1.2-1.8:1) and two Iiyama Pro ProLite TF2738MSC (27-inch) touch displays. Both (projection and touch displays) provided full HD resolution. The three devices were combined with one PC (Intel NUC 7I5) each. The touch displays and their computers were built into a housing made explicitly by a carpenter. Based on Schultz et al. (1998), we decided on a viewing angle of 45 degrees.

The projector was mounted 8.70 meters away from the projection wall, at the height of 3 meters. Since the visitors should not stand in the projection, the distance between the touch displays (visitors) and the projection had to be 4 meters. With this setting, we reached the intended projection size (see Figure 13.1).

Figure 13.1: Babenberg GenVis in the museum setting. Photographed by K. Blumenstein, 2019.

To make the installation fully functional, we set up communication between the touch displays and the projection. We established a connection through the WebSocket protocol. The projection acts as a server, and the touch displays connect to it as clients, identifying themselves as the left or right side. Each time a visitor selects a person on the touch displays, the person's identifier is sent to the projection, which displays the detailed information on the corresponding side. When starting the clients, the person Leopold III is selected and shown by default (see Figure 13.1). This way, both projection sides always show a person as initial content.

Projection

In order to efficiently use the projection space, we had to refine the starting positions of the vines for showing the connections between printed and selected persons. In the actual setup, we decided to change the dynamic positioning of the connector vines and re-draw them based on the distance to the starting positions. In addition, we finalized the size and placement of the selected person's relatives. To connect these relatives as a tree visualization, a specific size of the vines was needed to notice them even in 4 m distance. All three mentioned options (see Chapter 12) led to occlusion. Thus, we decided against a direct connection for the children and used proximity.

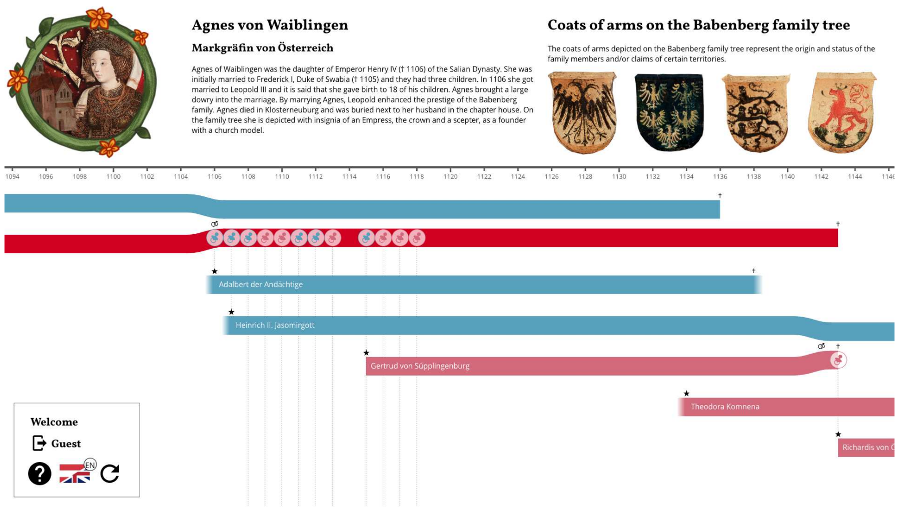


Figure 13.2: Improved version of the touch display implementation with fully functional visualization showing the application functionality on the bottom left.

Touch Displays

To position the dates more saliently and help with reading the visualized dates, we added well-known icons for birth ★, death †, and marriage ⚭.

Instead of small grey dots that marked a child, we implemented pacifier buttons colored in red (daughter) or blue (son) (see Figure 13.2). In order to make the buttons touchable, the x axis was extended to have tappable buttons. With a single tap, the corresponding child is highlighted and selected. A double-tap forces the visualization to scroll to the line of the respective child automatically.

The x axis was extended by a white background with a gradient, making the life trajectories disappear smoothly when scrolling up.

Additionally, the prototype was integrated into an application structure. We added a start and a help screen, multi-language support (German and English), as well as the possibilities to enter and leave the exploration at any time and to reset the visualization (see Figure 13.2).

13.1 Evaluation

To evaluate Babenberg GenVis in the wild, we used a mixed-method approach (Hornecker and Ciolfi, 2019), combining video observation with subsequent interviews in May 2019 (3.5 hours) and two additional video observations in June 2019 (2 hours each).

During the interviews, we asked questions focused on the understanding of the visualization and the connection between touch display and projection. Afterward, participants were asked to rate 1) difficulty of usage of visualization, 2) appeal of the touch displays' design, and 3) appeal of the projection's design. Each question required answers on a seven-point Likert scale varying from negative to positive scores. Finally, they rated the installation with the System Usability Scale (Brooke, 1996).

Subjects

In total, we observed 51 visitors (29, 14, eight) showing interest in Babenberg GenVis. We interviewed seven interacting visitors (two female and five male) aged from 30 to 73 years ($M = 55.4$, $SD = 16.1$). Three of them were asked to interact after they had inspected the installation without interacting. Interviewees were also asked to rate their data visualization experience ($M = 3.9$, $SD = 2.5$) on a seven-point Likert scale (low to high).

13.2 Results

Observations

In total, 32 visitors interacted with a dwelling time between 11 s and 383 s ($M = 115$ s, $SD = 114$ s). Six visitors started interacting after they had seen another visitor do so. We observed 16 single usages, six usages in pairs, and one family with four members. One person of the family started to use the second touch display after 13 seconds. The connection between the touch display and projection was noticed by only 14 of the interacting visitors.

Interviews

All interviewees (I) noticed the family tree on the touch displays. Furthermore, they directly named children (3x) and marriages (1x) when describing what they saw. Four visitors mentioned the history of the Babenberg and Leopold. I5 did not notice the interaction option to scroll, while I3 reported having noticed the scrolling option during usage. The projection was also described as a family tree - one could see the children, different generations, and how small the dukedom of Austria had been at that time.

The incentive to interact with the installation differed between participants: For I2, it was pretty looking, and she wanted to look at which information is conveyed. I3 was bored and visited the museum regularly, but had never interacted with Babenberg GenVis before. I4 wanted to try it and was interested in the family. I7 liked things to touch and additionally wanted to select persons on his own. The three visitors who were asked to interact by the test facilitator looked at the installation (mainly projection) for 0:25 (I1) and 1:34 (I5 and I6) min and then turned away. This was because I1 did not notice that it was interactive, and I5 and I6 completely missed the touch displays.

Figure 13.3 and Table 13.1 summarize the results of the post-study questionnaire. All questions were rated positively, which is also confirmed by the average SUS score (Brooke, 1996) of 79 ($SD = 9.9$). It is above average (68) and higher than approx. 83% of other systems in the SUS database (Sauro, 2018). Babenberg GenVis earned grade A-, meaning it is good and acceptable (Bangor, 2009).

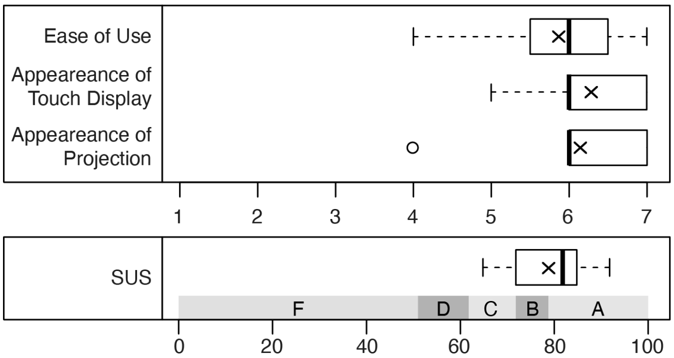


Figure 13.3: Evaluation 2. Scores from the post-study questionnaire.

Table 13.1: Evaluation 2. Means and standard deviations of the post-study questionnaire.

Ease of Use	Touch Display	Projection	SUS
5.9 (SD: 1.1)	6.3 (SD: 0.8)	6.1 (SD: 1.1)	79 (SD: 9.9)

13.3 Summary

In this chapter, we addressed the second iteration of the development of Babenberg GenVis. We refined our functional prototypes based on the results of Iteration 1 (Chapter 12), implemented the installation in the museum setting, and conducted observations and interviews to test in installation in the wild.

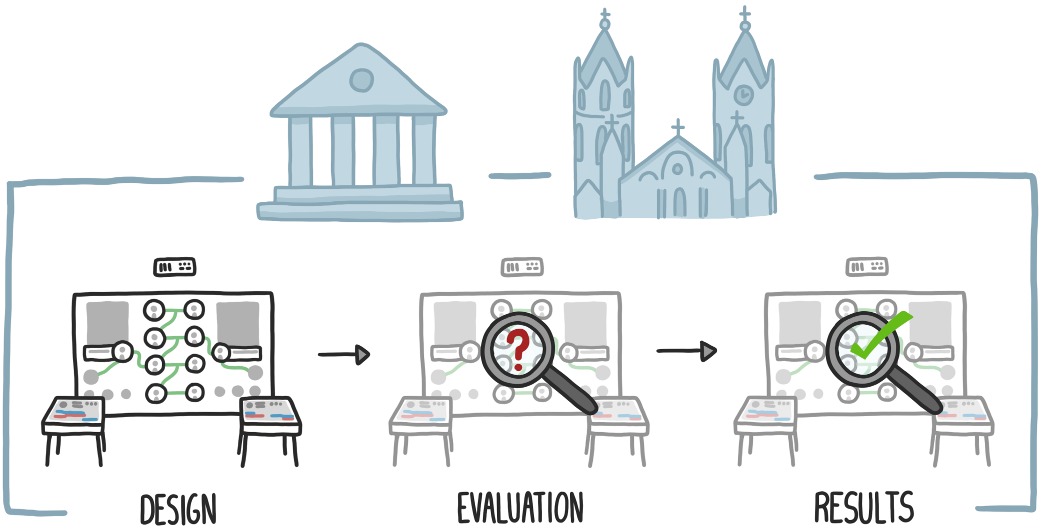
Overall, the visualization was perceived well. However, the results indicate a need for improvement in two points:

- Understanding the connection between the devices
- Convincing visitors to start interacting with Babenberg GenVis

In the next chapter, we implement changes to overcome these issues and present the final iteration (Chapter 14). To evaluate this changes, we performed an evaluation over 3 month with log data analysis, observations, and final reflection interview.

CHAPTER 14

Iteration 3: Final



This chapters describes the final iteration of the 3-staged process to develop Babenberg Genvis in detail. We first explain the changes made based on the results of the second iteration. Then, we address the evaluations performed over 3 month with log data analysis, observations, and final reflection interviews in the museum (Chapter 14.1) and its results (Chapter 14.2). A video showing Babenberg GenVis in action can be downloaded at https://phaidra.fhstp.ac.at/detail/o:4086.

In our final iteration, we focused on the two noticed challenges after evaluating Iteration 2: 1) helping visitors to understand the multi-device connection and 2) convincing them to start interacting.

To improve the multi-device connection on the touch displays, we implemented an overlay indicating changes in the projection. The overlay is shown the first three times when a visitor selects a person. On the projection, we used transitions (fade in and out) to add a visual clue on the dedicated side when changing persons.

For the second challenge - attracting visitors - we tested two versions during this iteration. In the first step, we changed the start screen. We have reduced to only one start button in the middle of the screen. To avoid language confusion, tapping on it will start the application in German, which is the most spoken language in the museum. Also, we increased the size of the touch button and heading, making them possible to be seen and read from 2 m distance. In the second step, we changed the projections' start screen. The initial idea was to show Leopold III as a start person (see Iteration 2, Chapter 13). Instead, we displayed a text to invite the user to interact with the touch displays.

14.1 Evaluation

Starting with September 2019, we collected log data from visitors who interacted with the exhibit (Lazar, 2017). To test the multi-device connection, we conducted another observation in the middle of September 2019 (2 hours). In the end, we did semi-structured reflection interviews.

Subjects

Interviews were performed with four persons (two female and two male) who had been involved in the exhibition as curators (I3 and I4) or guides (I1, I2, and I4). The age of our interviewees ranged from 29 to 64 ($M = 42.8$, $SD = 15.7$). One participant had been working in the museum field for two years, the others for 13 years and more.

Data Analysis

The log data were analyzed with R. On the one hand, we analyzed the frequency of dwell times. On the other hand, we evaluated the effects of our changes by analyzing the daily sessions. For a reliable comparison of the phases, we excluded outliers of daily sessions (4 items) through Q3 + 1.5 * IQR. When distributions were not Gaussian (according to Shapiro-Wilks tests), the effects of the phases on the daily sessions were evaluated using the Wilcoxon analyses (non-paired samples). Interview data were analyzed through qualitative content analysis (Mayring, 2014). The transcription of the interview is included in Appendix G.

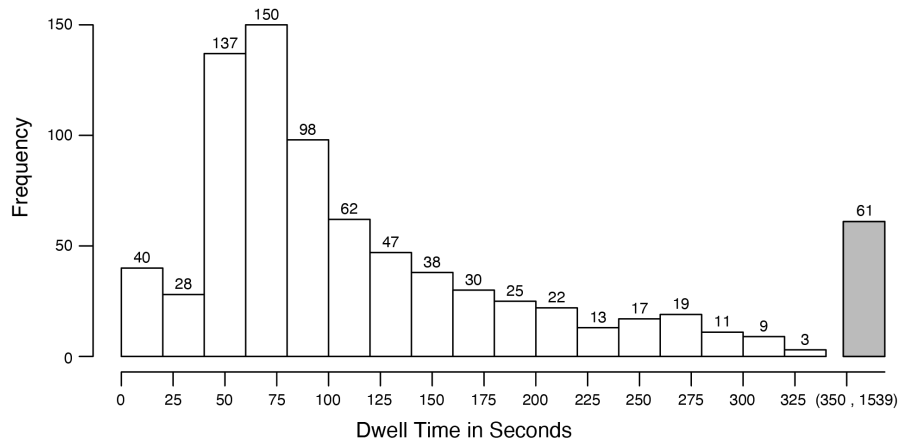


Figure 14.1: Evaluation 3. Histogram showing the dwell time frequency of the logged sessions. For optimized readability, we binned outliers above 324.4 seconds (Q3 + 1.5 * IQR) as a grey bar.

14.2 Results

Log Data

In total, 929 sessions were registered from September 3 to November 17, 2019. In the data, we noticed a high amount (119) of sessions lasting 45 s. We concluded that these were due to visitors tapping the touch screen but not interacting again, thus only activating the auto-logout timer, which lasted 45 s. We decided to eliminate those 119 interactions and hence lost 12.8% of recorded visitor interactions. Figure 14.1 visualizes the duration of the remaining 810 sessions with an average dwell time between 2 s and 1539 s (M = 137.6 s, SD = 142.5 s). Both touch displays were used approximately equal (left: 403, right: 407).

To evaluate the effectiveness of our two-step changes for challenge 2 (convincing visitors to interact), we compared the interaction counts per day for each phase (see Figure 14.2 and Table 14.1). The first phase (September, 3 to 11) was carried out with the version used in Iteration 2. The second phase (September 12 to October 6) included the changes on the touch displays (start screen), and the third phase (October 7 to November 17) featured the changes on the projection as well. A Wilcoxon test indicated a significantly higher amount of interactions in phase 3 than in phase 1 ($p < 0.05$). In conclusion, the changes on the touch displays in combination with those on the projection encouraged the attracted visitors to interact.

Observation

The observation of 39 visitors revealed that all visitors noticed the overlay and looked at the projection. Furthermore, visitors learned about the connection between the two

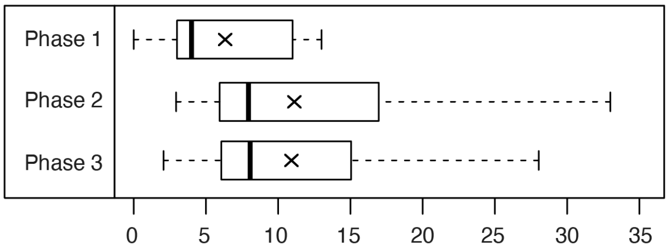


Figure 14.2: Evaluation 3. Counts per day in different phases.

Table 14.1: Evaluation 3. Means, standard deviation, and medians of counts per day in different phases. $M^{visitors}$ represent the mean of ratio between visitors and counts per day.

		M	SD	Mdn	$M^{visitors}$
Phase 1	03.09. - 11.09.	6.3	4.8	4	8.2%
Phase 2	12.09. - 06.10.	11.1	7.5	8	16.9%
Phase 3	07.10. - 17.11.	10.8	6.7	8	19.7%

devices, looking at the projection even after the overlay was no longer displayed.

Interviews

For the museum and the staff, it was the first exhibition with interactive installations. One lesson learned was that there is a need to convince all responsible staff members, e.g., cultural mediators (guides), supervisors, cashiers, of the integration of interactive exhibits, which could have been done better (I3). The two guides (I1 and I2) suggested special introductory tours because interactive exhibits are different from "normal" exhibits, *"I have a picture, I put it up in the exhibition, and when the exhibition is over, I put it down again"* (I3). In contrast, interactive exhibits need to be checked and maintained frequently, which also requires human resources (I3).

Regarding visitors, I1 and I2 observed fear of touching. *"When you have a relatively large number of visitors having grown up with the idea of not being allowed to touch anything in a museum, you have to get rid of this reluctance, so that people dare to explore it"* (I1). Some visitors needed to see somebody (e.g., a guide) interact with the installation to get started. The exhibit aimed to engage the visitors actively. With Babenberg GenVis, visitors could select what they were interested in by themselves (I3 and I4), and it was possible to show the intricate painting in a new and different way. *"We could somehow show this processuality of history a bit: That things are changing, it is not static"* (I4). Additionally, the visual representation fitted into the entire exhibition design very well (I4). I2 praised the amount of content: *"I have already dealt with the family tree, but there was still information I did not know."* Since the Babenberg genealogy is a complicated topic, though, the content of Babenberg GenVis seemed to be too complicated. Referring to this, I3 mentioned: *"If you have such a complex object, like the painting of the genealogy of the Babenberg family, you can only tell two or three stories - over and done."*

14.3 Summary

We presented the final iteration of developing Babenberg GenVis - an interactive, multi-device visualization of a historical genealogy painting. We evaluated through log data analysis of a three-month period, an observation, and semi-structured reflection interviews. Results show that the changes made were successful. Thus, visitors could better perceive the connection between the devices with the added overlay. By changing the start screen of touch displays in combination with the start screen of the projection to add more affordance to interact, more visitors interacted with Babenberg GenVis.

Next, we reflect on the process and the results of the development and derive implications for future studies on interactive, multi-device visualization.

CHAPTER 15

Reflection & Lessons Learned

Following the design study methodology by Sedlmair et al. (2012), we next reflect on the process and the outcomes of our design study and derive implications.

Immediate Apprehendability vs. Passive Viewing Experience

Museums are "free-choice learning" environments (Falk et al., 2006) in which visitors choose what they are interested in. Therefore, interactive installations like Babenberg GenVis need to be *immediately apprehendable* (Allen, 2004), a concept which expands the idea of affordance (Norman, 2013) but includes things with no direct physical use (Allen, 2004). In Iteration 2, we noticed the challenge of inviting visitors to interact, since many were reluctant to touch the displays. Some of them were impressed by the projection but did not realize interaction possibilities. This demonstrates that using large display technology is suitable for giving visitors the option to observe the installation from afar (passive viewing experience), also shown by Hinrichs et al. (2008). The combination of changes in Iteration 3 had a significant effect in convincing more visitors to interact. However, through changing the start screen of the projection, we attenuated the passive viewing experience when nobody interacted with the installation.

Future concepts should consider immediate apprehendability as well as the passive viewing experience of visitors. Finding a way to invite visitors to interact but at the same time transporting a take-away message even without interaction is valuable to the installation.

Placement in the Exhibition

The placement of the installation in the exhibition may influence how the installation is perceived. In the beginning, we did not see a problem with the intended location for Babenberg GenVis. The niche (see Figure 10.1) in which the installation was placed was ideal for minimizing distractions by other exhibits or passing visitors. However, the exit with the turnstile was located directly to the left of our niche, which resulted in visitors sometimes leaving before reaching Babenberg GenVis. The reflection interviews in Iteration 3 consolidated our impressions during the observations in Iteration 2. Regularly, people would stand in front of the exhibit looking at the projection, having the choice between going one step forward to interact, or one step to the left to leave the exhibition. This is also related to "museum fatigue" (Falk et al., 1985): Visitors' attention decreases after 15 to 30 minutes in an exhibition, which might be a reason for less interaction. However, Iteration 3 showed that this was not the case with Babenberg GenVis, since our changes increased the ratio between absolute visitor counts and session counts.

Still, the placement of the installation in the exhibition is an important design decision. For future studies, we need to consider the walking path of visitors as well as "museum fatigue". Nevertheless, we showed that it is possible to overcome position challenges by improving the immediate apprehendability of the installation.

Attention Switch in MDEs

In Babenberg GenVis, visualizations on the touch displays and the projection complemented each other. In such a context, it is crucial for the user to not only have a clear understanding of the capabilities of each device but also of how the different devices come together in a single application.

We positioned the touch displays in front of the printed family tree to clarify that it was possible to interact with the projection via the touch displays. Each interaction with a touch display triggered changes in the projection on the dedicated side of the family tree, allowing visitors to see the effects of their own navigation and their neighbor's. The highlighted family members were displayed on the projection using the same visual encoding as on the touch displays. All of these design choices allowed for a good cohesion between the distinct devices. However, we observed a lack of understanding of the connection between devices in Iteration 2. When discovering the setup for the first time, users might pay extra attention to the visualization on the touch display and not even realize the effects of the touch display on the projection. The same seemed to happen when visitors observed the printed family tree with the projection for a while and did not notice the touch displays. *Conveying cross-device interaction capabilities* is still a challenge (Brudy et al., 2019). With the changes in Iteration 3, we address this challenge and show improvement by adding extra cues to support attention redirection in the form of on-screen cues (for touch display and projection).

More research is needed in this area, for example, research aimed at comparing different approaches to supporting the shift of attention from one device to the other (e.g., auditory feedback, movement of objects). Especially for MDEs in which users do not set up the device connections themselves, this relationship needs to be conveyed very clearly.

Mobile App and Babenberg GenVis

As described in Chapter 5.4, visitors could connect to Babenberg GenVis through a mobile companion app for the exhibition. In Iteration 3, we logged 15 out of 810 sessions (1.9%), which were registered as connections through the app. Because of this comparably low number, we did not emphasize that in the results section.[1] However, we want to reflect on why we should provide such options and how to earn more attention. Integrating the visitors' device into the device ecology within the museum enhances the visitor's experience. In our case, this was done through a rich mobile application with visualization (see Part II) and detailed information about exhibits. Connecting the app to Babenberg GenVis enabled the visitors to earn two additional parts for creating their coat of arms. On the one hand, we maybe did not communicate this extra value. On the other hand, the feature might not have been beneficial enough to the visitors. Additionally, since Babenberg GenVis was developed in a way that does not force visitors to use the app to connect, we decided not to mention the possibility on the touch display.

Even though we are convinced that integrating the visitors' mobile devices in the museum ecology is useful for having a private space to explore, the option should only be provided if there is a clear benefit for visitors. Unlike Babenberg GenVis, the *Weißkunig quiz* - a multi-user quiz in which visitors can connect with their own devices to play against each other - is an excellent example of having and conveying a clear benefit.

[1] In Iteration 3, the app was used 250 times, which represents 4.4% of all possible visitors (5,619). Only 6% out of this 250 connected to Babenberg GenVis.

Technical Challenges

During the implementation and running of Babenberg Genvis in the museum, we faced several technical challenges. First of all, it was the first time for the museum to include interactive installations in an exhibition. As power in the museum was turned on and off manually, scheduling startup and shutdown of the devices would have been complicated. In our setting, the server (projection) needed to run before the clients (touch displays) logged in, which is why it was necessary to get a separate permanent power supply.

Since we used projection mapping to extend the printed visualization, the projector needed to be calibrated whenever the position of the object or the projector slightly changed. In Figure 13.1, a shine on the bottom and the left can be seen, indicating that the projector was not correctly calibrated when the photo was taken. Depending on the surroundings, checking for such little changes in the setting calls for responsible staff. Both ourselves and the museum team learned that performing regular checks whether everything is up and running is not self-evident for the staff.

Dwell Time at InfoVis Exhibits

During the entire development process, we evaluated data from nearly 1,000 interaction sessions with Babenberg GenVis in three iterations varying from a lab study with six participants in Iteration 1, over a total of 51 museum visitors in Iteration 2, up to 929 sessions in Iteration 3. In addition to the evaluation of the different design stages, we can derive new knowledge, e.g., about the dwell time of visitors at interactive visualizations in museums. We realized that we should have implemented a method to differentiate between active visitor logouts and automatic kick-outs in Iteration 3. Because of this flaw, we were only able to exclude sessions from our data, which lasted exactly 45 s (our kick-out time). However, we could not correct the duration of sessions where visitors interacted for a specific time and then left without explicitly logging out. Looking at the average dwell time in Iteration 2 (1:55 min) and Iteration 3 (2:37 min), there is a difference of 42 s, which is close to our kick-out duration (45 s). Additionally, when performing a log data study only, it cannot be confirmed whether the interaction sessions originated from one person only or consisted of multiple subsequent interactions without logging out in between. Therefore, a log data analysis, as in Iteration 3, combined with observation and video recording, as in Iteration 2, is a promising approach (Hornecker and Ciolfi, 2019) whereas it is not appropriate for long time logging as we did in Iteration 3. Our average dwell time also matches that in other museums (Hein, 2003; Hornecker and Stifter, 2006), which are not directly linked to InfoVis.

For future studies, we suggest a duration of no longer than 1:30 min for introductions, so that visitors still have the possibility to explore the data afterward freely.

Timelines for Casual Users

The timeline on our touch displays was built upon TimeNets (Kim et al., 2010). TimeNets had never been used in a museum or any other casual InfoVis setting before. Iteration 1 revealed that only using connected life trajectories in a timeline is not enough to make the visualization readable well enough to determine birth and death years, years of marriages, and seeing connections to children. We added well-known icons for such data to help visitors gain insights. Using such pictograms has been shown not to affect the viewer as long as they are used to represent data (Haroz et al., 2015) and improve recognition (Borkin et al., 2016). Additionally, we gave visitors more certainty in reading the timeline by displaying the birth and death dates as text on the projection.

In general, we can state that timelines are suitable for casual users as the target group. Visualizing estimated dates, though, needs additional explanations through text (e.g., showing details or adding a help screen).

Weighing up the Use of InfoVis Techniques

Our initial intention was to consistently use tree visualizations (Schulz, 2011) to extend the printed tree visualization through the projection. Due to our setting, visitors needed to be able to read the projection from a distance of at least 4 m. In order to avoid occlusion, we decided against tree visualizations for children and used the Gestalt principle proximity (Todorovic, 2008). Interviews in Iteration 2 showed that visitors understood the connection nevertheless.

To improve the understanding of data in future visualization concepts, we will again carefully weigh up the use of InfoVis techniques, especially if a large viewing distance impedes rich details.

Extending a Painted Visualization with InfoVis

Extending the *Babenberg Family Tree* - a painted tree visualization - and interpreting it in a new way gave us the option to show that the perception of history is changing over time. In former times, only Babenberg men were of interest for research (Neukam, 2011; Pohl and Vacha, 1995), even though wives were highly relevant for extending the political power of the Babenberg. In our interpretation, we included more recent research and visualized additional data such as relations between men and women as well as adding non-Babenberg husbands of daughters. Iteration 2 and 3 showed that visitors gained new insights with our free exploration tool. While it is somewhat analytical, we noticed that visitors do not always demand such completeness. Considering the average dwell time of app. 2 min, visitors could only dive into a small amount of data. Some of them might even have been overwhelmed when seeing the entire genealogy, starting with Leopold III as a timeline.

In future studies, we want to combine guided and free exploration, as also suggested by Hinrichs et al. (2008). Guided exploration could be implemented as an onboarding process (Stoiber et al., 2019) through storytelling. Our idea is to introduce the visualization through a story, which conveys a fact from the exhibition, carries a take-away message, and can be freely explored afterward.

15.1 Summary

In this design study, we followed a process of iterative design and evaluation (Nielsen, 1993) to address a particular domain problem by involving collaborators and users from the domain (Sedlmair et al., 2012). Following the design study approach (Sedlmair et al., 2012), we first characterized the problem (Chapter 10.2 and Chapter 11.2). We used a 3-staged iterative process to implement Babenberg GenVis. Each stage was completed with an evaluation. First, we developed functional prototypes and evaluated the visualization for the touch displays in a lab setting (Chapter 12). Results showed difficulties in reading the time-oriented visualization (parent-child connection or reading the dates for birth, marriage, or death). In Iteration 2 (Chapter 13), we improved the visualization mainly by using icons to overcome these challenges and implemented the installation into the museum. The subsequent in-the-wild evaluations revealed challenges in understanding the connection between the devices and getting visitors to start to interact. We again improved our Babenberg GenVis to overcome the challenges of Iteration 2 in the final iteration (Chapter 14) showing that the changes made were successful.

With the presented second design study, we addressed three gaps identified in Chapter 4.3:

Multi-Device Ecologies Integrating Visualization Are Rare. In this design study, we implemented a visualization across multiple devices with simultaneous use of the devices. We showed the feasibility and improved the design though an iterative process. Especially in Iteration 3, we addressed multi-device challenges such as getting the connection between the devices and handle the attention switch.

Physical Artifacts Are Not Often Linked to Visualization. We developed Babenberg GenVis to bring a reproduction of the original painting into the exhibition. Otherwise, it would not have been possible to present the huge painting (see Chapter 10.2). By extending the reproduction through projection, we present an example of how to interweave a physical artifact with interactive visualization on digital media in museums. We thus addressed, for example, the topic of how digital assets can be integrated to enrich exhibitions without being a distraction from the physical artifact.

Full Spectrum of Representation Techniques Is Not Used. We dealt with a complex data set combining genealogical (hierarchical and network data) with temporal as well as spatial data. This represents a unique combination compared to the presented papers in Chapter 4. As visualization technique, we choose a diagram (tree visualization of genealogical data) in combination with a graph (timeline axis) and added a map. As diagrams and graphs are underrepresented, we added a contribution to more variety in visualization techniques in museums. In Iteration 1, we gained insights in how participants are able to read the visualization and decided to use icons to improve the readability. Iteration 2 and 3 showed the usability by a large number of museum visitors.

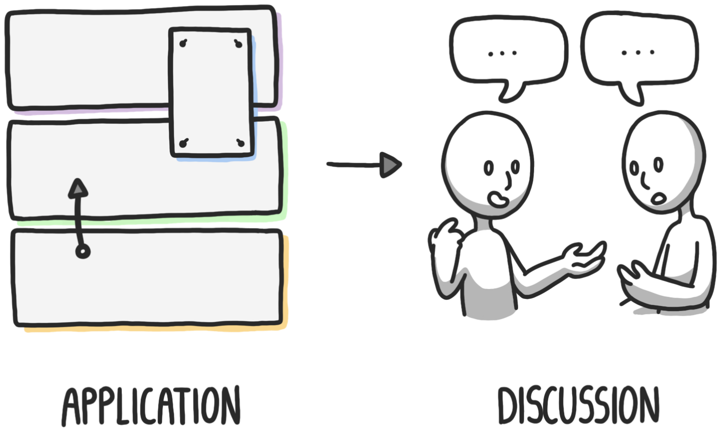
Next, in Part IV, we apply the design studies to our Design Space and discuss the descriptive, evaluative, and generative power (Beaudouin-Lafon, 2004) of our Design Space in relation to the first (Part II) and second design study (Part III).

Part IV

Application of Design Space & Future Perspectives

CHAPTER 16

Design Space Application & Discussion



This chapter describes the application of our Design Space to the presented design studies in Part II and III and the entire MEETeUX-multi-device ecology (Chapter 16.1). Furthermore, we discuss its descriptive, evaluative, and generative power, as well as its limitations (Chapter 16.2).

16.1 Application of the Design Space

After applying our Design Space to existing scientific literature (Chapter 4), we categorize our prototypes described in Part II and III and the entire multi-device ecology of the research project MEETeUX (Chapter 5). We also discuss the contribution of our prototypes to this area of research.

Application on the Section-based Visualization of Design Study 1

As outlined in Part II, we compared several time-oriented visualization techniques to determine which one is most suitable for a location-aware mobile application. Based on the results, we decided to include the Section-based design (see Figure 16.1). In the following, we describe the application along with the dimensions of our Design Space visualized in Figure 16.2.

Figure 16.1: Section-based design of the mobile application in design study 1 (Part II) showing exhibits in the section *The Monastery and the Provost*.

Physical Space: As the museum of interest has a collection of various artifacts and presents selected artifacts in a building, our museum is a *traditional museum*. We integrated *observable* artifacts that were placed in the exhibition within the mobile application. A subset of these artifacts was presented in the time-oriented visualization.

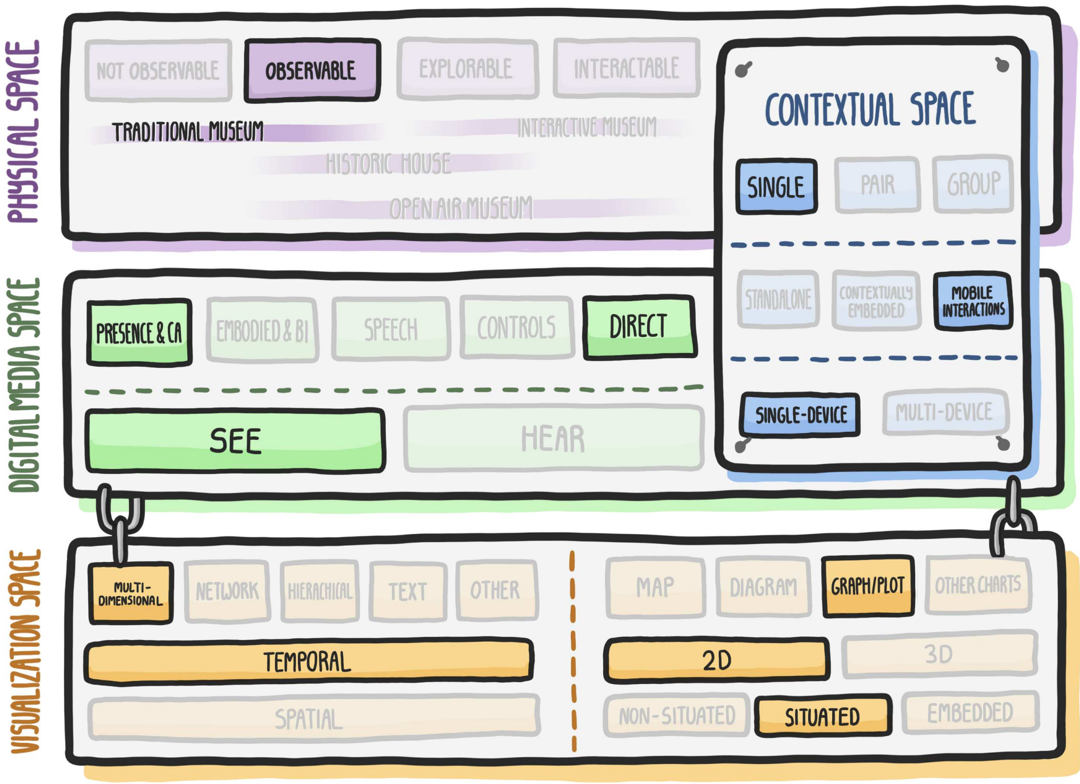


Figure 16.2: Applying our Design Space to the Section-based visualization. The addressed categories are highlighted.

Digital Media Space: The application was designed for smartphones. Thus, we addressed mobile displays (*see*) in our *perception* dimension. Describing the *action* dimension, visitors interacted through *direct manipulation (touch)* with the mobile device. On the other hand, we implemented a *presence and context-awareness* action by detecting the exhibit that is the closest to the visitor via Bluetooth sensors.

Contextual Space: As we integrated the visitors' smartphones, the application was focused on *single* visitors. The mobile application is categorized as a *mobile interaction* - visitors carry their mobile device, and the app triggers actions based on their position in the exhibition. If we only look at this mobile application, we describe a *single* device use.

Visualization Space: Data contained a title, time (year(s)), detailed description as text, images, and additional interactive components (e.g., AR or a single choice game). Thus, we have *multidimensional* in combination with *temporal* data. As visualization techniques, we tested different ones (diagram, graph/plot, and other charts). The final implementation integrated the Section-based approach that visualizes a time axis across different sections (pages). Thus, we categorize the visualization as *graph/plot*. We designed a *2D* visualization that is *situated*. The situated visualization is achieved by showing the relevant information of the visualization depending on the exhibit that is closest to the visitor.

The work in this design study fits into the cluster *mobile interaction combined with visualization* (see Chapter 4.2). Thus, we extended the knowledge about designing visualizations for mobile devices. We compared different time-oriented visualization techniques on smartphones and tested them with casual users, finding that a linear timeline design was best suited. We selected the Section-based approach as a linear timeline to implement in a location-aware application. The exhibits (items in visualization) were unlocked by passing by, and the visualization scrolled to the closest exhibit (Part II).

Application on Babenberg GenVis (Design Study 2)

In Part II, we described the development of Babenberg Genvis, an interactive, multi-device visualization of a historical genealogy painting. In the following, we explain the installation along with the dimensions of our Design Space visualized in Figure 16.3.

Physical Space: The museum of interest is the same as explained before. Offering practical experience as in science and interactive museums is not the main interest of the museum. The museum/exhibition space is neither an open-air museum nor a historic house. Thus, we categorize it as *traditional museum*. The artifact that is of interest for Babenberg GenVis is a vast painting of 8 by 4 meters (see Chapter 10.2). This exhibit cannot be moved to the exhibition space. Therefore, we worked with a *not-observable* artifact that was reinterpreted as a large printing.

Digital Media Space: We designed the application for two touch displays (horizontal displays) and one projection (room display). Thus, we addressed the *see*-category in our *perception* dimension. In terms of *action*, we implemented two methods. On the one hand, visitors could directly interact with the timeline visualization (*direct manipulation (touch)*). On the other hand, through selecting persons on the touch display, visitors controlled the room display (*control (touch)*).

Contextual Space: The installation was designed with a view to *pairs* of visitors. Of course, a single visitor could also use the application, and groups could split up between the two displays. We designed a *contextually embedded* installation as the visitor is pointed to the large replication of the Babenberg Family Tree. We used *multiple devices*, and visitors had to use them simultaneously.

Visualization Space: On the one hand, we dealt with *hierarchical* data when it comes to parent-child relationships. As we also added spouses, we combined family trees and formed a *network* of relationship. Besides, we integrated *temporal* and *spatial data*. We developed a timeline that shows the genealogical data as a combination of

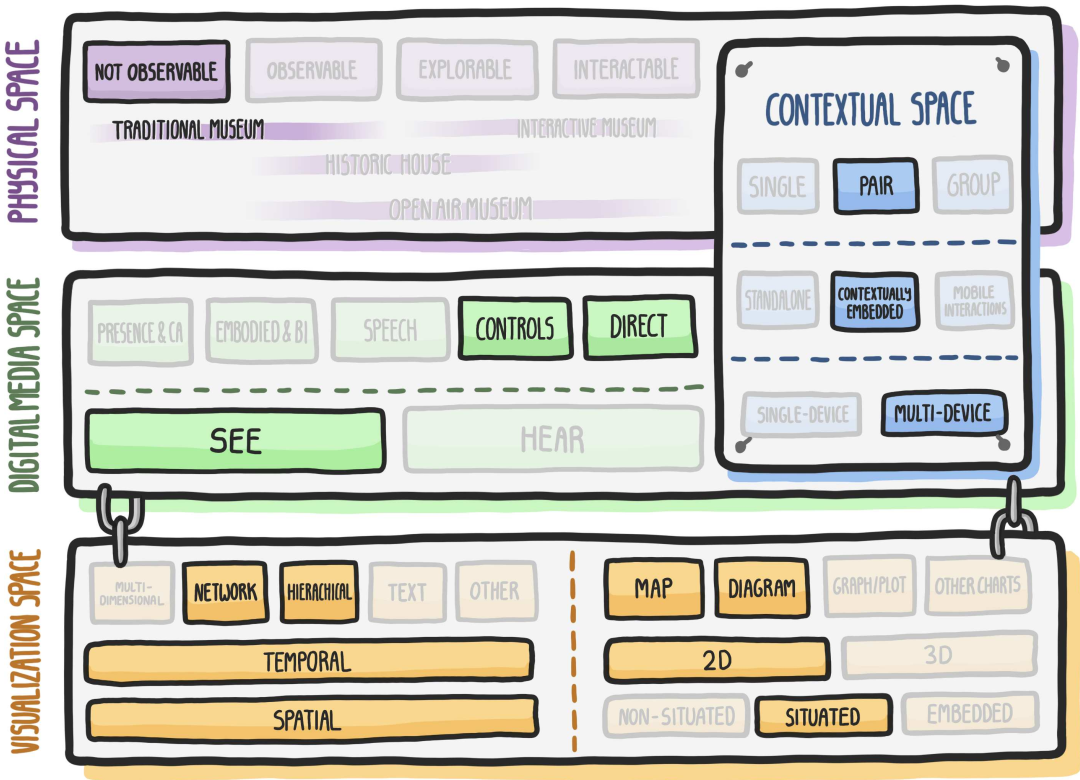


Figure 16.3: Applying our Design Space on Babenberg GenVis. The addressed categories are highlighted.

graph and *diagram* and integrated a map to visualize the Babenberg dominion. The visualization is in *2D* and is classified as *situated* visualization as it is interwoven with the replication of the original family tree.

Babenberg GenVis fits into the two clusters *2D visualization on horizontal touch display* and *use of controls together with horizontal, vertical, or room display* (see Chapter 4.2). We mainly extended knowledge about designing visualizations across multiple devices for casual users. Besides, with genealogy data, we addressed the visualization of hierarchical combined with network data (Part III).

Summary

Based on our Design Space, we described the design studies that were conducted during this thesis in detail. Table 16.1 gives an overview of the categorization of the two studies. The two design studies each fit into one or two of our defined clusters.

Next, we discuss the descriptive, evaluative, and generative power of our Design Space as well as its limitations.

Table 16.1: Overview of the categorization of design study 1 (Part II) and 2 (Part III) categorization along with our Design Space.

		Section-based Visualization (Part II)	**Babenberg GenVis** (Part III)
Physical Space	Type of Physical Artifact	observable	not observable
	Type of Museum	traditional	traditional
Digital Media Space	Action	presence, direct manipulation ↪ touch	controls ↪ touch, direct manipulation ↪ touch
	Perception	see ↪ mobile display	see ↪ horizontal & room display
Contextual Space	Number of Visitors	single	pair
	Relationship to Physical Space	mobile interactions	contextually embedded
	Number of Devices	single	multiple ↪ sequential
Visualization Space	Type of Data	multidimensional, temporal	network & hierarchical, temporal, spatial
	Type of Visualization	graph/plot, 2D, situated	map & diagram, 2D, situated
Cluster		Mobile interaction combined with visualization	2D visualization on horizontal touch display, Use of controls together with horizontal, vertical, or room display

16.2 Discussion

To demonstrate the practical applicability of our Design Space for visualization designers and developers, we discuss the space along three dimensions described by Beaudouin-Lafon (2004) in this section. A good model must "strike a balance between generality (for descriptive power), concreteness (for evaluative power) and openness (for generative power)" (Beaudouin-Lafon, 2004, p.17). In addition, we address the limitations of our approach.

Descriptive Power: The Design Space for interweaving physical artifacts with data visualization on digital media in museums (see Chapter 3) describes the different spaces addressed when developing an installation. Besides, it provides an overview of the common techniques used in these spaces (Physical Space, Digital Media Space, Contextual Space, and Visualization Space), such as different types of physical artifacts, interaction, or visualization techniques. In Chapter 4.1 and 16.1, we demonstrated the descriptive power of the Design Space. We first described 28 existing approaches from scientific literature and then, our results from the two design studies presented in this thesis. Besides, we also show that it is possible to describe a more sophisticated setting, such as the entire MEETeUX multi-device ecology. Through this descriptive power, it is possible to compare existing approaches (as shown in Chapter 4.1) and to determine clusters (as shown in Chapter 4.2) and knowledge gaps (as shown in Chapter 4.3).

Evaluative Power: As we did not integrate dimensions or aspects that have the ability to help assess multiple design alternatives, our Design Space does not have any evaluative power.

Generative Power: Our Design Space systematically shows the possibilities from which an interactive exhibit designer might choose. With the four spaces (Physical Space, Digital Media Space, Contextual Space, and Visualization Space) and their dimensions and aspects, we provide a valuable structure of what to think about. Thus, the Design Space description (Chapter 3) can be used as a starting point to get acquainted with the aspects that are usually addressed when developing installations with visualization interwoven with physical artifacts. With our Design Space, we did not develop a system blueprint or a high-level architecture. In contrast, within the MEETeUX project, we developed the system architecture for a multi-device ecology integrating different types of exhibits and the own device of the visitors (described in Chapter 5.6, shown in Figure 5.3). Based on this architecture new designs can be created and thus, the architecture is an example of a more generative model.

Limitations

The initial idea for our Design Space was to systematically investigate what currently exists in the museum context and make it comparable. Therefore, the perception dimension is restricted to perceptual channels that have been used already. For example, the categories feel and taste are not included. Even though there has been some research in this area (e.g., Batch et al., 2020; Miotto, 2016; Obrist et al., 2016), applications are currently not typical in museums. However, we see the opportunity for future research in multi-sensory immersive analytics (McCormack et al., 2018) for museums, e.g., using vibration to show increases or decreases in the data or heating metal parts to explore a heat map.

With our Design Space, we focused on the description of the installation and its surrounding. Thus, we were not addressing how the presented approaches were evaluated. The scientific community (e.g., Hornecker and Ciolfi, 2019; Hornecker and Nicol, 2012) already addressed the evaluation of applications for museums but not specifically for data visualization. However, in our Design Space, an evaluation dimension could increase our Design Space's evaluative power as designers could benchmark their evaluation settings against existing applications.

In our research, we did not capture disabled persons and questions of accessibility. Nevertheless, especially museums should take care of including disabled persons. Anagnostakis et al. (2016), for example, developed a prototype for visually impaired persons to enhance their museum visit. Visually impaired visitors can navigate with their smartphone through the exhibition and explore replicas using touch-sensitive audio descriptions. Focusing on data visualization, research in multi-sensory immersive analytics, as already mentioned above, could also improve the experience of impaired visitors.

Finally, we did not address aspects of different cultures. As stated by Norman (2013), people in different cultures see, for example, time differently. We addressed time-oriented visualizations in both of our design studies and designed our visualization along with the mental model of the left-to-right writing system from the past (left or top) to the future (right or bottom). This also represents the known mental model of people from technological cultures. However, other cultures might expect the future at the top or to the left (e.g., in Arabic or Hebrew regions). Through using labels for timelines, it is possible to reduce distraction. Nevertheless, people with different mental models in mind might have a higher effort in reading our visualization.

16.3 Generalization of the Design Space

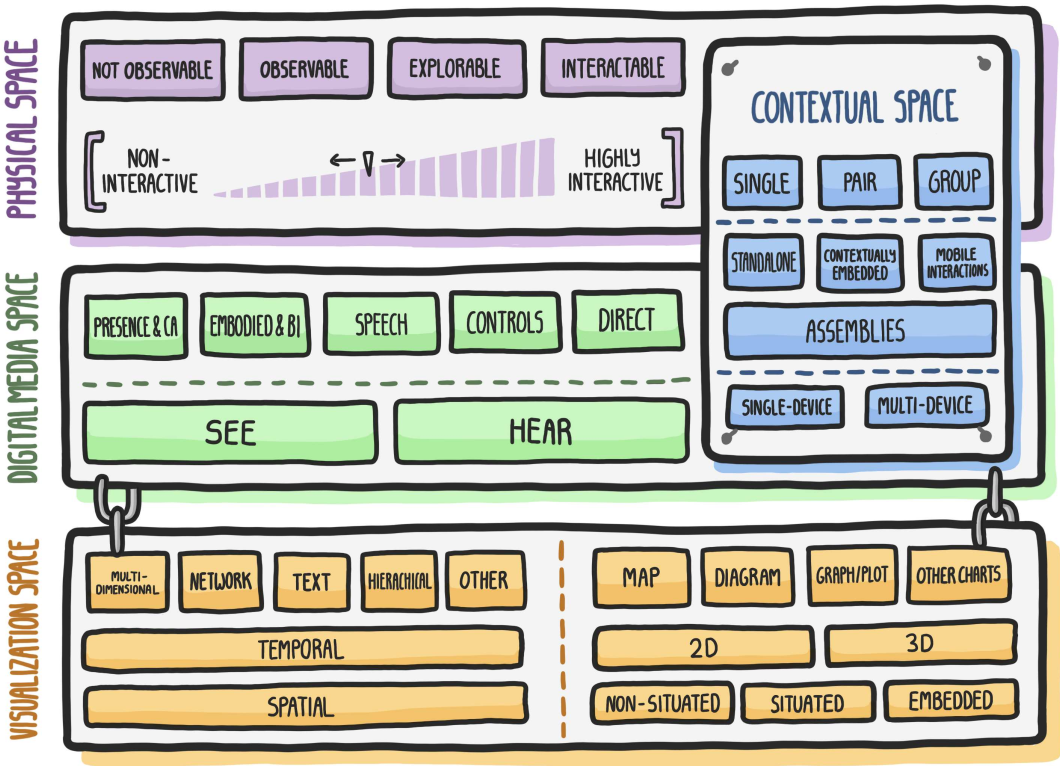


Figure 16.4: Generalizing our Design Space. The dimensions of Physical Space are changed to type of physical referent (same categorization) and type of environment (changing the categorization to from non-interactive to highly interactive).

We modeled the Design Space for interweaving physical artifacts with data visualization on digital media for a museum setting. By splitting the entire Design Space into four subspaces (Physical Space, Digital Media Space, Contextual Space, and Visualization Space), there is the possibility to apply the model not only in a museum setting. Each of the spaces can be applied on their own or in combination. Taking, for example, Digital Media Space and Visualization Space, we can describe any visualization system on digital media devices based on their action and perception as well as the type of data and type of visualization used.

Replacing or rephrasing the dimensions in Physical Space with the dimensions of interest for another setting, allows applying it to every installation using visualization on digital media device preferring environments in which people are acting not only with their own devices and the visualization can be connected to physical referents. Therefore, we change the type of physical artifact to type of physical referent (with the same categorization as the type of physical artifact) and the type of museum to type of environment focusing on how people are supposed to interact with digital media devices in this environment (from non-interactive to highly interactive). Figure 16.4 visualizes the generalized Design Space.

Activity Wallpaper (Skog, 2004), for example, is an application that was designed for a public space. It analyses audio data of a café and visualizes this data time-oriented (see Figure 16.5). In the following, we describe this approach along with our Design Space with a modified Physical Space.

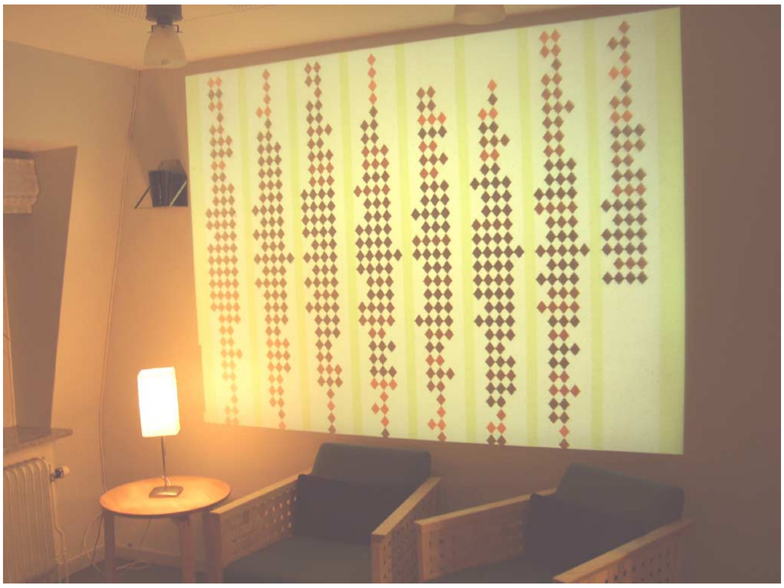


Figure 16.5: Activity Wallpaper analyses audio data in a café (Skog, 2004).

Physical Space: The *physical referents* are the visitors of the café in which Activity Wallpaper is placed. Within the visualization, *not observable* and *observable* referents were integrated into the display of the activity history for the current day and the last six days. The *environment* is a café where people are usually not aware of interacting with digital media devices on-site (*not interactive*).

Digital Media Space: For *perception*, the installation was designed addressing the *see* category using a *room display*. The *actions* the visitors could set were explicit as *presence* was detected based on the analysis of audio data.

Contextual Space: The approach did not address a specific number of visitors. Based on the visibility of a room display, *single* visitors, *pairs*, and *groups* could interact. Describing the *relationship to Physical Space*, the installation is a *contextually embedded* one. Visitors had to deal with a *single device*.

Visualization Space: Addressing the data, Activity Wallpaper was created based on *multi-dimensional* data with *temporal* semantics. In terms of representation techniques *graph/plot* were implemented as a *2D* visualization. The approach can be categorized as *situated* visualization as the physical referents are the visitors of the café.

As in our Design Space, the context-awareness of an approach is of interest in several dimensions such as type of physical artifact (or referent), relationship to Physical Space, and the situatedness of the visualization itself, approaches that address such situatedness like in the Activity Wallpaper (Skog, 2004) can be classified with our Design Space. Situatedness is also of interest in the research field of immersive analytics (Dwyer et al., 2018; Thomas et al., 2018). The Egocentric Bar Chart approach by Quach and Jenny (2020), for example, is an immersive bar graph visualization addressing augmented reality headsets in outdoor settings to get familiar with the surrounding landscape (see Figure 16.6). In the following, we classify this approach with our Design Space:

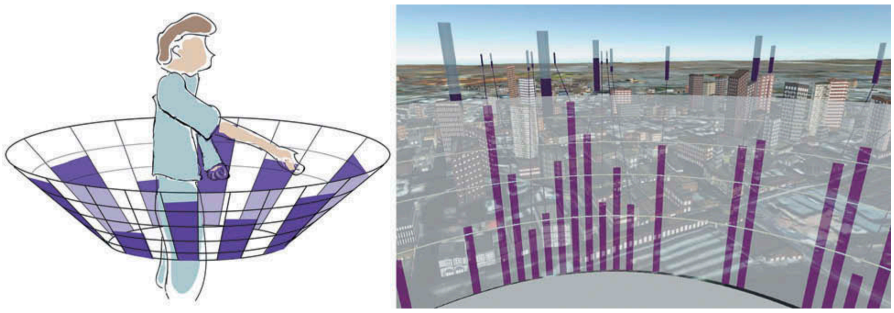


Figure 16.6: Egocentric Bar Chart, an immersive bar graph visualization for augmented reality headsets (Quach and Jenny, 2020).

Physical Space: The *physical referents* are physical locations (e.g., buildings, points of interest) that are *observable*. The *environment* are outdoor viewing points. In such settings, people are usually not aware of interacting with digital media devices on-site (*not interactive*).

Digital Media Space: Addressing the *perception* dimension, the application is categorized as *see* using a *Mobile display* (head mounted display). In terms of the *action* dimension, the visualization adapts on the location of the user *presence* and on the viewing angle *embodied and bodily interacting*.

Contextual Space: The approach addresses *single* users as it is designed for non-collaborative settings and users deal with a *single device*. Describing the *relationship to Physical Space*, the installation is a *contextually embedded* one.

Visualization Space: The visualization shows *multi-dimensional* data with *spatial* semantics as a *graph/plot* in *3D* visualization. The approach implemented a *situated* visualization as the physical referents (buildings, points of interest) are close to the user.

Table 16.2 summarizes the categorization of Activity Wallpaper (Skog, 2004) and Egocentric Bar Chart (Quach and Jenny, 2020) along with our generalized Design Space.

Table 16.2: Overview of the categorization of Activity Wall paper (Skog, 2004) and Egocentric Bar Chart (Quach and Jenny, 2020) along with our generalized Design Space.

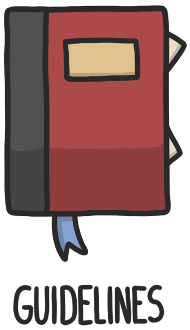
		Activity Wallpaper (Skog, 2004)	**Egocentric Bar Chart** (Quach and Jenny, 2020)
Physical Space	Type of Physical Referent	not observable, observable	observable
	Type of Environment	not interactive	not interactive
Digital Media Space	Action	presence & context awareness	presence & context awareness, embodied & bodily
	Perception	see ↪ room display	see ↪ mobile display
Contextual Space	Number of Visitors	single, pair, & group	single
	Relationship to Physical Space	contextually embedded	contextually embedded
	Number of Devices	single	single
Visualization Space	Type of Data	multidimensional, temporal	multidimensional, spatial
	Type of Visualization	graph/plot, 2D, situated	graph/plot, 3D, situated

16.4 Summary

This chapter summarized the work on our Design Space. We first applied the Design Space to our research (Chapter 16.1). We demonstrated the applicability on the two design studies presented in Part II and III. Afterward, we discussed our Design Space concerning its descriptive, evaluative, and generative power (Beaudouin-Lafon, 2004). We described the limitations of our Design Space and our conducted design studies that indicate future perspectives. In addition, we generalized our Design Spaceby rephrasing the dimensions in Physical Space. Thus, the Design Space can be applied to every installation using visualization on digital media device preferring environments in which people are acting not only with their own devices and the visualization can be connected to physical referents (Chapter 16.3). Next, we present guidelines derived from our research (Chapter 17) and discuss future directions (Chapter 18).

CHAPTER 17

Guidelines



This chapter presents guidelines for designing and evaluating future projects that interweave physical artifacts with data visualization on digital media in museums (Chapter 17).

We critically reflect on the results and the process within the two design studies performed for this thesis (Chapters 9 and Chapter 15). Based on these lessons learned, we derived implications that we formulated as guidelines. We also developed guidelines in the framework of the research project MEETeUX. This section combines the essential guidelines in the context of interweaving physical artifacts with data visualization on digital media in museums[1]. These guidelines should help designers, developers, and exhibition curators better understand applications with data visualization connecting the physical with the digital world and how they can be integrated into exhibitions.

17.1 Method

For the research project MEETeUX, we based the guidelines on our experience with the development and operation of the multi-device ecology in the exhibition (Chapter 5). After the end of the exhibition, we conducted a workshop with the head of the curator team and the entire project team (ten participants). The aim of this workshop was to formulate *Dos and Don'ts* for six stations: Administration, BYOD: mobile app, data visualization, multi-device, interactive installation, and augmentation. Each participant took part in the discussion once at each station. To start the discussion, we asked questions for each station[2] based on initial reflections on the research project. Afterward, we clustered the *Dos and Don'ts* and reduced them with the criterion that they were arguable based on our experience and evaluation data from the development process. We formulated this selection as guidelines. These guidelines were iteratively refined based on various feedback sessions. For this thesis, we also conducted an in-depth reflection on the results and the process of the two design studies (Part II and Part III). Therefore, we carried out an additional reduction step for the presented guidelines, in which we selected the guidelines that are related to the design studies. Furthermore, we added guidelines that were derived from the reflection sections of the two studies (Chapter 9 and Chapter 15) and had not been captured before.

17.2 Guidelines

I. Choose familiar and linear visualization techniques.

Recommendation: For the visualization of time-oriented data on mobile devices, designers should choose familiar and linear visualization techniques.

Motivation and evidence: Börner et al. (2016) found that familiarity is essential, especially for visitors with low data literacy. Thus, we decided for our three basic designs (Chapter 7)).

[1]The complete guidelines developed during the research project MEETeUX are attached in Appendix H.

[2]These questions are attached at Appendix I.

The *Timeline* design is known from news feeds and social media apps. The grid-based metaphor of *Bookshelf* is known from mobile apps such as Netflix[3] or Amazon Prime Video[4]. Even if the *Timeflower* design was not so common, using a wheel for selection was implemented before for the wheel interaction on iPods (Gartenberg, 2018).

When comparing the three designs visualizing time-oriented data in Iteration 1 of our design study in Part II, the *Bookshelf* and the *Timeline* designs were more apparent and more familiar to the users than the *Timeflower* design. However, the *Bookshelf* design was significantly less understandable than the *Timeline* design. Since the *Timeline* design also reflects the same linear structure found in many mobile applications, we chose this familiar and linear visualization technique. The three versions of a linear timeline in Iteration 2 showed that participants were able to complete the tasks well with all designs, with no significant difference in performance and user experience. We also implemented a linear timeline concept in our second design study (Part III). Evaluations also showed that this concept is suitable for casual users as the target group.

This guideline refers to the reflection of the first design study (Chapter 9).

II. Support readability in timeline visualization.

Recommendation: A linear timeline concept is suitable for museum visitors. However, the disambiguation of such timelines must be supported, e.g., by familiar icons and detailed text.

Motivation and evidence: Using such pictograms has been shown to improve recognition (Borkin et al., 2016). They do not affect the viewer when they represent data (Haroz et al., 2015).

We developed our timeline for Babenberg GenVis (Part III) based on TimeNets (Kim et al., 2010). Since it has never been used in any casual InfoVis setting, we tested the visualization with a functional prototype. This evaluation revealed that using only connected life trajectories in a timeline is not enough to make the visualization readable well enough to determine birth and death years, years of marriages, and seeing connections to children. To improve readability, we added well-known icons for such data. In addition, we displayed birth and death dates as text as well, when a person was selected.

This guideline refers to the reflection of the first design study (Chapter 15).

III. Combine guided and free exploration.

Recommendation: If visitors' engagement is a requirement for the visualization, start with an author-driven approach by giving users an exploration task (guided exploration), and open the visualization to a reader-driven approach (free exploration). Keep in mind

[3]Netflix App: https://apps.apple.com/de/app/netflix/id363590051, last access August 1, 2020.
[4]Amazon Prime Video App: https://apps.apple.com/de/app/amazon-prime-video/id545519333, last access August 1, 2020.

that the guided exploration should not take too long (no longer than 1:30 min), as the visitors' attention span decreases over time in the exhibition.

Motivation and evidence: As a martini glass structure, the visualization can start with an author-driven approach (Segel and Heer, 2010) by showing layered information. So visitors are not overwhelmed in the beginning but delve deeper the more they interact. Guided exploration could be implemented as an onboarding process (Stoiber et al., 2019).

For Babenberg GenVis (Part III), we showed that visitors had gained new insights with our free exploration tool. Although it is somewhat analytical, we found that visitors do not always demand such completeness. Sometimes, visitors were interested, but they did not know where to start and needed a rather long time to understand it. Considering the average dwell time of app. 2 min, visitors could only dive into a small amount of data.

This guideline refers to the reflection of the second design study (Chapter 15).

IV. Prioritize immediate apprehendability.

Recommendation: Instructions on how to use interactive elements should be visible (preferably just by looking at the installation) and easy to understand.

Motivation and evidence: Interactive installations should be designed so that their design alone gives an idea of how to interact with them (Parker and Tomitsch, 2017). If an installation contains interaction possibilities that may not be intuitive from the outset, visitors should be reminded of them during use.

In the second iteration of the development of Babenberg GenVis (Part III), we found the challenge of inviting visitors to interact, as many were reluctant to touch the displays. Some of them were impressed by the projection but did not see any possibility of interaction. The combination of the changes in Iteration 3 (adjusting the start screens of the touch displays and the projection to invite visitors to interact) had a significant effect on getting more visitors to interact.

This guideline refers to the reflection of the second design study (Chapter 15).

V. Keep visitors' walking paths in mind.

Recommendation: Interactive exhibits should be well integrated and not stand off the path through the museum. Furthermore, installations should not be positioned so that their users block the way of other visitors or make them feel observed by passers-by.

Motivation and evidence: The placement of installations can have an impact on how it is perceived. Flegel et al. (2018) noticed that installations are perceived differently because of their placement. For example, visitors walk around the installation to see other artifacts and thus, passing by the interactive installation (Flegel et al., 2018).

We initially saw no problem in the intended location for Babenberg GenVis (Part III). The niche in which it was placed was ideal for minimizing distractions from other exhibits or passing visitors. However, the exit with the turnstile was located directly left of our niche, which meant that visitors sometimes left the exhibition before reaching Babenberg GenVis. The reflection interviews corroborated our observations: Visitors regularly stood in front of the installation and watched the projection, choosing to either walk one step forward to interact or leave the exhibition.

This guideline refers to the reflection of the second design study (Chapter 15).

VI. Allow to enter at any state.

Recommendation: In any case, the visitor should be able to enter and leave the installation at any state as smoothly as possible. Define a starting point for the installation and provide a reset function that reverts all changes made by a visitor to this starting point.

Motivation and evidence: Bitgood (1991) suggested that ideally an application is at the beginning when a visitor starts interacting with it. For all of our exhibits, visitors could enter and exit at every time they want. There was no need for a reset function for the Weißkunig Quiz in the mobile app as the visitors used their devices. For the stationary device, the visitor had to leave the answer view. For Babenberg GenVis (Part III), we implemented a reset function to start over. Furthermore, we implemented an auto-logout for all exhibits, starting a timer when no interaction was detected and resetting to our predefined starting point.

This guideline refers to the MEETeUX guidelines (Appendix H.2.2).

VII. Involve the exhibition staff through co-design.

Recommendation: The overall aim when developing an interactive exhibition should be to involve as many stakeholders as possible in the design process.

Motivation and evidence: The use of co-design as a strategy of participatory development (Ciolfi et al., 2016) could help integrate the exhibition staff (e.g., cultural mediators and museum guards) to get a clear overview of their requirements for the entire system and see how the staff will use it later. Also, a more reflective design practice that incorporates critical discourse can change interactive exhibition design and thus the museum experience (Claisse et al., 2020).

In our design process, we integrated the curators from the beginning. However, we failed to integrate the exhibition staff. When the exhibition was opened, we noticed a need for an additional explanation of the interactive exhibits. For example, for Babenberg GenVis (Part III), the projector needed to be calibrated whenever the position of the object or the projector changed minimally. Having responsible personnel in the design process can make the staff feels more responsible and take care of even such small changes in the environment.

This guideline refers to the MEETeUX guidelines (Appendix H.3.3).

VIII. Be aware of technical challenges.

Recommendation: Check the technical constraints in the design phase (e.g., power supply options, range of Bluetooth beacons, Wi-Fi availability and signal strength, phone reception). Be aware that there might be a difference between technical restrictions (technically not feasible) and organizational restrictions (change power supply option, add additional access point).

Motivation and evidence: During the design process, we addressed those issues. It was hard to argue that we needed a constant power supply instead of a manual on/off switch for Babenberg GenVis (Part III), or an additional access point in an area where there was little Wi-Fi coverage to have access with the mobile app (Part II). We were faced with Wi-Fi challenges during the exhibition when a large group entered and used the mobile application. Additionally, the communication with the museum's IT staff was not always easy as they were not familiar with the required technology.

This guideline refers to the reflection of the second design study (Chapter 15) and the MEETeUX guidelines (Appendix H.3.4).

IX. Make the connection between multiple devices salient.

Recommendation: In a multi-device environment where more than one device is part of the interaction process, the connection between these devices must be visible - visitors should know that the devices belong to the same installation. For example, visual or auditory effects, or call-to-action messages, such as "Look at the large screen", can be used to visualize this direct connection.

Motivation and evidence: Brudy et al. (2019) still describe this communication of cross-device interaction capabilities as a challenge. In Babenberg GenVis (Part III), we positioned the touch displays in front of the printed family tree to clarify that it was possible to interact with the projection via the touch displays. Each interaction with a touch display triggered changes in the projection on the family tree's dedicated side, allowing visitors to see the effects of their navigation and their neighbor's navigation. In Iteration 2, we observed a lack of understanding of the connection between devices. When exploring the setup for the first time, visitors might pay special attention to the visualization on the touch display and not even notice its impact on the projection. The same seemed to happen when visitors looked at the printed family tree with the projection for a while and did not notice the touch displays. With the changes in Iteration 3, we addressed these challenges. We showed improvement by adding additional cues to support attention redirection in the form of on-screen cues (for touch display and projection).

This guideline refers to the reflection of the second design study (Chapter 15).

X. Connect mobile devices only if it provides a clear added value.

Recommendation: Integrating the visitors' own mobile device into the museum ecology can be useful to create a private space for exploration and enhance the visitors' experience.

This option should only be offered if there is a clear benefit for visitors.

Motivation and evidence: Hakvoort (2016) suggests that when using a mobile device for user interaction within a museum, the device should be treated as an integral part of the intended interaction. If the mobile device is only used for a part of the interaction, it becomes an inconvenience that the user tries to resolve.

In our case, we developed a rich mobile application with visualization (Part II) and detailed information about exhibits. By connecting the app to Babenberg GenVis (Part III), visitors could collect two additional parts to create their coat of arms. Only 6% of the app users were connected to Babenberg GenVis. On the one hand, we may not have communicated the added value well enough. On the other hand, the feature might not have been beneficial enough for the visitors. In contrast to Babenberg GenVis, the Weißkunig Quiz, in which visitors could connect with their devices to play against each other, was an excellent example of having and communicating a clear benefit.

This guideline refers to the reflection of the second design study (Chapter 15).

XI. Keep in mind the technical requirements of a multi-device setting.

Recommendation: Consider the technical requirements, such as the need for an extensive backend, and the challenges of a multi-device setting (e.g., latency and scalability).

Motivation and evidence: During the exhibition, we had different multi-device installations. For instance, in Babenberg GenVis (Part III), visitors could interact with the projection using two stationary touch screens. In Weißkunig Quiz, on the other hand, users could join mainly with their own devices, apart from the stationary tablet. In the first example, we have a relatively static setting, in which the devices are already connected when the visitor arrives. The latter example is a dynamic setting, in which multiple visitors can connect and disconnect their devices. That involves infrastructure and usability challenges, as users have to figure out how to join the experience, and the system has to support multiple connections from different device types.

This guideline refers to the MEETeUX guidelines (Appendix H.2.5).

XII. Prefer widely available smartphone features.

Recommendation: In a BYOD setting, make the app accessible to most devices. It is important to pay attention to which sensors and functionalities are fundamental for the application.

Motivation and evidence: The more devices and operating systems the development team tries to cover, the more difficult it is to get the application running on most devices. The decision for a web application that runs in a web view enabled us to support more operating systems. However, when designing an app that uses Bluetooth for location awareness, not every device behaves the same way. During the design phase, we conceived an app which would first display exhibitions as locked items on the screen (Part II). As the visitor navigates through the museum and passes by the exhibit, the app's corresponding item should unlock automatically. Even after testing multiple devices and operating systems, we could always find visitors whose device behaved unexpectedly. Then, to allow for consistent user experience, we stopped relying on Bluetooth detection to unlock the content. For every user, the content was then available from the beginning. Nevertheless, if the device would support Bluetooth detection, we allowed the visualization to scroll to the closest exhibition as an smart extra feature.

This guideline refers to the MEETeUX guidelines (Appendix H.1.4).

XIII. Create entry points for the mobile app.

Recommendation: Mark the connection between the app and physical artifacts very clearly. If the app lists the artifacts visitors can find in the exhibition, visitors should be able to correlate physical artifacts and digital elements easily. Create mechanisms, such as entry points, in which the user knows exactly when to take the mobile.

Motivation and evidence: The user should focus on the exhibits when necessary and on the mobile on-demand. It helps visitors not to walk around the museum with their eyes only on the mobile app and miss the museum experience.

Our first solution to establish the connection between physical artifacts and the mobile app's content was to automatically scroll the screen and highlight the corresponding item depending on the position of the visitor (Part II). Furthermore, we had stickers around the exhibition signaling which artifacts were also displayed on the mobile app. Such stickers carried the logo of the app and the color of the corresponding section (see Figure 17.1). However, when the location-aware features were not available in a device, the sticker was not enough to inform where to find information about the physical artifact in the app.

This guideline refers to the MEETeUX guidelines (Appendix H.1.6 and Appendix H.1.7).

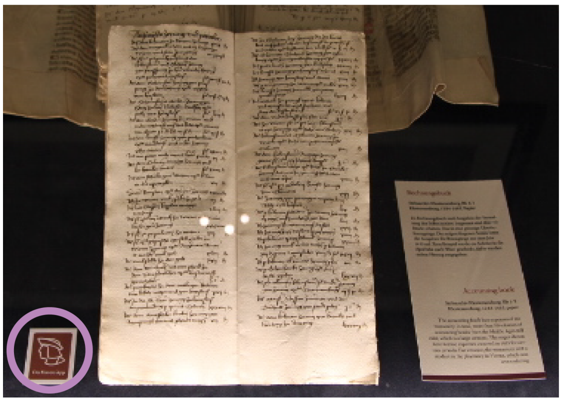


Figure 17.1: Sticker indicating physical artifacts connected to the mobile app.

XIV. The prototype option should consider the interaction needed.

Recommendation: Interaction should be the key factor when deciding on prototype fidelity. If the interaction varies between designs, all interactions must be implemented as they should work in the final version (i.e., with higher fidelity). Otherwise, use lower-fidelity prototypes and simulate interactions (Hartson and Pyla, 2018) (e.g., with a wizard-of-oz technique (White and Lutters, 2003)).

Motivation and evidence: In Iteration 1 of our mobile visualization design (Part II), we created medium-fidelity clickable mockups as we wanted to make use of the real physical device (Hartson and Pyla, 2018). Nevertheless, we noticed that there might be an effect of the static mockup setup, particularly on the *Timeflower* assessment. The design of *Timeflower* included a wheel interaction not present on the other designs. Missing interaction elements (e.g., a smooth spinning of *Timeflower*) may influence the perception of the visualization representation, especially when comparing familiar (*Timeline* or *Bookshelf*) with non-familiar techniques (*Timeflower*). Therefore, we conclude that click dummies are not always optimal for comparing different visualization techniques.

This guideline refers to the reflection of the first design study (Chapter 9).

XV. Be aware of different target groups among the museum visitors.

Recommendation: The aim of interactive visualization must be precise and must focus on specific target visitors. The content that is interactive, cooperative, and personalizable would also address different groups differently. It is, therefore, necessary to test the content with participants with different profiles.

Motivation and evidence: In general, museum audiences and thus casual users of visualizations are described as diverse, different in age, interests, experience with technology, and motivation in dealing with technology (Hinrichs et al., 2013; Pousman et al., 2007). When assessing different visualization alternatives for the mobile app (Part II), we observed no differences in performance with the exception of user experience. Familiarity with the visualization type and the ability to understand it was notably different across different age groups. The better experience reported by middle- and old-aged subjects, who are the primary visitors to the exhibition, was decisive to choose the final visualization. Reflective interviews also showed the interactive installations being highly attractive to young groups and school classes due to their playfulness. Finally, we also observed different ratings from visitors with different levels of visualization literacy. Therefore, it is always essential to consider visitors with different profiles in a museum exhibition.

This guideline refers to the reflection on the first design study (Chapter 9).

XVI. Combine quantitative scores with qualitative feedback.

Recommendation: Since quantitative data can support qualitative data interpretation (Creswell and Creswell, 2018), prefer approaches with mixed methods when evaluating museums' applications.

Motivation and evidence: In our studies for the development of the mobile app visualization (Part II), we wanted to perform a comparative evaluation while still considering the users' experience. Therefore, we selected a combination of a task-based method and structured Likert-scale questions, which could also work in the real museum situation and had been used before (e.g., Jimenez and Lyons, 2011). This allowed us to adequately observe when the users' performance deviates from their perceived performance. Using a mixed-method, we were able to search for statistical effects between the designs. Asking the participants about the motivation for their ratings also provided us with additional qualitative information that could be combined with the ratings. We also used the combination of task-based method and structured Likert-scale questions to evaluate Babenberg GenVis (Part III). In addition, we performed a log data analysis to extend the amount of quantitative data and reflection interviews for a deeper reflection based on qualitative feedback.

This guideline refers to the reflection of the first design study (Chapter 9 and Chapter 15).

XVII. Performing tests in the museum is always essential, leave highly controlled comparison tests for the lab.

Recommendation: Run observations and functional tests in the museum. Highly controlled comparative evaluations should be performed in a controlled lab setting.

Motivation and evidence: In Iteration 2 of our first design study (Part II), we tested our location-aware mobile visualization in two settings. The lab provided a controlled setting aiming at high internal validity. Besides, we wanted to address the lack of knowledge about the context of usage (Blumenstein et al., 2016) through additional testing in the museum. Performing a comparative study in a running exhibition environment meant much effort. That is why we used a school class. However, in such classes, the population is far too homogeneous, with participants presenting similar profiles. In our study, the two questions focusing on the location-aware aspect (noticing the closest object & suitability as a guide) were rated significantly higher by the museum group, which might indicate a clear benefit in using the real exhibition setting. However, the museum group was the same as the youngest age group. Therefore, we cannot differentiate between the effects of age group and test set.

This guideline refers to the reflection on the first design study (Chapter 9).

17.3 Summary

This chapter presented our guidelines for designing and evaluating future projects that interweave physical artifacts with data visualization on digital media in museums. Table 17.1 shows an overview of our guidelines and categorizes them along with their topic(s) addressed (visualization, installation in museums, multi-device ecologies, mobile app, or

Table 17.1: Overview of our guidelines that are categorized based on the topic(s) they addressed and the subspace(s) of our Design Space.

Guideline	Topic	Design Space
I. Choose familiar and linear visualization techniques.	Visualization	Visualization Space
II. Support readability in timeline visualization.	Visualization	Visualization Space
III. Combine guided and free exploration.	Visualization	Visualization Space
IV. Prioritize immediate apprehendability.	Installation in Museums	Physical Space, Digital Media Space, Contextual Space
V. Keep visitors' walking paths in mind.	Installation in Museums	Physical Space, Digital Media Space, Contextual Space
VI. Allow to enter at any state.	Installation in Museums	Digital Media Space, Contextual Space
VII. Involve the exhibition staff through co-design.	Installation in Museums	Physical Space
VIII. Be aware of technical challenges.	Installation in Museums	Physical Space
IX. Make the connection between multiple devices salient.	Multi-device Ecologies	Digital Media Space, Contextual Space
X. Connect mobile devices only if it provides a clear added value.	Multi-device Ecologies, Mobile App	Digital Media Space, Contextual Space
XI. Keep in mind the technical requirements of a multi-device setting.	Multi-device Ecologies, Mobile App	Digital Media Space, Contextual Space
XII. Prefer widely available smartphone features.	Mobile App	Digital Media Space
XIII. Create entry points for the mobile app.	Mobile App	Physical Space, Digital Media Space, Contextual Space
XIV. The prototype option should consider the interaction needed.	Evaluation, Mobile App	Digital Media Space, Visualization Space
XV. Be aware of different target groups among the museum visitors.	Evaluation, Visualization, Installation in Museums, Mobile App	Physical Space, Contextual Space
XVI. Combine quantitative scores with qualitative feedback.	Evaluation	-
XVII. Performing tests in the museum is always essential, leave highly controlled comparison tests for the lab.	Evaluation	Physical Space

evaluation) and the subspace(s) of our Design Space that is influenced by this guideline (Physical Space, Digital Media Space, Contextual Space, or Visualization Space). These guidelines were derived from the critical reflection of our two design studies in Part II and III, combined with the reflection of the research project MEETeUX. With these guidelines, designers, developers, and exhibition curators can better understand applications with data visualization connecting the physical with the digital world and how they can be integrated into exhibitions.

Next, we discuss future research directions based on our research (Chapter 18).

CHAPTER 18

Future Directions

This chapter describes future directions based on our research results in Part I, Part II, and Part III, as well as the guidelines we developed (Chapter 18).

Based on our research results, we propose future research directions that guide researchers, designers, and developers of interactive visualization systems for museums that are interwoven with physical artifacts. We extracted these future directions from the development of our Design Space (Part I), the two performed design studies (Part II and Part III), the application of the design studies to our Design Space, and the derived guidelines (Part IV).

Extending Design Space with Evaluation Space

Evaluation is essential for developing meaningful and entertaining visualization installation for museums. While early evaluations are necessary, initial prototypes of installations are often not ready for a "naturalistic user study in the wild" (Hornecker and Nicol, 2012). Hornecker and Nicol (2012) also found that usability problems "observed in the wild were largely identical to those in our semi-realistic user study." However, especially observations of social behavior patterns were different between a semi-realistic lab and a museum setting. To fully understand the installation, an iterative approach using mixed-methods is useful. Therefore, a deeper understanding of the success of different evaluation methods is necessary. Besides, Konstantakis and Caridakis (2020) already explored user experience research in cultural heritage.

As our Design Space is currently modeled from four areas (Physical Space, Digital Media Space, Contextual Space, and Visualization Space) to mainly describe installations that integrate visualization in museums, it cannot hold information about evaluation methods. In a future step, we can extend our model with an Evaluation Space to give a structured overview of evaluation methods for such installations.

Combining Guided and Free Exploration

Onboarding is an essential process, not only for casual users, to learn and understand how visualization should be perceived (Stoiber et al., 2019). For museum visitors, this process must be short or integrated into the visualization, as visitors interact for an average of only about 2 min. Therefore, a combination of guided and free exploration could be promising. Our idea is to start with a guided exploration through a story that transfers the main story of the exhibition into the visualization. The visualization then, step by step, expands the underlying data to open the visualization for free exploration.

Designing Diverse Visualization for Museum Visitors

Data visualization can make hidden but existing data of museums visible to their visitors. On the other hand, museum visitors have a rather low level of visualization literacy (Börner et al., 2016). However, we see the potential to counteract this low level by introducing different visualization techniques to museum visitors. To achieve this goal, the visualization must be easy to understand, which might require an adaption of existing techniques. The point already mentioned (Combining Guided and Free Exploration) can help here as well.

We can also use devices that visitors are already familiar with (e.g., the mobile phones they carry). In this way, we reduce the interaction barrier, as visitors already know how to use the device and can explore the visualization in a private space. In our work, we focused on time-oriented visualization for mobile devices (Part II) and an installation with multi-devices (Part III). For the mobile app, we dealt with different timeline visualization (diagram, graph/plot, and other charts). For the multi-device setting, we combined a genealogical tree visualization with a timeline (diagram and graph/plot). However, other visualization techniques need to be explored and brought to museum visitors to increase their visualization literacy level.

Interweaving Artifacts with Visualization for More Immersion

As we found in Chapter 4, only a small number of current visualization installations (seven times) in museums are interwoven with physical artifacts and represent a situated visualization. However, mainly traditional museums with their exhibited artifacts (observable artifacts) offer enormous potential for such visualization. With this work, we provided a starting point to focus on the connection between physical and digital visualization worlds in museums. Nevertheless, more research can be done in this area, focusing on situated analytics and direct visitors' attention between the physical and digital worlds. An exciting aspect could be the use of glasses and how these changes as opposed to using a mobile device combined with see-through technology to link data with the context in which visitors are currently located.

Creating Accessible Data Visualization in Museums

"New technology in a museum environment can provide access for disabled people through digital media." (Lisney et al., 2013) However, visually impaired people, in particular, suffer from the use of screen technology alone (Lisney et al., 2013) that we used in our two design studies in Part II and Part III. Integrating visitors' devices (used in Part II) can represent an opportunity for them as they are known and assist with screen reader technology when developed correctly.

Dealing with perception dimensions other than the sense of sight is essential to developing integrative applications and present an artifact to the broadest possible audience. Therefore, we should intensify research in the field of sonification (Kramer et al., 2010) for museum visitors in order to additionally use the audio channel for the transport of data information. On the other hand, we should direct the attention of research in multi-sensory immersive analytics (McCormack et al., 2018) to museums, e.g., by integrating data physicalization (Jansen et al., 2015) or haptic data visualization (Paneels and Roberts, 2010).

Focusing on the Attention Switch in Multi-Device Ecologies

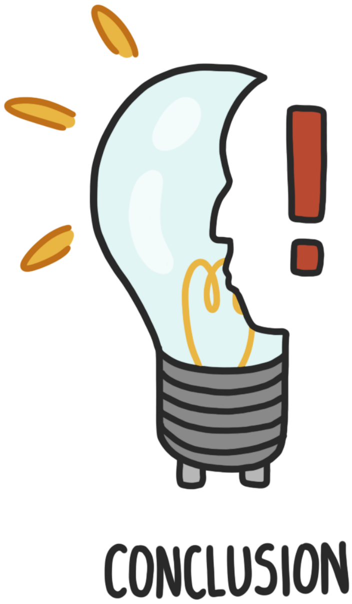
Brudy et al. (2019) stated "conveying cross-device interaction capabilities" is still a challenge. In our research (Iteration 3 (Chapter 14) in Part III), we addressed this challenge and showed improvement by adding extra cues to support attention redirection in the form of on-screen cues. Still, more research is needed in this area. For example, a comparison of different approaches to supporting the shift of attention from one device to another (e.g., auditory feedback, movement of objects). Especially for MDEs where visitors do not set up the device connections themselves, this relationship needs to be conveyed very clearly.

Combining Embodied & Bodily Actions with Multi-Device Experience

This work was completed in 2020 during the outbreak of SARS-CoV-2 (COVID-19). Therefore, we could not change the research, which mainly focuses on touch interactions. However, such surfaces might become contaminated through touch or droplets. Even if it seems that indirect transmission of the virus via surfaces tends to play a lesser role in its spread (Döhla et al., 2020), HCI research should address this potential risk of infection from person to surface to person. As shown in Chapter 4, embodied actions have attracted increasing interest in recent years. This interaction possibility reduces the risk of infection via surfaces as visitors interact with their bodies and not directly with a surface. Such indirect interactions for installations in museums can be combined integrating the visitors' mobile device in a multi-device ecology. As the visitors' device is usually only used by a single person, infection risks can be reduced. This combination seems to be a promising approach that still allows for interactive installations in museums without the need to disinfect surfaces frequently. We did not find such combinations in our state-of-the-art report (Chapter 4). Therefore, we should address this issue in future projects.

CHAPTER 19

Conclusion



In this chapter, we conclude this thesis with a summary of our work and answer the research question raised in Chapter 1.3.

This thesis aimed to explore how we can interweave physical artifacts with data visualization on digital media in museums. We wanted to gain a better understanding of how the physical and digital worlds can be combined and how visualizations for museum visitors can be designed. Therefore, we raised research questions in Chapter 1.3 and can now answer them in detail. The answers are based on the two performed design studies on developing and evaluating applications integrating data visualization into museums: 1) a mobile app visualizing historical data (see Part II) and 2) Babenberg GenVis – an interactive multi-device visualization extending a painted genealogy (see Part III). These design studies fill knowledge gaps determined by a state-of-the-art report categorized along our Design Space for interweaving physical artifacts with data visualization on digital media in museums (see Part I).

Main Question: *How can visualization methods be used in interweaving physical artifacts with digital media in museums?*

In our Design Space (Chapter 3), we discussed the fundamentals for creating data visualization applications interwoven with physical artifacts in museums. Within Visualization Space, we summarized the most common visualization methods. Our STAR (Chapter 4) showed which visualization methods are currently used in museums and how physical artifacts are interwoven. Currently, mainly multidimensional data are used (17 out of 28 times). Network, hierarchical, and other data are underrepresented. Temporal and spatial semantics are often integrated (16 and 18 times). In terms of presentation techniques, maps are the most commonly used technique (15 times). Graphs/plots, diagrams (often tree visualization), and other charts (from volumetric visualization to the use of the metaphor of tree rings) are underrepresented. Most visualization is implemented in 2D. Furthermore, it is not common in museums to interweave visualization with physical artifacts as physical referents. Only seven researched approaches are implemented as situated visualization and thus linked to a physical artifact.

To answer the main question further, we first give the answers to our sub questions.

Sub Question 1: *What types of interweaving physical artifacts with digital media are feasible in museums?*

Within Contextual Space (Chapter 3.3) in our Design Space, we introduced various ways to interweave digital media with physical artifacts: Standalone (there is no connection), contextually embedded (highly integrated with a focus on the physical artifact), mobile interaction (the mobile device is carried by visitors and triggers actions based on location or exhibition content). In addition, there is the possibility to combine a mobile artifact with standalone and/or contextually embedded installation to create assemblies. In general, all of these installation types exist in museums. However, our STAR (Chapter 4) showed that in combination with visualization, the most frequently shown installations are standalone ones (24 times). Thus, the combination of installations with visualization with exhibition objects is not common at present. An example (Rogers et al., 2014) presented a mobile application that displayed detailed information about the exhibits using a search. Three other installations (Cho et al., 2019; Cosley et al., 2008; Roberts et al., 2018) were placed next to the exhibit in relation to the visualization presented in the installation (contextually embedded).

In our first design study (Part II), we developed a mobile visualization integrated into a location-aware mobile application (mobile interaction). Visitors walking through the exhibition automatically received additional information and interaction possibilities next to a featured physical artifact. For this purpose, we integrated texts and images, augmented reality extension (e.g., a transcription from unreadable Old German into Higher German), a multiple-choice quiz, and possibilities to connect to interactive installations such as Babenberg GenVis (Part III) or the multi-user quiz (Weißkunig Quiz). Our visualization served as a guide through the exhibition.

In our second design study (Part III), we worked with a not observable physical artifact that could not have been presented in the exhibition space. We created a printed reconstruction of the Babenberg family tree (Chapter 10.2) and extended it by projection with Babenberg GenVis - an interactive, multi-device visualization. Therefore, we developed a contextually embedded installation that goes beyond positioning the installation next to an artifact. We tightly interweaved the analog and digital world, since the digital implementation could not work without the printed artifact.

We demonstrated the feasibility of two options for interweaving physical artifacts with digital media in museums: 1) the tightly interwoven Babenberg GenVis and 2) a mobile visualization that automatically connects to the artifacts providing additional information or interaction possibilities. Two further options are presented in the literature to position installations (e.g., horizontal or vertical displays) either next to the corresponding artifact or somewhere where it has no connection to a physical artifact (Chapter 4).

Sub Question 2: *What types of visualization and types of interaction can best be used for the chosen design studies?*

Both design studies presented an application area selected based on knowledge gaps identified in our state of the art report (Chapter 4). The first design study (Part II) addressed the gaps *missing mobile visualization for museums* and *full spectrum of representation techniques is not used* by developing visualization designs for a location-aware mobile application for visualizing historical data. During the iterative development, we first created three basic visualization concepts (the linear vertical *Timeline*, the grid-based *Bookshelf*, and the radial *Timeflower*). By conducting a comparative evaluation with clickable mockups, we found that the linear timeline approach was the most appropriate visualization technique. For the second iteration, we therefore compared three linear timeline approaches (*Stack-based* – a faceted layout, *Section-based* – a chronological scale with pagination, *All-in-one* – a chronological scale as unified option prioritizing time over exhibits' order). Our qualitative results showed that participants performed slightly better with the *All-in-one* design. On the other hand, the *Stack-based* and *Section-based* design yielded close and slightly better scores than the *All-in-one* design in quantitative results. Especially middle- and old-aged participants rated the *Section-based* visualization as more comprehensible. We, therefore, decided to implement the *Section-based* approach into our mobile application.

In our second design study (Part III), we addressed the gaps *multi-device ecologies integrating visualization are rare*, *physical artifacts are not often linked to visualization*, and *full spectrum of representation techniques is not used*. We developed Babenberg GenVis – an interactive, multi-device visualization of a historical genealogy painting. We followed a 3-staged iterative development process starting with functional prototype testing in a lab setting, followed by the installation and testing in the museum with an additional iteration within the museum to address challenges we identified such as understanding the connection between the devices and convincing visitors to start interacting with Babenberg GenVis. We demonstrated the applicability of horizontal timelines combined with a tree visualization in this multi-device and casual user environment. However, there is the need to support the readability of the visualization by well-known icons (e.g., for birth, death, and marriage dates) and to show a clear connection between children and parents, which we also supported with icons.

In terms of interaction, we showed in our STAR (Chapter 4) that the most common interaction method is direct touch manipulation (16 times). Using tangibles, controls, presence, or embodied / bodily interaction is currently not that common in combination with visualization techniques. For our first design study (Part II) on mobile devices, we decided to implement the most common interaction technique for mobile phones: presence (the visualization reacted on the exhibit the visitor is next to) and direct touch manipulation (for direct interaction with the visualization via the mobile touch screen). We did not observe any challenges for visitors to interact with the visualization. Also, visitors did not show difficulties in using the vertical scrolling of the timeline. As our second design study (Part III) was a multi-device visualization, visitors had to deal with different explicit interaction techniques. On the one hand, we implemented direct touch manipulation to interact with the visualization on the touch displays again. On the other hand, visitors controlled the projection by selecting persons on the touch display (touch control). Overall, visitors noticed direct touch interaction and were able to use them. However, the horizontal scrolling of the timeline was not obvious for every visitor. Recognizing that they control the projection as well was not that apparent and needed additional cues. We implemented a visual overlay that hinted to the projection when a person was selected on the touch display, which showed an improvement in understanding this control.

In conclusion, we can summarize that visualization designers should prefer familiar and linear visualization techniques (Guideline I, Chapter 17). Since we focused on time-oriented data, timelines were shown as suitable in general for use in a museum. These timelines can be designed in a horizontal (as shown in Babenberg GenVis, Part III) as well as in a vertical layout (as shown for our mobile application, Part II). Using well-known interaction techniques is also crucial. When connecting multiple devices, visitors need additional cues to understand the connection, especially how they control one device with another (Guideline IX, Chapter 17).

Sub Question 3: *If the physical artifact itself is a visualization - how can the artifact be dynamically extended through a backchannel?*

We have not found any examples of such installations in museums in our state-of-the-art report (Chapter 4). Babenberg Genvis (Part III) shows an example of how a physical artifact representing a visualization can be dynamically extended. The printed (physical) artifact was a tree visualization showing the direct bloodline from Leopold III to the last legitimate heir of the Babenberg family together with their wives. We extended the physical artifact using projection based on visitors' selection on one of the two touch displays. Visitors were able to select a person from the Babenberg family with the timeline on a touch display. We then used the projection to show further information and connected the selected person with the relative(s) depicted on the printed physical artifact by an additional branch. Through the creation of a reconstruction of the original painted tree visualization, we mastered three challenges: 1) the original could not be moved into the exhibition space, 2) a projection on the original painting would have raised concerns about conservation issues such as too much light, and 3) in the original painting, we would have no space to project additional information.

Another idea not captured by this thesis is to use such a backchannel to combine an existing (analog) visualization with user-generated data. Similar to our map showing the dominion of the Babenberg, this map (or a bigger one showing entire Europe) could be extended by marking the home towns of visitors who are viewing the exhibit, if it were a physical artifact. This could be realized with a mobile application asking for this information, and when visitors are close to the exhibit, the analog visualization would get extended digitally.

Sub Question 4: *How can multi-device ecologies enrich such settings?*

In our Design Space (Part I), we differentiate between three options for multi-device usage: simultaneous (used at the same time), sequential (devices are used one after the other), and mirrored (interactions are mapped to an additional device). These options were also present in our STAR, focusing on approaches with visualization (Chapter 4). Compared to the single device use (20 times), implementing multiple devices is underrepresented (eight times). The simultaneous settings often utilize smaller touch displays to control a visualization on a room display. The sequential setting is often used first to specify (own) data on one smaller device and then experience the visualization with another device. However, all of the analyzed multi-device settings are not interwoven with a physical artifact.

Our second design study (Part III) presented an example of how a multi-device ecology can be interwoven with a physical artifact. We extended the artifact through projection. Visitors could control the projection by interacting with a time-oriented genealogy visualization on touch displays. Through this MDE, we were able to highly interweave the analog world of the physical artifact with the digital world of the projection and touch displays. This interdependence would not have been so strong, when we used a single-device setting, e.g., positioning only the touch display next to the physical artifact.

Sub Question 5: *What are best-practice guidelines for interweaving physical artifacts with digital media in museums?*

We derived best-practice guidelines for developing installations that interweave physical artifacts with data visualization on digital media in museums from the reflection and lessons learned in our two design studies (Part II and III) combined with developed guidelines in the framework of the research project MEETeUX. Chapter 17 presented these guidelines.

I. Choose familiar and linear visualization techniques.
II. Support readability in timeline visualization.
III. Combine guided and free exploration.
IV. Prioritize immediate apprehendability.
V. Keep visitors' walking paths in mind.
VI. Allow to enter at any state.
VII. Involve the exhibition staff through co-design.
VIII. Be aware of technical challenges.
IX. Make the connection between multiple devices salient.
X. Connect mobile devices only if it provides a clear added value.
XI. Keep in mind the technical requirements of a multi-device setting.
XII. Prefer widely available smartphone features.
XIII. Create entry points for the mobile app.
XIV. The prototype option should consider the interaction needed.
XV. Be aware of different target groups among the museum visitors.
XVI. Combine quantitative scores with qualitative feedback.
XVII. Performing tests in the museum is always essential, leave highly controlled comparison tests for the lab.

This thesis showed that it is currently not common to use visualization methods interwoven with the physical artifacts of museums. With our two design studies, we presented two options for visualization methods in such settings. On the one hand, visualization on mobile devices (Part II) can guide the visitor through the exhibition and, thus be interwoven with the presented physical artifact in the sense of providing additional data (e.g., text, image, quizzes, augmented reality extensions) situated based on the location of the visitor. On the other hand, a multi-device visualization (Part III) can be tightly interwoven with a physical artifact that itself represents a visualization.

Our research focused on rather small amount of data necessary to enrich the exhibits in our exhibition (Chapter 5.3). Scientific research in visualizing cultural heritage collections (e.g., Goldfarb and Merkl, 2018; Gortana et al., 2018; Salisu et al., 2019; Windhager et al., 2019) deals with larger amounts of data. Nevertheless, such cultural heritage collections are usually not known to be used during a museum visit. Future research could combine these two worlds and make large cultural heritage collections accessible for a museum visit. For sure, there is the need to adapt currently used visualization techniques, for example, for location-aware mobile phone use.

Furthermore, when focusing on interweaving physical artifacts with data visualization, we did not address the research of learning effects when integrating visualization in an exhibition. Other research exists about the visualization literacy of museum visitors (Börner et al., 2016; Wojton et al., 2018). As we have now evaluated examples of how physical artifacts can be interwoven with visualization methods, it would be interesting to continue with research on how visualization impacts the learning of visitors.

Part V

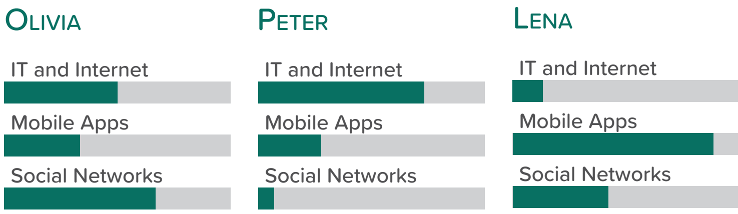
Appendix, Bibliography, Lists of Figures & Tables

APPENDIX A

Personas Developed in the Context of the MEETeUX Project

Family Egger

AGE 10, 35, 37
OCCUPATION -
STATUS -
LOCATION Pressbaum
LANGUAGE German, English



Picture by Elene Borisova on Pixabay

Picture by melancholiaphotography on Pixabay

Picture by Pezibear on Pixabay

GOALS

- plan museum trips at home
- see the route through the museum on the mobile phone

BIO

The family Egger consists of the father Peter (37), the mother Olivia (35), and Lena, a girl of 10.

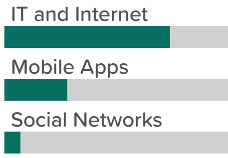
Although they have different interests, they try to do more things together during their free time. As the mother works from home, she doesn‘t want to spend her free time there as well. Therefore, the family makes short trips to the countryside and visits cities nearby. Nearly every weekend, one family member gets to choo-se an activity that balances all family members‘ interests.

Their technology skills also vary widely, but together they have a solid understanding of technology.

Peter Egger

AGE 37
OCCUPATION Technician
STATUS Married
LOCATION Pressbaum
LANGUAGE German

TECHNOLOGY



Picture by melancholiaphotography on Pixabay

GOALS

- finish building his house
- interested in a museum app which shows him parking spaces near the museum and the cafeteria

BIO

Peter is currently employed at Neuman Aluminium in Lilienfeld as an automation technician. He and his wife bought a house in Pressbaum, which is an hour‘s drive from his workplace.

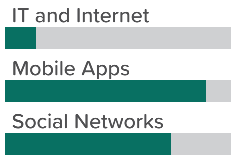
Peter doesn‘t use many apps. He likes the weather app, and sometimes he plays mobile games while he is on the train to work. He used to be on Facebook but he didn‘t like the structure, and he didn‘t understand why everyone had to know what he does with his free time.

Peter has a daughter named Lena. He would never go to the museum alone, but since his daughter is interested in dinosaurs, he wants to go to the museum with his daughter on his day off.

Lena Egger

AGE 10
OCCUPATION Student
STATUS -
LOCATION Pressbaum
LANGUAGE German

TECHNOLOGY



Picture by Pezibear on Pixabay

GOALS

- to study anthropology
- interested in interactive exhibits at the museum which allow her to approach the topics in a playful manner
- wants to experience exhibits by touching them

BIO

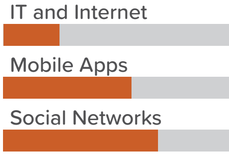
Lena attends the 4th grade at the Volksschule Pressbaum. She is always on her mobile phone, using WhatsApp and Snapchat to communicate with her friends. Lena likes to play on her console. She couldn't decide between the two new consoles, so now she owns the X-Box One and the PS4.

At the age of 8, she started being interested in dinosaurs. In addition to her hobby, she has read many books on anthropology. Because her dad has such long working days and she isn't allowed to visit Vienna on her own, she was amazed to get a ticket to the Natural History Museum on her 10th birthday last week.

Anneliese Eichberger

AGE 66
OCCUPATION Retired, former tram driver
STATUS Widowed
LOCATION Vienna
LANGUAGE German

TECHNOLOGY



Picture by Orna Wachman on Pixabay

GOALS

- wants to be up to date
- straightforward installations
- doesn‘t want to hold her mobile phone during the whole visit
- has many interests but doesn‘t want to explore everything in the museum
- doesn‘t like small buttons on a touch surface

BIO

Anneliese is a former tram driver, and she lives in Vienna in a flat. She walks daily to stay fit and meets with her girlfriends for a coffee. They have their own Facebook group to discuss upcoming meetings and talks.

She relies on crutches since she underwent hip surgery a while back. Since then, it has been challenging for her to climb stairs.

Anneliese frequently visits the museum so that the conversation topics always remain stimulating. She has an annual ticket for all museums in Vienna. Anneliese visits the museums on her own because she wants to enjoy the moment alone.
The new exhibitions always bring new gadgets in technology. Anneliese likes to try new things and tell her grandchildren about it. For the grandchildren, it is sometimes nothing new, but she wants to feel like a grandma who keeps up with the times.

High School Class 3RG

AGE 13, 28
OCCUPATION Teacher and students
STATUS -
LOCATION Pressbaum
LANGUAGE German, English

Students

IT and Internet

Mobile Apps

Social Networks

Teacher

IT and Internet

Mobile Apps

Social Networks

Jochen Zick, action press / Flickr, CC BY-ND 2.0, https://creativecommons.org/licenses/by-nd/2.0/licenses/by-sa/2.0/

GOALS

- class trip to Rome
- an interactive exhibit which allows them to play games together

BIO

This is the high school class 3RG of the Gymnasium Lilienfeld. All students are 13 years old. They all choose the science branch because they are more interested in technology than languages. All students have their own mobile phones. They don‘t use Facebook because of the age limits, but they have a WhatsApp group, and most of them are on Instagram and Snapchat.

Their German teacher is a young woman (28 years old). Mag. Stefanie DiLorenz is technically versed. In her free time, she is a lifestyle blogger.

Every year she and her 3rd-grade school class visit the Landesmuseum St. Pölten. The museum offers science exhibitions and also some interactive installations. The science classes are always very interested because there is a strong emphasis on putting the theory into practice.

Stephanie DiLorenz

AGE 28
OCCUPATION High School German teacher / Lifestyle blogger
STATUS In a relationship
LOCATION Lilienfeld
LANGUAGE German, English

TECHNOLOGY

IT and Internet

Mobile Apps

Social Networks

Pixino.com

GOALS

- a mobile app which offers quizzes for her school class
- extend theoretical educational material with the visit to a museum and bring the learning experience from the museum into the classroom afterward

BIO

Stephanie is a German teacher in Lilienfeld, and besides, she blogs about everything that happens in her life. She heeps her blog separate from her private life, so only friends can see personal information. She posts pictures of her cooked meals, the interior design of her home, and creates travel guides of cities that she visited and makes book recommendations.

Stephanie and her boyfriend also offer courses in photography and image editing. Her life is very public, but she loves to share the beauty of life with the world. She only promotes items that support her lifestyle. Her new favorite app is an Augmented Reality app, which allows her to furnish her home.

Stephanie has front-end skills and writes her blog with Wordpress. She also knows how to update the site.

Stephanie is also very active on Instagram and Snapchat. She has two accounts, one for closer friends and a public one.
She loves being a teacher, this is what she always wanted to be.
Stephanie still feels up-to-date because she works with the younger generation.

ALINA ZIMMER

AGE 13
OCCUPATION Student
STATUS Single
LOCATION Lilienfeld
LANGUAGE German, English

TECHNOLOGY

IT and Internet

Mobile Apps

Social Networks

Jochen Zick, action press / Flickr, CC BY-ND 2.0, https://creativecommons.org/licenses/by-nd/2.0/licenses/by-sa/2.0/

GOALS

- interactive installations which offer the possibility to interact with others (teamplay)
- understands processes better when she can see them

BIO

Alina is a student of the 3RG and is well integrated into the class. Alina likes to educate herself further.

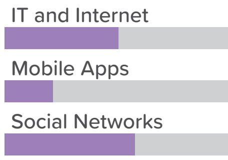
She likes school trips to museums the most. There are sometimes helpful installations that she wants to try out. She loves applications which offer a multiplayer mode.

Playing games like Quiz Duell together where each student has their own questions on their device is very popular in her class.

Raphael Halm

AGE 13
OCCUPATION Student
STATUS -
LOCATION Wilhelmsburg
LANGUAGE German, English

TECHNOLOGY



Jochen Zick, action press / Flickr, CC BY-ND 2.0, https://creativecommons.org/licenses/by-nd/2.0/licenses/by-sa/2.0/

GOALS

- applications for single-use
- personalization applications and collectibles

BIO

Raphael is also a student of the 3RG, but unlike Alina, he is timid and calm. His classmates accept him, but Raphael doesn‘t like to interact with them. He enjoys quiet privacy.

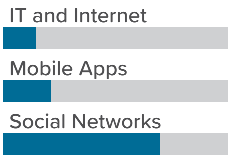
The class trip to the museum is another experience of teamwork for Raphael, so he tries not to get lost in the shuffle and try out applications himself. Raphael would like to see some apps which are using new technologies like Augmented Reality or Virtual Reality. Also, apps with which he doesn‘t have to interact with others.

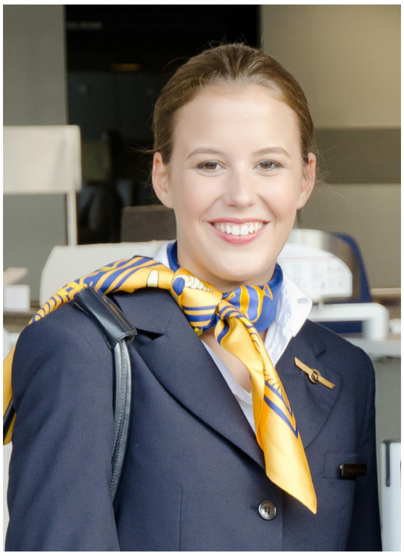
Raphael doesn‘t use apps on his smartphone. He is always on the computer and watches YouTube videos. „Linus“ is a YouTuber who explains computer technology - his channel is Raphael‘s favorite. He tries to put Linus‘ experiments into practice.

Aleksandra Virtanen

AGE 34
OCCUPATION Flight attendant
STATUS Single
LOCATION Finland
LANGUAGE Finnish, English, Spanish, Italian

TECHNOLOGY





Condor.com / Flickr, CC BY-SA 2.0, https://creativecommons.org/licenses/by-sa/2.0/

GOALS

- learn more about the culture of the countries she visits
- an app for all museums in a city and planning an efficient route to visit more museums on a day
- navigation to the museums
- wants to be guided to the important exhibits because of lack of time

BIO

Aleksandra is a 34-year-old Stewardess from Finland. She visits 2 different cities every week. She has not much free time, and her only contact with her family and friends is through Facebook, WhatsApp, and Skype.

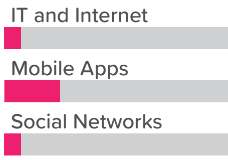
Because she wants to learn something about the cities she visits, Aleksandra sometimes visits museums on her own. She doesn‘t have extra time for this, so she rushes trough the museums and takes pictures. Aleksandra deliberately obtains information about the attractions of the museums, and sometimes she only wants to see them.

She looks up the path through the museum on the internet. Some museums have a multimedia guide with a map. Still some museums don‘t have any information about the loations of the exhibition pieces at all. That is frustrating for her.

Christian Esbichl

AGE 57
OCCUPATION Museum Employee
STATUS Married
LOCATION Vienna
LANGUAGE German

TECHNOLOGY




Picture by Pexels on Pixabay

GOALS

- mobile guides which are easy to maintain
- more interactive exhibits at the museum

BIO

Christian is 57 years old, married, and lives in a house in Vienna. He repairs things in his house, builds the treehouse in his garden for his four grandchildren and reads novels in the evening. His grandchildren sometimes try to explain Facebook to him because he wants to stay in touch with his friends.

Christian has no fear of new technology. He bought smartphones for his wife and himself and tries to learn how to use them. He likes the crossword and Sudoku app and is proud to know how to install apps.

Christian is an employee at a museum in Vienna. He works at the entrance and as a guide. This museum offers a multimedia guide, and although he is one of the oldest employees, Christian was the first to accept it. He tries to help visitors with the installation of the app. It would be nice to have more interactive exhibits at the museum so he can learn more and be a more valuable employee.

APPENDIX B

A Fictitious Sample Visit to a Museum

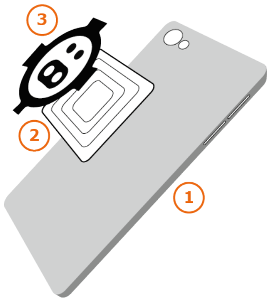
In the following fictitious usage scenario, we describe a museum visit by family Egger (Lena, 10 years, and her parents Peter and Olivia, both in their mid-30s). The sample visit describes positive as well as negative experiences when using interactive exhibits.

When entering the museum, family Egger purchases a family ticket. With the ticket every family member receives a removable sticker (see Figure B.1a) for their own devices (ODs) (Figure B.1b (1)). Thus, they will be informed about the possibility to use their own devices during the visit. The family scans the visual markers with the installed app on their OD. Afterward, they stick the markers on the back of their ODs. The family members have different interests and so they split up. As a result of being a group (through purchasing a family ticket), e.g., Olivia can observe the location of her husband and daughter on a floor plan.

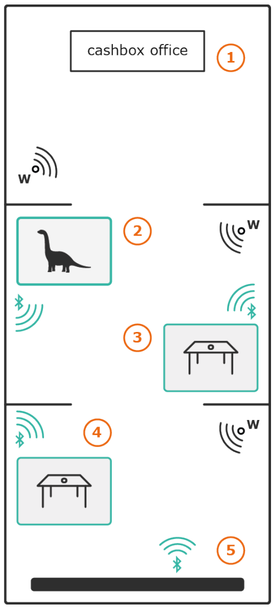
Walking through the museum, Lena passes the skeleton of a dinosaur (Figure B.1b (2)). Her OD recognizes the exhibit automatically and vibrates to draw her attention to the app. The information about the station appears automatically. Lena reads further information about the dinosaur and can choose between a video of the dinosaur or augmented reality (AR) functionality. With the AR option, Lena pans her OD over the skeleton and the dinosaur is shown with skin and comes alive.

Lena sees in the app that there is an interactive table exhibit in this room (Figure B.1b (3)). It seems that only one person can directly interact with the table. However, Lena does not know how to use the table. She wants to try but another visitor, Christoph, wants to interact with the table as well. The ensuing argument is ended by Olivia and Peter.

As a family group, they want to try the next table (Figure B.1b (4)). When they are near the table, their ODs directly show the information how to interact with this exhibit - it



(a) The sticker for the visitors' OD (1) includes an RFID tag (2) as well as a visual marker (3). The visual marker and the RFID tag is needed to identify the visitors' OD at the various active exhibits. If the exhibit is, e.g., a capacitive table, the visitors' OD can register itself by means of RFID readers installed at the table. If the exhibit uses an optical approach (e.g., optical table), the visitors' OD can be identified by its visual marker.



(b) floor plan of the museum: (1) cashbox office - the visitors get the identifier, (2) passive exhibit (dinosaur with video and AR content), (3) active exhibit - optical table for single usage, (4) active exhibit - capacitive table (magnifying table, multi user game), (5) active exhibit (photo wall). Exhibits are equipped with a Bluetooth beacon and rooms with a Wi-Fi hotspot (W).

Figure B.1: Fictitious sample visit to a museum.

is the magnifying table, so their OD functions as a magnifying glass (like in (Strohmeier, 2015)). As shown in the app, Lena puts her OD directly on the table which is showing a human skeleton. By panning her OD over the skeleton, special areas are highlighted on her OD. In addition, a quiz is started on the device. The goal is to identify how the person died. Olivia and Peter follow Lena with their ODs and so they can find all hidden quizzes together.

At the end of the visit, the family arrives at a photo wall (Figure B.1b (5)). Lena can choose her favorite photographed exhibits on her OD and sends them to the wall by dragging the image to one side of her OD. Her avatar and a short note are shown beside the picture.

APPENDIX C

Material for the Comparative Study 1 of Design Study 1 (in German)

MEETeUX Evaluation Timeline

Counterbalanced within subject design: Mindestens 12 TeilnehmerInnen (eventuell 18 oder 24)

○ 123	○ 123	○ 123	○ 123	(1=Timeline, 2=Bücherregal, 3=Blume)
○ 213	○ 213	○ 213	○ 213	
○ 231	○ 231	○ 231	○ 231	
○ 312	○ 312	○ 312	○ 312	
○ 132	○ 132	○ 132	○ 132	
○ 321	○ 321	○ 321	○ 321	

Allgemeine Daten

Alter: _______________ iOS ○ Android ○

Geschlecht: weiblich ○ männlich ○ keine Angabe ○

Haben Sie Erfahrung mit Smartphones?

ja ○ nein ○ keine Angabe ○

Aufgabenorientierte Evaluation

Stellen Sie sich vor, Sie bewegen sich mit ihrem Smartphone durch eine Ausstellung. Sie haben bereits die ersten Objekte passiert und betrachten gerade die Informationen zu Konflikten.

Durchgang 1: __________________________

Aufgabe 1:

Beschreiben Sie bitte, was Sie hier sehen.

____
____
____
____
____
____

Aufgabe 2:

Bringen Sie mehr über die Habsburger in Erfahrung.

Aufgabe erfüllt: Klick auf „mehr erfahren“

Aufgabe 3:

Kehren Sie nun zur Überblicksseite zurück.

Aufgabe erfüllt: über Back-Button zur Übersicht zurück

Gibt es andere Wege?

Aufgabe 4:

Wählen Sie ein anderes Objekt aus und sehen Sie sich dazu Detailinformationen an.

Fragen:

- Befindet sich das Objekt in der Ausstellung vor oder nach dem vorigen Objekt?

  Wird verstanden, dass nur bereits passierte Objekte gewählt werden können?
- Welcher Zeit ist das Objekt zugeordnet?
  Werden die Jahreszahlen verstanden?
- Können Sie sich vorstellen, was diese Unterteilungen bedeuten?
  Werden die Sektionen erkannt?

Aufgabe erfüllt: nach oben Scrollen und „mehr erfahren" bei anderem Objekt auswählen

Fragebogen

Die Navigation durch die Ausstellungsobjekte war für mich:

Verständlich ○ ○ ○ ○ ○ ○ ○ Nicht verständlich

Der Wechsel zu den Informationen früherer Objekte war für mich:

Verständlich ○ ○ ○ ○ ○ ○ ○ Nicht verständlich

Bewertung Visualisierungen

Wie einfach war die Verwendung der Visualisierung?

Sehr einfach ○ ○ ○ ○ ○ ○ ○ Sehr schwierig

Durchgang 2:___________________________

Aufgabe 1:
Beschreiben Sie bitte, was Sie hier sehen.

____

____

____

____

Aufgabe 2:
Bringen Sie mehr über die Habsburger in Erfahrung.

Aufgabe erfüllt: Klick auf „mehr erfahren“

Aufgabe 3:
Kehren Sie nun zur Überblicksseite zurück.

Aufgabe erfüllt: über Back-Button zur Übersicht zurück

Gibt es andere Wege?

Aufgabe 4:
Wählen Sie ein anderes Objekt aus und sehen Sie sich dazu Detailinformationen an.

Fragen:

- Befindet sich das Objekt in der Ausstellung vor oder nach dem vorigen Objekt?

  Wird verstanden, dass nur bereits passierte Objekte gewählt werden können?
- Welcher Zeit ist das Objekt zugeordnet?
  Werden die Jahreszahlen verstanden?
- Können Sie sich vorstellen, was diese Unterteilungen bedeuten?
  Werden die Sektionen erkannt?

Aufgabe erfüllt: nach oben Scrollen und „mehr erfahren“ bei anderem Objekt auswählen

Fragebogen
Die Navigation durch die Ausstellungsobjekte war für mich:

Verständlich ○ ○ ○ ○ ○ ○ ○ Nicht verständlich

Der Wechsel zu den Informationen früherer Objekte war für mich:

Verständlich ○ ○ ○ ○ ○ ○ ○ Nicht verständlich

Bewertung Visualisierungen
Wie einfach war die Verwendung der Visualisierung?

Sehr einfach ○ ○ ○ ○ ○ ○ ○ Sehr schwierig

Durchgang 3:____________________________

Aufgabe 1:
Beschreiben Sie bitte, was Sie hier sehen.

____

____

____

____

Aufgabe 2:
Bringen Sie mehr über die Habsburger in Erfahrung.

Aufgabe erfüllt: Klick auf „mehr erfahren“

Aufgabe 3:
Kehren Sie nun zur Überblicksseite zurück.

Aufgabe erfüllt: über Back-Button zur Übersicht zurück

Gibt es andere Wege?

Aufgabe 4:
Wählen Sie ein anderes Objekt aus und sehen Sie sich dazu Detailinformationen an.

Fragen:

- Befindet sich das Objekt in der Ausstellung vor oder nach dem vorigen Objekt?

  Wird verstanden, dass nur bereits passierte Objekte gewählt werden können?
- Welcher Zeit ist das Objekt zugeordnet?
  Werden die Jahreszahlen verstanden?
- Können Sie sich vorstellen, was diese Unterteilungen bedeuten?
  Werden die Sektionen erkannt?

Aufgabe erfüllt: nach oben Scrollen und „mehr erfahren“ bei anderem Objekt auswählen

Fragebogen
Die Navigation durch die Ausstellungsobjekte war für mich:

Verständlich ○ ○ ○ ○ ○ ○ ○ Nicht verständlich

Der Wechsel zu den Informationen früherer Objekte war für mich:

Verständlich ○ ○ ○ ○ ○ ○ ○ Nicht verständlich

Bewertung Visualisierungen
Wie einfach war die Verwendung der Visualisierung?

Sehr einfach ○ ○ ○ ○ ○ ○ ○ Sehr schwierig

Abschlussfragebogen

Welche der 3 Visualisierungen war Ihr Favorit?

Wie verständlich war für Sie die Visualisierung?

Timeline:	Sehr verständlich	○	○	○	○	○	○	○	Sehr unverständlich
Bücherregal:	Sehr verständlich	○	○	○	○	○	○	○	Sehr unverständlich
Blume:	Sehr verständlich	○	○	○	○	○	○	○	Sehr unverständlich

Wie bewerten Sie den Überblick, den die Visualisierung bietet?

Timeline:	Sehr gut	○	○	○	○	○	○	○	Sehr schlecht
Bücherregal:	Sehr gut	○	○	○	○	○	○	○	Sehr schlecht
Blume:	Sehr gut	○	○	○	○	○	○	○	Sehr schlecht

Wie einfach ist die Visualisierung zu navigieren?

Timeline:	Sehr einfach	○	○	○	○	○	○	○	Sehr schwierig
Bücherregal:	Sehr einfach	○	○	○	○	○	○	○	Sehr schwierig
Blume:	Sehr einfach	○	○	○	○	○	○	○	Sehr schwierig

Wie viel Spaß macht die Visualisierung?

Timeline:	Sehr viel	○	○	○	○	○	○	○	Sehr wenig
Bücherregal:	Sehr viel	○	○	○	○	○	○	○	Sehr wenig
Blume:	Sehr viel	○	○	○	○	○	○	○	Sehr wenig

Wie einfach war die zeitliche Zuordnung der Objekte?

Timeline:	Sehr einfach	○	○	○	○	○	○	○	Sehr schwierig
Bücherregal:	Sehr einfach	○	○	○	○	○	○	○	Sehr schwierig
Blume:	Sehr einfach	○	○	○	○	○	○	○	Sehr schwierig

Wie gut ist der Mix zwischen Überblick und Detailinformation?

Timeline:	Sehr gut	○	○	○	○	○	○	○	Sehr schlecht
Bücherregal:	Sehr gut	○	○	○	○	○	○	○	Sehr schlecht
Blume:	Sehr gut	○	○	○	○	○	○	○	Sehr schlecht

APPENDIX D

Material for the Comparative Study 2 of Design Study 1 (in German)

APPENDIX E

Material for the Usability Study 1 of Design Study 2

MEETeUX Evaluation Timenet Visualization

Goal: understandability of visualization

Number of participants: 5 to 8

General Data

Age: _______________

Gender: female ○ male ○ n/a ○

Experience in data visualization?

	1	2	3	4	5	6	7	
low	○	○	○	○	○	○	○	high

Experience in usage of touch displays?

	1	2	3	4	5	6	7	
low	○	○	○	○	○	○	○	high

Do you have any visual issues (e.g., color blindness)?

yes ○ no ○

Task-oriented Evaluation

Imagine you are going through an exhibition about Maximilian I. and St. Leopold. There you find an installation on which you can interact with a touch display. In addition, you see a huge projection of some persons of the Babenberg dynasty. [Show paper prototype of projection in addition to touch display]

Task 1

Please, describe us, what you see here (on the touch display).

____
____
____
____
____
____
____
____
____
____
____

Born, death, marriages, children, guessed data, gender?

Task 2

When Leopold III. was born, was married and died? Are these known dates?

year of birth: around 1075 Answer ____

year of marriage: 1. Around 1100, 2. 1106 Answer __________________________________

year of death: 1136 Answer ____

Overall, how difficult or easy did you find this task?

	1	2	3	4	5	6	7	
Very difficult	○	○	○	○	○	○	○	Very easy

Do you have any suggestions for improvement?

____
____
____
____
____
____

Task 3

Please select the first daughter of Leopold III. (Bertha)

○ Yes ○ No ○ Help needed? ____

Overall, how difficult or easy did you find this task?

	1	2	3	4	5	6	7	
Very difficult	○	○	○	○	○	○	○	Very easy

Do you have any suggestions for improvement?

____
____
____
____
____
____

Task 4

Please select the wife of Leopold V. (Helene)

○ Yes ○ No ○ Help needed? ____

Overall, how difficult or easy did you find this task?

	1	2	3	4	5	6	7	
Very difficult	○	○	○	○	○	○	○	Very easy

Do you have any suggestions for improvement?

____
____
____
____
____
____

Task 5

[Show first paper prototype] What do you think it shows?

____

[Show second paper prototype] What do you think it shows?

____

If no divorce, which one is better to show a divorce?

○ 1 ○ 2

If both are divorce, which one is better to show a divorce?

○ 1 ○ 2

Post Questionnaire

Overall, how difficult or easy did you find the usage of the visualization?

	1	2	3	4	5	6	7	
Very difficult	○	○	○	○	○	○	○	Very easy

How understandable was the visualization of the precise dates?

	1	2	3	4	5	6	7	
Not understandable	○	○	○	○	○	○	○	Understandable

How understandable was the visualization of the estimated dates?

	1	2	3	4	5	6	7	
Not understandable	○	○	○	○	○	○	○	Understandable

Which additional information would you like to know about the persons?

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APPENDIX F

Material for the Usability Study 2 of Design Study 2

MEETeUX GenVis Evaluation – Post Observation Questionnaire

*Daten durch Testleiter*in auszufüllen*

Uhrzeit ___________

Mit Smartphone verbunden? O Ja O Nein

Wie lange mit Applikation interagiert? ______________

Auf welcher Seite? O Links O Rechts

Wie viele Personen waren bei Start der Interaktion durch die Testperson bei der Anwendung?

Aktiv _____________ Passiv ____________

Allgemeine Daten

Alter: ______________

Geschlecht: O Weiblich O Männlich O Anderes O Keine Angabe

Wie viele Minuten nutzen Sie Ihr Smartphone täglich?
O Besitze keines
O Nicht täglich O Weniger als 10 Minuten O 10 bis 15 Minuten O 15 bis 30 Minuten
O 30 bis 45 Minuten O 45 bis 60 Minuten O Über 61 Minuten

Wie hoch schätzen Sie Ihre Erfahrung mit Datenvisualisierungen ein?

	1	2	3	4	5	6	7	
Niedrig	O	O	O	O	O	O	O	Hoch

GenVis

Beschreiben Sie uns bitte, was sie gesehen haben.

____
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Fokus Touch Display: Was haben Sie hier erkunden können?

____
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____

Fokus Projektion: Was war hier zu sehen?

____
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____

Wann haben Sie erkannt, dass Ihr Touch Display mit der Projektion verbunden ist?

____

Mit welcher Seite auf der Projektion waren Sie verbunden?

○ Links ○ Rechts

Warum haben Sie mit der Installation interagiert?

____

Zusammenfassend, wie schwer oder einfach war die Verwendung der Visualisierung?

	1	2	3	4	5	6	7	
Schwer	○	○	○	○	○	○	○	Einfach

Wo gab es Schwierigkeiten? ____

Wie ansprechend fanden Sie die Gestaltung des Touch Displays?

	1	2	3	4	5	6	7	
Nicht ansprechend	○	○	○	○	○	○	○	Ansprechend

Warum? ____

Wie ansprechend fanden Sie die Gestaltung der Projektion?

	1	2	3	4	5	6	7	
Nicht ansprechend	○	○	○	○	○	○	○	Ansprechend

Warum? ____

Haben Sie Verbesserungsvorschläge für uns?

____
____
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____
____

Wie wahrscheinlich ist es, dass Sie Ihr Smartphone in einer Ausstellung nutzen werden?

	1	2	3	4	5	6	7	
Unwahrscheinlich	○	○	○	○	○	○	○	Wahrscheinlich

Warum? ____

System Usability Scale

Markieren Sie für jede der folgenden Aussagen das Kästchen, was Ihre heutigen Reaktionen auf die Installation am besten beschreibt.

Ich kann mir sehr gut vorstellen, das System regelmäßig zu nutzen.

	1	2	3	4	5	
Stimme nicht zu	○	○	○	○	○	Stimme zu

Ich empfinde das System als unnötig komplex.

	1	2	3	4	5	
Stimme nicht zu	○	○	○	○	○	Stimme zu

Ich empfinde das System als einfach zu nutzen.

	1	2	3	4	5	
Stimme nicht zu	○	○	○	○	○	Stimme zu

Ich denke, dass ich technische Unterstützung benötigen würde, um das System zu nutzen.

	1	2	3	4	5	
Stimme nicht zu	○	○	○	○	○	Stimme zu

Ich finde, dass die verschiedenen Funktionen des Systems gut integriert sind.

	1	2	3	4	5	
Stimme nicht zu	○	○	○	○	○	Stimme zu

Ich finde, dass es im System zu viele Inkonsistenzen gibt.

	1	2	3	4	5	
Stimme nicht zu	○	○	○	○	○	Stimme zu

Ich kann mir vorstellen, dass die meisten Leute das System schnell zu beherrschen lernen.

	1	2	3	4	5	
Stimme nicht zu	○	○	○	○	○	Stimme zu

Ich empfinde die Bedienung als sehr umständlich.

	1	2	3	4	5	
Stimme nicht zu	○	○	○	○	○	Stimme zu

Ich habe mich bei der Nutzung des Systems sehr sicher gefühlt.

	1	2	3	4	5	
Stimme nicht zu	○	○	○	○	○	Stimme zu

Ich musste eine Menge Dinge lernen, bevor ich mit dem System arbeiten konnte.

	1	2	3	4	5	
Stimme nicht zu	○	○	○	○	○	Stimme zu

APPENDIX G

Transcript of Interviews of Design Study 2 (in German)

Interview #1

KB: Würden Sie mir Ihr Alter verraten? #00:00:30-6#

I1: 29 #00:00:37-2#

KB: Wie würden Sie Ihren Job im Zusammenhang mit der Ausstellung beschreiben? #00:00:41-1#

I1: Vermittlung von Geschichte und Kultur #00:00:58-5#

KB: Wenn Sie alle Ihre Jahre zusammenzählen, die Sie schon im Museumsumfeld aktiv sind, wie viele wären das? #00:01:05-8#

I1: 13. Ich habe begonnen während der Schule mit der Aufsicht. #00:01:28-8#

KB: Was ist Ihr Hintergrund? Was haben Sie eventuell studiert, gelernt, Arbeitserfahrung in dem Gebiet? #00:01:38-8#

I1: Grundsätzlich bin ich Jura-Student. Ich habe jetzt demnächst die letzte Prüfung und bin eigentlich in einem Personalbüro fix angestellt als Verwaltungsmitarbeiter mit Spezialgebiet juristische Recherche. #00:02:10-1#

KB: Wie würden Sie ihre Computerkenntnisse beschreiben? #00:02:18-4#

I1: Fortgeschritten bzw. normale Anwenderkenntnisse im Bereich von MS Office und ab dem Zeitpunkt, wo es tatsächlich in Software reingeht, da ist es dann mehr oder weniger blank aber ich kann eigentlich Computer bedienen. #00:02:37-2#

KB: Und einfache Probleme auch selbst lösen? #00:02:40-3#

I1: Ja #00:02:42-0#

KB: Waren Sie schon vorher in einer Ausstellung involviert, in denen interaktive Ausstellungsstücke integriert waren? #00:02:51-4#

I1: Nein #00:02:57-1#

[…] #00:03:33-1#
KB: Denken Sie, dass Sie mir zu dieser Installation [GenVis] Fragen beantworten können? […] #00:03:36-1#

I1: Mit der weniger #00:03:52-5#

KB: Dann würde ich mich eher in die allgemeine Richtung gehen und nicht den Fokus auf die Installation setzen, wenn das für Sie ok ist #00:04:03-4#

I1: Ja #00:04:03-4#

KB: Wir haben interaktive Installationen in der Ausstellung, welche Herausforderungen sehen Sie auf Besucher*innenseite, wenn solche Installationen in einer Ausstellung integriert werden? #00:04:28-2#

I1: Die größte Herausforderung, die ich mitbekommen habe, war mit der App. Weil man sich ins eigene WLAN einwählen musste, gab es immer wieder Probleme, habe ich mitbekommen. Also dass da die Internetverbindung passt. Sonst ist die große Herausforderung, die ich bei sowas sehe, dass man relativ schnell sich eigentlich damit auseinander setzen können muss. Das Tutorial darf nicht zu lang sein. […] #00:05:06-4#

KB: Haben Sie da ev. Sachen beobachtet vielleicht auch bei den anderen Ausstellungsstücken, ob etwas gut funktioniert oder nicht - abseits der App? #00:05:14-7#

I1: Ich sage mal bei dem Tisch vom Stammbaum, da habe ich gemerkt, da musste man wirklich aktiv mal auf - also als Führungsperson selbst - draufklicken, um denen zu zeigen, dass das auch angegriffen werden darf. Ich glaube, da ist eine sehr große Zurückhaltung vor allem von den Besuchern, ob man das jetzt angreifen darf oder nicht - Wenn vorher schon von einer Führung sozusagen, das zurückgelassen wurde, also wenn man dort z.b. näher gezoomt hat, dann haben die meisten schon bemerkt, aha mit dem Tisch kann man was anfangen. […] Aber wie gesagt, man musste einfach mal auf irgendeinen von den Babenbergern draufklicken und auf die Geschichte und sobald man das gemacht hat, dann sind dann eh alle da gestanden und haben begeistert gedrückt. Also ich glaube, bei solchen interaktiven Geschichten da fehlt auch ein bisschen - gerade weil man in einem Museum ist - fehlt so ein bisschen auch das Wissen, dass man Hingreifen darf. Weil im Museum ist es ja so, um Gottes willen nicht angreifen, weil es könnte ja irgendwas kaput gehen. Das heißt, da müssten, finde ich, auch die Exponate entsprechend gekennzeichnet werden, dass sie eben interaktiv sind. Ich glaub irgendwo in einem Museum, habe ich im Sommer gesehen, dass da eben eindeutig solche Ständer aufgestellt sind mit “Touch Me” und sowas. Auch z.B. beim DaVinci Museum in Florenz, das war vor allem sehr stark interaktiv aufgebaut. Da war jetzt eindeutig, was da alles angegriffen werden konnte - aber wie gesagt, das war auch wirklich interaktiv gestaltet mit VR Brillen und so weiter. #00:07:40-1#

[…] #00:08:52-6#
KB: Welche Herausforderung haben Sie für sich wahrgenommen vom Museumspersonal her, wenn man mit solchen interaktiven Installationen arbeitet? #00:09:03-7#

I1: Wie gesagt, das Wichtigste, dass man den Leuten klar macht, dass man eben hingreifen darf. Das war einerseits eine der Herausforderungen. Aber sonst waren es recht wenig Herausforderungen, find ich. Es war auch die Ausstellung sehr gut aufgebaut. Die Leute haben doch relativ schnell verstanden, was da eben interaktiv ist und was nicht. Die Herausforderung war eher für den Besucherempfang. Dass man da die App auch entsprecht klar gestaltet. Ich glaub, das war eher das Problem. #00:09:57-2#

KB: Was meinen Sie genau damit? #00:09:57-2#

I1: Dass die Leute auch damit arbeiten. Wenn ich irgendwo in ein Museum gehen, dann muss ich sozusagen diese App als Hauptding bewerben. Also wenn ich z.B. denke an das

Stiegl-Museum in Salzburg. Da haben die eine App, wo man im Endeffekt die ganze Führung durchmachen kann. Die wird gleich am Anfang beworben, wird entsprechend ausgeschildert als App herunterladen und die Tour durchmachen. In dem Fall bei uns war es eher so nebenbei als nice-to-have. Aber es ist jetzt nicht soo großartig rüber gekommen. Aber das kann auch eine subjektive Einschätzung sein. #00:11:00-1#

KB: Also es hätte für die App speziell ein konkreterer Nutzen da sein müssen in der Bewerbung? #00:11:21-9#

I1: Es hätte auch wirklich ein Weg gelegt werden müssen: Laden Sie die App runter und dann gehen Sie auf die Führung. Lassen Sie sich durchführen. Aber wenn das so nebenbei irgendwo beworben wird - man kann sich es halt runter laden - dann glaube ich, dass die meisten da eher zurückhaltender sind. #00:11:49-1#

KB: Weil der Nutzen nicht 100%ig klar war? #00:11:50-5#

I1: Ja #00:11:52-0#

[…] #00:12:25-3#

KB: Die Frage ist auch, ob es nicht doch immer noch eine zu große Hürde ist eine App im Museum zu nutzen #00:12:37-9#

I1: Glaube ich jetzt eigentlich ehrlich gestanden nicht, dass es eine Hürde ist. Wie gesagt, es müsste entsprechend gezeigt werden. Weil im Endeffekt ein Smartphone hat jeder und mit einer App selber kann man das Ganze interaktiver gestalten und auch mehr aus dem Museumsbesuch rausholen. Aber es muss dann auch entsprechend die Ausstellung sehr stark darauf ausgerichtet sein bzw. es darf auch nix kosten. Das ist halt auch der Punkt. Ich kauf mir doch nicht eine Museumskarte, nur dass man mir dann sagt, ok und jetzt zahlen sie noch einmal 3 Euro für die App. Aber sonst glaube ich, ist da doch ein großer Nutzen, dass man da, wie gesagt, alles interaktiver gestalten kann. […] Das war im Stieglmuseum interessant mit der App, im DaVinici mit vor Ort Geräten - besser funktioniert hat es im DaVinci Museum. Im Stieglmuseum konnte man sich mit der App Videosequenzen anschauen und anhören und das war irgendwie ja - es war halt eine Führung. […]

#00:16:29-1#

I1: Ich glaube, es ist halt gerade bei den Ausstellungen immer ganz schön, wenn man so einen Ansatz hat, dass man es selber in der Hand hat, dass man durch die Gegend gehen kann und sich selbst seinen Weg suchen kann. Das ist ein netter Ansatz, aber ich glaube, die meisten, die ins Museum gehen, brauchen eine vorgefertigten Pfad und da ist es angenehmer mit den stationären Geräten. Das man sagt, man geht da einen gewissen Weg ab und das ist unproblematisch. Mit der App ist es halt so ein, ja ein freierer Zugang, dass man einerseits dahin gehen kann andererseits dorthin. Aber wie gesagt, die meisten brauchen einfach einen gewissen Weg, den sie abgehen können und das ist ja das selbe Spiel mit den Audioguides, wo die Menschen in die Schatzkammer gehen und ein Exponat nach dem anderen abgehen. Ich glaube, da funktioniert es, weil da weiß man ungefähr wie man durch muss. Aber das ist halt unterschiedlich zur App, weil ich glaub die meisten, wenn sie sehen, dass es eine App gibt, sind da eher zurückhaltender, weil bei älteren Personen ist das noch so ein komisches Ding […] ich glaube, da ist es doch angenehmer mit stationären Geräten als mit der App (wie beim Quiz). #00:18:32-3#

KB: Was würden Sie sagen, hätten Sie sich gewünscht im Anfangsprozess der Ausstellung, was hätte besser sein können? Oder war eh alles in Ordnung so wie es war, wie Sie mit den interaktiven Exponaten in Kontakt gekommen sind, die Informationen, die Sie dazu bekommen haben? #00:18:57-4#

I1: Ich glaube, es wäre angenehmer gewesen - der untere Teil der Ausstellung, der wäre auch mal interessant gewesen, die verschiedenen Geräte durch zu gehen. Einfach damit man weiß, was hat man da alles. Und das man dann auch die Besucher weiter verweisen kann. Das man sagen kann, grundsätzlich haben wir jetzt den Tisch Babenberger Stammbaum gespielt, sie können unten noch weitere Geräte finden. Sie können sich unten den eigenen Stammbaum zusammen stellen. Also solche Dinge - sowas wäre im Endeffekt wünschenswert gewesen. Aber ich habe selbst zu wenig Zeit gehabt, mich mit dem unteren Teil der Ausstellung noch eingehender zu befassen. […] #00:21:35-4#

KB: Aus ihrer Sicht in Richtung kritische Erfolgsfaktoren gedacht: Welche Dinge müssen gegeben sein, damit interaktive Installationen in Ausstellungen funktionieren? #00:21:56-7#

I1: Grundsätzlich eine leichte Bedienbarkeit […] das Tutorial darf nicht zu lang sein, wie schon erwähnt. Ich glaub, das ist das Wichtigste. Und dass die interaktiven Objekte, wenn es nicht gewollt ist, dass die unterschiedlich agieren, dass die ein einheitliches Bild - einheitliches Layout haben. Das ist glaube ich extrem wichtig, dass man einen schnellen Wiedererkennungswert hat. Dass man sozusagen sich beim ersten Gerät relativ schnell einschulen kann und dann feststellt, das zweite Gerät schaut ja ähnlich aus – ich weiß schon wie das funktioniert und .. ich glaube, das ist extrem wichtig für interaktive Ausstellungsgegenstände. Und wie gesagt die Hinweise, wo ich was angreifen darf und wo nicht. Wenn man dann doch relativ viel Besucher hat, die damit aufgewachsen sind, in einem Museum darf ich nichts angreifen, muss man dann sozusagen diese Zurückhaltung zerstören, damit die Leute auch wirklich sich trauen damit zu arbeiten. #00:23:23-6#

KB: Wie ist das, was sie gerade aufgezählt haben, wie ist das aus ihrer Sicht in der Ausstellung gelöst oder nicht gelöst wurden? Was mich jetzt besonders interessiert, das einheitliche Layout? #00:23:44-3#

I1: Wie gesagt, im Endeffekt habe ich nur das Quiz unten gemacht und den Babenberger Stammbaum unten habe ich nur beim Vorbeilaufen gesehen. Aber irgendwo fehlt mir dann doch von der Farbgebung her, wenn ich mich recht erinnere, fehlt mir da einfach das Einheitliche. Also da hätte dann vielleicht besser ansetzen können. Und wie gesagt der BBS im geführten Ausstellungsbereich, der ist dann eigentlich recht… ja, ich mein da sieht man … es waren im Endeffekt zwei Ausstellungsbereiche und für mich hat es so gewirkt als wäre im Endeffekt, der eine Teil vollkommen vom anderen losgelöst. Das war irgendwo… vielleicht war es so geplant, und wenn nicht dann hat mir da die Verknüpfung gefehlt. #00:25:04-8#

KB: Das voneinander losgelöst, ist das jetzt aus Ihrer Sicht generell auf die gesamte Ausstellung bezogen, diese Aussage oder ist es aus Ihrer Sicht nur für das interaktive? #00:25:18-3#

I1: Für die beiden Ausstellungsbereiche - also generell. #00:25:20-3#
Aber man hätte ja z.b. die drei Figuren - unten gab es ja den Kaiser, den Hofnarr und den Gelehrten, das man die vielleicht irgendwie versucht hätte in zweiten Ausstellungsbereich hinzugeben. Das Einzige, was man da gehabt hat, wo irgendein Zusammenhang war, war eigentlich nur der Hofnarr, dass man oben im zweiten Ausstellungsbereich den Till Eulenspiegel gehabt hat. Aber das man vielleicht sozusagen irgendwie den Gelehrten auch wieder aufgebracht hätte, so dass ein stärkerer Zusammenhalt gewesen wäre #00:26:25-7#

KB: Im Prinzip hat die Klammer gefehlt #00:26:25-7#

I1: Ja #00:26:25-7#

[…]
KB: Haben Sie irgendwelches Feedback mitbekommen, Besucher*innen, Kolleg*innen aus anderen Museen über die Ausstellung, über die interaktiven Installationen? #00:27:07-1#

I1: Besucher waren begeistert, was ich so mitbekommen habe von der Ausstellung. Es war halt auch die Sache, von wegen interaktive Dinge: Im oberen Teil war es ja so, dass man ja die Druckerpatte durchgeben konnte […] ich glaube, es hat den meisten irgendwo gefallen, dass man da aufgeweckt worden ist. […] Für die haptischen Werte hatte man am Anfang den Stammbaum Table, da konnte man ein bissel auf dem Touchdisplay rumarbeiten, dann wurde man in der Regel eingeschläfert im zweiten und dritten Raum. Und im vierten Raum hat man dann wieder was in die Hand gedrückt bekommen, womit man dann wieder aufgeweckt wurde. […] Ich glaub, es ist relativ wichtig, dass man da verschiedenste Lerntypen anspricht. Was fürs Auge, was fürs Ohr und was fürs Angreifen. Und das ist sehr gut angekommen. Ich hab persönlich immer ein gutes Feedback bekommen von den Besuchern. Von Kollegen aus anderen Museen hab ich eigentlich überhaupt nichts bekommen. Aber da bin ich auch zu wenig involviert in das Ganze.

Interview #2

KB: Wie alt sind sie? #00:00:10-7#

I2: Also ich bin 64 #00:00:16-9#

KB: Wie würden Sie Ihren Job im Zusammenhang mit der Ausstellung beschreiben? #00:00:25-2#

I2: Also ich bin Kulturvermittlerin. So sehe ich mich und mein inneres Anliegen ist zu dem Thema, wenn ich selber einen Bezug dazu aufbauen kann, was ich eben führe oder diese Ausstellung jetzt, Besucher na Interesse zu wecken. Das ist ein wichtiger Teil in meinen Augen des Kulturvermittlers. Also ich gebe so ein paar Starter und wenn sie dann selber noch weiter machen, dann ist es schön. #00:01:12-8#

KB: Wenn sie alle ihre Jahre zusammenrechnen, die sie im Museumsumfeld verbracht haben. Wie viele sind das dann ca.? #00:01:21-3#

I2: Also da muss ich schon unterscheiden, denn ich bin ja selber Archäologin und Mittelalter - also Schwerpunkt Historikerin. Und diese Ausstellungssache, die ich da jetzt mache, ist eigentlich der letzte Teil meines Lebens. Und ich habe selber archäologische Ausstellungen vorbereitet allerdings damals noch mit wesentlich weniger interaktivem Beiwerk. #00:01:53-8#

Das fing mit meiner ersten Anstellung an und die war 1989. und seitdem bin ich mehr oder weniger in diesem Ausstellungs- und Kulturbereich - manchmal mehr Kultur führen und manchmal mehr über Ausstellungen. #00:02:22-0#

Ca. 30 Jahre #00:02:38-1#

KB: Was ist ihr Hintergrund, was haben Sie studiert, welche Arbeitserfahrung haben Sie? #00:02:40-7#

I2: Naja eben Archäologin klassische und Frühgeschichte hieß das in Deutschland und bis rauf ins hohe Mittelalter. Also Geschichtswissenschaft. Und ja ich habe natürlich noch ein Handwerk im Hintergrund, ich bin Keramikerin. Und das ist für die Archäologie in dem Fachbereich jetzt mal nicht uninteressant. Aber ich habe auch Volkskunde studiert und da geht es viel ums Handwerk und diese haptischen Sachen und die Erfahrungen und der Bereich mit Druck und Drucktechnik hat mich dann schon sehr interessiert. #00:03:28-0#

KB: In welchen Bereichen haben Sie dann gearbeitet? #00:03:31-5#

I2: Also Sammlungen aufarbeiten, das war die Archäologie, dann Fremdenführerausbildung in Wien und jetzt dann im Stift seit vielen Jahren. Und im Stift immer wechselnde Sachen. Ah ja, kommt noch was dazu Altenpflege, da habe ich also Schwerpunkt jetzt was Ausstellungsführung angeht mit dementen Menschen oder mit Leuten mit körperlicher Beeinträchtigung also Rollstuhl, blind, hörgeschädigt. Das ist ein ganz wichtiges Thema für mich und da merk ich auch, dass ich da gut arbeiten kann. #00:04:24-7#

[…] #00:05:09-6#

KB: Mit Bezug in Richtung interaktiver Ausstellung, war das für sie die erste? #00:05:11-5#

I2: Zum Führen ja. #00:05:21-4# Ich bin eher jemand, der dem also so ein bisschen zurückhaltend gegenübersteht. Wenn ich jetzt privat in Ausstellung gehe, bin ich so der vorletzte, der sich dann an diese technischen Geräte ran wagt. Da sind die anderen schon längst am Greifen, Wischen und Tun. #00:05:48-9#

[…] #00:05:57-2#
KB: Wie sind ihre Computer-Kenntnisse? #00:06:02-3#
#00:06:05-2#

I2: Schlecht oder nicht gut. Also das Notdürftigste genügt mir und ich habe auch nicht das Interesse, mich da rein zu begeben. Also das Kosten-Nutzen-Niveau diese Rechnung, da halt ich mich lieber ein bissel zurück. #00:06:26-3#

[…] #00:06:58-6#
KB: Fangen wir bei Ihnen persönlich an, wie ist es Ihnen selbst mit den Installationen ergangen, haben sie mal eine ausprobiert? #00:07:06-2#

I2: Ja, ja, also ich - das ist das schöne, wenn ich Zeit habe und am Beginn der Ausstellung habe ich dann die Freizeit, da fiel ja manchmal was aus oder so, benutzt, um selber da drauf rum zu spielen. Also einfach auszuprobieren und was mir da gefallen hat, ist erstens das hohe Niveau von den Informationen. Also speziell jetzt das Maximilian-Spiel da unten. Das fand ich ganz toll und also da war ich überrascht, positiv überrascht. Also nicht nur jetzt irgendwie hinten rum so noch was drauf, so ein Zusatzding, sondern das war wirklich was den Geist erweitern kann. Das war das eine, das Kinderspiel fand ich spannend. Das habe ich mit einer Kollegin erobert. Ich muss immer dazu sagen erobern, weil das ist immer eine Hürde für mich da loszulegen. Und das fand ich einfach wieder so schön kindgerecht. Das hat mir auch gut gefallen. Und oben mit dem Stammbaum - also den Stammbaum auf der Thronebene - und da habe ich selber für mich einiges rausgezogen, was ich nicht wusste. Also ich habe mich schon mit dem Stammbaum befasst, aber da sind Informationen gewesen, die mir nicht bekannt waren. Das ist dann natürlich schön. Allerdings muss ich dazu sagen, ich habe es lieber schriftlich, also schwarz-weiß auf Papier. Ich bin einfach noch die Generation, die Angst hat, dass das dann durch irgendeinen Klick oder Wischer auf einmal weg ist und dann bin ich wieder Meilen zurück und kann von vorn anfangen und das ist desillusionierend. #00:09:06-8#

[…] #00:09:49-6#
KB: Wenn wir doch kurz dann bei dem Stammbaum auf der Thronebene bleiben. Wenn Sie sich zurückerinnern, als sie das das erste Mal ausprobiert haben, war Ihnen da sofort klar, was sie machen müssen? #00:10:02-9#

I2: Nein #00:10:02-9#
Also, ich bin natürlich nicht firm auf dem Gebiet und ich habe es dann mit jemandem zusammen gemacht. Und die hat mir dann den Einstieg gezeigt und dann war es easy für mich. Aber ich brauch eigentlich jemand, der sich neben mich hinstellt und mir erst einmal die Grundschritte vormacht oder mit mir gemeinsam macht und ich glaub, das ist wirklich

meinem Alter geschuldet. Weil ich denk, dass jüngere Leute einfach diesen Zugang leichter haben. #00:10:48-2#

[…] #00:11:07-7#
KB: Haben Sie selbst Besucher beobachten können, die Installationen versucht haben zu nutzen? #00:11:15-3#

I2: Also, ich kann nur sagen, ich habe dann begonnen, wenn jüngere Gäste in der Gruppe waren und dann habe ich - also ich habe die oben geführt - und dann habe ich schon wenigstens die zwei Minuten Zeit gelassen und gesagt, da gibt es eine App, die kann man runterladen, da ist der Zettel dazu und so. Und da habe ich gemerkt, ich war noch nicht draußen bei der Schranke, hatten die jungen Leute das schon aktiviert und waren damit schon befasst. Also da war ich über die Schnelligkeit überrascht. Und was ich aber sehen muss, so Hauptpublikum sind einigermaßen aus früheren Zeiten mit irgendeinem Gymnasium bedarfte Herrschaften, die jetzt dann so alt sind wie ich oder älter und da ist einfach der gängige Zugang lesen, wenn ich propagier und das sind super Texte ganz knapp, nehmen sie sich Zeit oder so, dann springen die viel eindeutiger auf diese alten Zugangsmedien als auf jetzt elektronische Sachen an. #00:12:49-3#
Wobei man auch sagen muss, wenn ich schon so negative oder leicht gefärbte Einstellung habe, dann funktioniert es auch meist nicht gleich beim ersten Schritt und das ist alles frustrierend oder es ist wiedermal defekt. Also ich habe einige Male dieses Tablet in die Hand nehmen wollen und da ging es nicht. #00:13:13-5#
[…] #00:13:42-8#
Soll ich über die obere Ebene auch? #00:13:37-1#

#00:13:40-3#
KB: Ja,

I2: Also da steht ja oben diese Truhe mit dem Stammbaum und ich bin es natürlich gewohnt, dass ich da was erzähle und die Leute mir zuhören und dann sobald die Sache auf der Truhe elektronisch läuft, sind einige da dabei zuerst nur rumzuschieben. Ich weiß nicht im zweiten Kanal, ob sie da zuhören, ich habe lieber immer die Augen im Blick beim Führen und weiß dann kommt es an oder nicht. Das fällt da natürlich weg, aber dann habe ich gemerkt, ich mache es zweigeteilt, das ist nämlich super gelaufen. Ich gebe eine Einleitung vor dem Original zum Stammbaum und dann spiegelt das ja so extrem. Und da habe ich gesagt, und da gibt es jetzt die Möglichkeit, kommen sie und dann haben wir die einzelnen Medaillons einzeln rausgeholt und vergrößert natürlich und ohne Spiegeln konnten wir die dann wunderbar anschauen. Und das war für mich eine optimale Ergänzung auf der Ebene, da fand ich es wirklich super, weil das von den Voraussetzungen da oben, was die Lichtführung angeht einfach katastrophal ist, um was zu erklären. #00:14:59-7#

[…]
KB: Das heißt also, sie haben dann Ihre Führung umgestellt und danach war es super integriert. #00:15:30-8#

I2: Ja, also wenn es mir gelingt, dass - also, wenn ich selber überzeugt bin, von dem Nutzen, dann kann ich es auch glaubwürdig integrieren und dann ist es wirklich eine Bereicherung. #00:15:47-4#

KB: Dann kommen wir mit dem Anknüpfungspunkt zum letzten Teil, was hätten Sie sich gewünscht, was wir hätten gerade in Bezug in Richtung der Kunstvermittler besser, anders machen können? #00:15:56-4# Damit sie z.B. jetzt schneller die Sachen integrieren können. #00:16:03-6#

I2: Also, ich glaub nicht, dass es an Euch liegt, sondern da ist noch eine Ebene drunter, die ich wirklich kritisiere, denn ich kann mir vorstellen, dass das bei dem Konzept für die Ausstellung noch nicht so klar war, dass wir dann im Endeffekt 55 Minuten für den oberen Teil haben. Und diese Ausstellung, das ist einfach rein rechnerisch sehr sehr knapp. Das heißt, ich lasse alles weg, […] also ich muss total kürzen und aufpassen, dass ich keinen Satz zu viel sage und da fehlt dann das Interaktive schon zwischenmenschliche und das ist von vornherein eine schlechte Basis, um so weiterführende Sachen zu integrieren. #00:17:00-7#

KB: Diese 55 Minuten waren auch mit der Zeit, die Sie nach oben brauchen? #00:17:01-6#

I2: Naja, ich glaub, mit der Zeit sind es 60 Minuten, aber das heißt in 5 Minuten kann ich nicht mit 20 Leuten, wo dann noch 3 nachgebracht werden und ich noch Karten kontrollieren soll usw. nach oben gehen und was dann in der Praxis diese Schwierigkeit macht - um wirklich diese Zeit einhalten zu können, fahr ich mit dem Lift und das heißt die ganze Zugangsweise, die man so schön hätte aufbauen können, wenn man da unten durch die Ausstellung geht am Thron vorbei, dann schließlich raus, das ist schon einmal dem Zeitproblem geschuldet und fällt flach. #00:17:51-2#
Und das ist einfach, da könnt ihr nix dafür, das ist einfach ein falsches oder unabgestimmtes Konzept. #00:17:58-2#

[…] #00:20:24-8#
KB: Noch eine letzte Frage, mal abgesehen von dem Zeitkonstrukt, hätte es irgendwas gegeben, wo wir hätten Ihnen früher eine Einführung in die Installationen geben sollen, generell jetzt für die Guides - oder ist das aus Ihrer Sicht eigentlich alles ok gelaufen? #00:20:40-6#

I2: Also da hatte ich wenig Instruktionen, ich habe die mir eher indirekt geholt über persönliche Kontakte. #00:20:51-9#

KB: Das heißt, es wäre eigentlich schön gewesen, wenn man da hätte, etwas gemacht oder nicht? #00:20:53-5#

I2: Ja, einfach so wie für den oberen Teil eine Einführung in die Ausstellung, so eine Stunde mit den Guides Einführung und selber ausprobieren vielleicht in die Sache unten. #00:21:14-5#

KB: Haben Sie noch irgendetwas, was sie mir mitgeben möchten? #00:21:15-5#

I2: Ja, also ich denke, bei den ganzen Ausstellungskonzepten, […] also, wenn das jetzt so getimt sein muss, wie in unserem Fall und dann noch zu bedenken, dass der der die Ausstellung macht, sich ja voll mit dem Material da befasst, der ist voll da drin, aber der Gast kommt ganz neu zu dem Thema oder fast neu. Und der muss sich - das merke ich an mir, wenn ich in eine Ausstellung gehe - ich muss mich erst einmal geistig irgendwie orientieren und es braucht immer wieder kleine Zeiteinheiten bis ich da anspringe. Und die Zeit wird nicht bedacht. Und wenn man diesen Moment des sich da Einfühlen und Losgehens, wenn man den überspielt, dann ist auch kein Interesse da. […] Ich bin ein langsamer Mensch, dafür vielleicht gründlich, aber ich brauche als Mensch ein paar Sekunden zum Anspringen. Ich glaube, junge Leute sind da schneller, aber die meisten unserer Gäste sind einfach ältere Herrschaften. Das ist der Kulturbereich. #00:23:06-0#

[…] #00:23:38-3#

Also ich habe lang gebraucht, bis ich dann gemerkt hab, dass ja diese modernen Medien sich sehr schön ergänzen können mit dem Lesen oder mit haptischen Sachen, dass ich irgendwas anfassen kann usw. Und in dem Sinn, glaube ich, geht die Entwicklung schon in eine gute Richtung, aber man muss es verknüpfen. Also nur Medien und denken, da krieg ich alle Informationen, das halte ich für falsch. #00:24:12-0#

Interview #3

KB: Wir fangen erstmal mit statistischen Daten an. Ich würde gern Dein Alter wissen. #00:00:14-9#

I3: 45 #00:00:21-7#

KB: Was ist Dein Job im Zusammenhang mit der Ausstellung? #00:00:28-5#

I3: Die inhaltliche und organisatorische Koordination und Hauptverantwortung. #00:00:40-4#

KB: Wie viele Jahre hast Du bereits Erfahrung im Museumsumfeld? #00:00:47-5#

I3: 25 mehr fast. Ich habe schon als Student Führungen gemacht. #00:01:25-6#

KB: Was ist Dein Hintergrund - Studium, Arbeitserfahrung? #00:01:29-1#

I3: Mein professioneller Hintergrund ist ein Studium der Germanistik und Geschichtsforschung mit einer Zusatzqualifikation im Sammlungsmanagement […] #00:02:08-8#

KB: Wie würdest Du Deine Computerkenntnisse einschätzen? #00:02:14-1#

I3: Sehr gut. Also ich bin jetzt kein C+ Programmierer, aber ich kann mich schon zurecht finden in beiden Systemen und mit diversen Spezialsoftwaren. #00:02:29-4#

KB: Warst du vor dieser Ausstellung bereits in die Erstellung von interaktiven Ausstellungsstücken involviert? #00:02:49-8#

I3: Ja, in Admont indirekt. #00:03:05-0#

KB: Aber sonst nicht weiter #00:03:08-4#

I3: Nein, bei der letzten Ausstellung haben wir das noch nicht gehabt. #00:03:12-1#

KB: Ok, dann kommen wir jetzt zu den wichtigen Fragen. Ich möchte zuerst bei dem Babenberger Stammbaum Projektion anfangen und dann gehen wir ein Stück zurück in die allgemeine interaktive Ausstellung mit App und den anderen Installationen. Also Babenberger Stammbaum, welchen Mehrwert hat aus Deiner Sicht eine interaktive Installation wie die des Babenberger Stammbaums in einer Ausstellung. #00:03:58-0#

I3: Dass die Besucher*innen ins Tun kommen und dass man den Content ein wenig auseinander schneiden kann sozusagen also praktisch differenziert sehen kann und beim Babenberger Stammbaum, der ist so komplex. Und die Information dadurch aufdröseln kann und zwar der Besucher, die aufdröseln kann. Prinzipiell. #00:04:36-4#

KB: Welche Probleme oder Schwächen hat aus Deiner Sicht die Installation? #00:04:40-2#

I3: Die Schwächen sind meiner Meinung nach die Blickführung. Das heißt man hat dieses Tablet vorne oder diesen Touch Screen vorne und der Blick ist eigentlich recht nahe und man hat eigentlich genug Platz, um viel Content darzustellen also im Gegensatz zum Smartphone zum Beispiel. Und es ist dann sehr schwer, wenn man den Blick auf die Projektion richtet, dass man dann weiß, wo man ist. Vor allem weil zwei also, weil es geteilt ist. […] Das wäre so die Problematik, die ich sehe. Was wir vorher nicht wissen haben können. Was sich, glaube ich, gezeigt hat, dass man eigentlich lieber dann dort [Touch Display] bleiben würde. #00:05:47-6#

KB: Wo würdest du Stärken sehen? #00:05:49-4#

I3: Stärken würde ich sehen, dass so eine Projektion, eine interaktive Projektion an sich, schon sehr cool ist. Dass man wo rein fokussieren kann, Sachen sich vergrößern kann und vor allem wie es bei dieser komplexen Bildmaterie ist, wo ja wirklich ein dichtes Programm drin ist, dass man das auseinanderschneiden kann. Und projizieren find ich grundsätzlich gut. Ich find beide Teile gut. Die Projektion und den Screen. Aber ich find, dass die Kombination schwierig ist - in dem Thema. Es gibt vielleicht andere Themen, wo das perfekt funktioniert. Wenn man z.B. ich glaub, wenn der Besucher was zeichnen könnte und dann drückt der auf einen Button und es wird dann projiziert und es entsteht dann irgendwas Neues. #00:06:56-9#

KB: Wenn Du Benutzer beobachtet hast bei der Installation, sind Dir da irgendwelche Unklarheiten aufgefallen? #00:07:14-6#

I3: Schwierige Frage, weil ich da eigentlich nie jemanden beobachtet habe. #00:07:19-6#

KB: Wenn wir an dem Punkt bleiben. Was glaubst Du, woran könnte das gelegen haben? #00:07:26-0#

I3: Ich glaube, es ist einerseits der Position geschuldet. Dass es eigentlich schon am Ausgang ist und nicht ganz klar war, was da ist. Und eben diese Treppe, die den Flow so unterbrochen hat. Also ich glaub, einerseits wär es wahrscheinlich besser gekommen, wenn man die zwei interaktiven Teile mit den Thron und dem Dings ein bissel weiter auseinander gehabt hätte. […] Und ich glaube, dass der ursprüngliche Gedanke, dass dort hinzustellen, wo jetzt der Thron steht, dass man von unten schon drauf raufgeht und dann praktisch die Besucher sich schon interessieren, was ist da, von der Wegführung sicher besser funktioniert hätte, wenn man schon sieht, dass da oben jemand was macht. Also ich glaub, das war wirklich ein großer Teil die Platzwahl. #00:08:29-7#

KB: Habt ihr von anderen Personen Feedback bekommen, also nicht nur Besucher*innen sondern auch Kolleg*innen aus anderen Museum? #00:08:38-3#

I3: Ich habe nur allgemeines Feedback gekriegt zur Ausstellung von Leuten, die mir erzählt haben, wie es war. Die waren alle durchwegs positiv. Aber konkretes Feedback ist mir nicht zugespielt worden. […] #00:09:01-2#

KB: Solche Ausstellungsstücke mit Datenvisualisierung. Mit welchen Daten oder mit welchen Ausstellungsstücken könntest Du Dir vorstellen, wo könnte so eine Kombination funktionieren, was könntest Du Dir vorstellen und mit welchen vielleicht eher nicht? #00:09:36-1#

Ich könnte mir gut vorstellen mit Daten - oder sagen wir so - Inhalten, die nicht in einer Ausstellung gezeigt werden können, z.B. du hast ein Bild oder Skulptur oder irgendwas, wo der Originalraum - die Kirche oder das Schloss nicht mehr vorhanden ist, weil es zerstört ist. Das wäre eine Möglichkeit, dass man das visualisiert, wie es im Original ausgeschaut hat. Aber das ist jetzt eher konservativ. Das zweite wäre, dass man eben Objekte reinholen kann, die nicht gezeigt werden können und kontextualisiert. Und das interaktiv zu gestalten, glaube ich, ist einfach andere Sichtweisen reinnehmen. Also einerseits ist es nicht schlecht, den Besucher in Bewegung zu bringen oder halt den Eindruck zu vermitteln, dass er da was machen kann. Andererseits ist es schwierig z.B. ich war letztes Jahr in Rumänien in einem Museum, die haben, glaube ich, sehr viel Geld investiert in eine interaktive Installation, wo man wie bei der XBOX steuern konnte. Wenn man die Hand gehoben hat, hat sich das 3D Visualisierungsobjekt nach oben bewegt und so. Und man hat, wenn man 2x mit der Hand gewinkt hat, praktisch wie ein Mausklick das Objekt fangen können. Und das ist zwar recht nett gewesen, aber ich habe mir dann gedacht - ich hoffe, ich bin nicht zu kritisch - dass es eigentlich vom Thema ablenkt. Und dass es eigentlich keinen großen Mehrwert hat, wenn man dann die Vase danebenstehen hat und dann kann man da die Vase drehen. Also es ist schwierig, weil die Aufmerksamkeit des digitalen Objektes eigentlich nicht auf den Content geht. Ist mir so aufgefallen. Andererseits muss ich auch sagen, dass ist das was bei mir hängen geblieben ist aus dem Museum. […] Ich glaub, dass der Königsweg ist, sehr genau zu überlegen, was man in der Form präsentiert und was man eigentlich damit will. Und da können wir vielleicht eh zurück zu diesem Babenberger Stammbaum. Die Grundidee war ja dieses Riesenobjekt, das unbeweglich ist, in einen anderen Ausstellungsbereich zu bringen. Und das finde ich nach wie vor eine gute Sache. Und man muss aber glaube ich aufpassen, dass man sich nicht von der Spielerei verführen lässt […] #00:13:01-9# Also wenn der Mensch zu viel interagieren muss, um etwas zu machen. Aber das ist auch durchaus ein Problem der Stammbaum Installation. Man muss zu viel tun, um herauszufinden, was ist dann dahinter - also der Einstieg ist noch zu schwierig. #00:13:18-3# Also ich glaube auch, wenn ich jetzt drüber nachdenken, dass das auf einem zu hohen Niveau eingestiegen ist. Zu hohe Voraussetzungen. Und es wäre wahrscheinlich jetzt im Nachhinein gesehen, besser gewesen den Babenberger Stammbaum doch in irgendeiner Form als Gesamtes zu repräsentieren. Damit man dann sagt. Ok und jetzt beschäftigen wir uns mit der Zerschnipselung von dem. Und was wir jetzt auch noch einfällt und vielleicht weiterführend ist, wenn man als Besucher oder Benutzer den Eindruck hat, ah das ist irre viel da drinnen und man ist seit 5 Minuten dort und man merkt, das werde ich aber nie durchsteigen in den 10 Minuten, die ich Zeit habe. Ich glaube, dass man den Content sehr begrenzt halten muss. Also z.B. die ganze Babenberger Geschichte auf den Screen zu bringen mit allen Stammbäumen war einfach zu viel. #00:14:18-1#

KB: Dabei haben wir ja schon reduziert #00:14:18-1#

I2: Ja, genau. Und da sind wir jetzt wieder bei der schwierigen Frage, wenn Du so ein komplexes Teil, wie den Babenberger Stammbaum hast, dass man dann wirklich sagen muss - 2 bis 3 Szenen - aus Maus. #00:14:33-3#

[…]

KB: Wir haben bereits diskutiert, im Sinne von Storytelling einen konkreten Einstiegspunkt zu nutzen, der dann nachfolgend eine Breite ermöglicht. Du kommst ja über die Translatio nach oben vom Leopold. Und wenn Du direkt jetzt am Touch Display oder auch an der Projektion als Einstieg […] den Leopold nur abgefangen hättest und die Geschichte vom Leopold nur erzählt hättest, der dann die Agnes heiratet und dann viele viele Kinder hat. Auf eine ganz einfache Art und Weise einen Einstieg gibt und danach dann auf Basis der Kinder dann im Endeffekt die Möglichkeit der freien Exploration gibt, kannst Du einerseits eine kurze Sache, die Du mitnimmst, die relativ schnell erfassen kannst und gleichzeitig, danach mehr machen können. Die Idee hätten wir mal zu Anfang haben sollen, aber man lernt dann draus. […] #00:15:48-8#

I3: Das stimmt. Aber man muss schon mit sagen, es war insgesamt zu viel die 5 Projekte. Also wenn man nur mit dem gespielt hätte, dass man in der bestehenden Ausstellung unten hinweist, dass das da kommt. Und das so aufbaut. Also, ich glaub, dass es in Wirklichkeit genügt hätte, 2 Projekte zu machen, wo man dann zum Schluss auf diese Babenberger Geschichte - das mit Leopold als Ausgangspunkt find ich eh super - draufkommt und dann auch motiviert ist und sich auch freut auf das Spiel. Und das war einfach zu viel. #00:16:41-1#

KB: Also im Endeffekt eine Story hin zu den interaktiven Installationen aufbauen. #00:16:47-6#

I3: Genau, dass zum Schluss die Besucherin so kompetent ist, dass sie auch Ansätze hat, was es da alles zum Schauen gibt. Also dass man es praktisch im pädagogischen Sinne der Festigung des Gesehenen noch mehr mit dem Informationen spielen kann. Also wenn man z.B. das Weißkunig Quiz schon auf das bezogen hätte, dass man sagt da geht es eigentlich auch schon um den Babenberger Stammbaum. Aber in einem anderen Ding. Und dann gibt es vielleicht hinten einen Augmented Reality Teil, wo man gewisse Szenen aus dem Babenberger Stammbaum sieht […] Würde ich jetzt mit der Erfahrung schlüssiger finden. #00:17:36-2#

KB: Wann haben wir die Möglichkeit nochmal so eine Ausstellung zu machen? #00:17:37-6#

I3: In 2 Jahren. #00:17:42-9#

[…]

KB: Was würdest Du für eine nächste Ausstellung mit ähnlichen interaktiven Installationen anders machen wollen? #00:18:31-3#

I3: Eine Hauptgeschichte durchlaufen lassen. Und die aufbauen, dass die Kompetenz der Besucher steigt. […] Dass die zum Schluss ein Erfolgserlebnis haben, dass sie das jetzt wissen und deshalb dynamisch sich was bauen können. Dass ist vielleicht ein bissel viel gewollt aber, ja. #00:19:00-1#

KB: Das wäre ein interessanter Ansatz das auszuprobieren. Welche Herausforderungen siehst Du auf der Besucher*innenseite - wobei Du eh schon gesagt hast, dass Du gar nicht so viele Besucher*innen beobachtet hast. Wobei das ist allgemein auf alle interaktiven Installationen bezogen. Ist Dir bei den Handysachen etwas aufgefallen? #00:19:22-0#

I3: Ich kann da nur unseriöse Einzeleindrücke machen. Ich hab den Eindruck, dass die jungen - also Schülergruppen - die sind ziemlich abgefahren auf das Handyzeug. Da dürfte es wirklich perfekt gepasst haben. Meine Generation ist eher wieder dabei sich ein Nokia zu kaufen. Für die Augmented Reality war das super - also das finde ich auf jeden Fall ausbaufähig. Weil aber sicher ein Fehler von uns auch war diese Geschichte, dieser Text. Und wieder genauso: Ich schau aufs Handy lese den Text und komme dann eigentlich vom Objekt weg. Und deshalb glaube ich, dass es eigentlich am Handy interessant ist wirklich rein in die Augmented Reality rein zu geben. Wo man dann sagt, ok ich halt jetzt über ein Objekt mein Handy drüber und krieg dann eine Zusatzinformation. Was auch immer das ist. Das wäre auch leichter, weil dann braucht es auch keine Bluetooth Beacons oder so. Denn das geht dann rein auf Mustererkennung. Und das zweite was man beim Handy auch machen kann, das haben wir eh kurz diskutiert, aber zum Glück nicht gemacht, weil es zu aufwendig gewesen wäre, wäre eben akustisch - das man sagt der Individualbesucher geht mit Kopfhörer durch, die hat er eh selber mit und […] geht dann praktisch durch ein Hörbild oder […] es wird was erzählt - also man geht durch ein Feature, das würde mich noch reizen sowas mit dem Handy zu machen - also Feature kombiniert mit Augmented Reality - dass man dann das ein bissel dynamisch macht, wo der sein Handy hinhält und demnach erfährt er noch was anderes. Aber die Geschichte, die wir gemacht haben, - ich mein ich find es super, wie gesagt, es ist eh gut angenommen worden für einer der Zielgruppen - war einfach zu steuernd. Was aber auch das Thema war - message control. Und vielleicht auch als Selbstkritik: War glaube bei den ganzen digitalen Dingen, dass wir zu viel im Team gemacht haben, also von unserer Seite her - also jeder wollte seinen Content noch reinbringen. Und ich glaube, dass es fast besser ist, da ein Bottleneck zu haben von einer Person, die sagt ok, ich bestimme, und wenn es nämlich der einen Person schon zu viel wird, dann weiß man, dass es dem Benutzer zu viel werden wird. […]
Alles Abbilden zu wollen also ein Wunsch nach Vollständigkeit, der ja ein bissel dahintergesteckt hat. […] Was wirklich am tollsten bewertet worden ist, war das Legend Game. Das haben alle total cool gefunden sowohl jung als auch alt. #00:22:44-6#

KB: Kannst Du Dir erklären warum? #00:22:44-3#

I3: Weil das einfach glaub ich diese lustige Sache ist, da kann man herumdrücken, direkt auf dem Bildschirm und es waren die Animationen halt auch sehr toll. Also die Leute waren wirklich begeistert. Und äh, das was am Zweitbesten angekommen ist, war das Weißkunig-Quiz, abgesehen vom Multitouch oben, der fasziniert alle. […] Das Weißkunig Quiz hat eine gewisse Zielgruppe, die […] Bildungsbürgerlichen oder ja, es hat keiner wirklich durchgespielt, weil es zu lang war. #00:23:39-1#

KB: Wir waren ja mit der FH da als Betriebsausflug und da haben wir das WLAN zu nichte gemacht. Weil wir schon zu Anfang Probleme hatten mit dem Einsteigen. Weil es dann zu viele waren. Beim Weißkunig Quiz hat es erstaunlich gut funktioniert, natürlich gab es auch Ausfälle. Aber es ist immer schön zu sehen, wie sich da ringsum die Traube bildet und da tatsächlich viel passiert. Was ich da - nicht schade, aber was halt da zu überlegen ist, […] Ich glaube, dass wesentlich mehr Leute mit dem stationären Tablet gearbeitet haben als mit ihrem mobilen Gerät. Und wenn das besetzt war, dann sind viele vermutlich vorbei gegangen und haben gar nicht erst gemacht. Von dem her ist da die Challenge, wie man sowas - weil es ja eigentlich gut ankommt - tatsächlich nutzbar macht, ohne das Handy zu nutzen. Weil ich glaube auch mittlerweile, dass das Handy nicht unbedingt - wir haben auch mit einer Schulklasse evaluiert gehabt, es war auch super und schön zu sehen, wie das funktioniert - aber eben die breite Masse, naja das ist die Frage dann zum Schluss, ist uns die breite Masse Wurscht und wir machen trotzdem die App oder konzentriert man sich eher auf Installationen und weniger die App wobei halt AR hast Du vollkommen recht, das ist auch super angekommen und war beim Betriebsausflug zu beobachten, dass die Leute damit super gewerkelt haben, dafür brauchst Du dann halt wieder die App. Da sind noch einige Sachen, die man eigentlich wirklich weiter forschen müsste und weiter ausprobieren müsste. #00:25:28-6#

I3: Ja, ich glaub die App ist im Prinzip nicht schlecht. Wenn man es wirklich total auf ein Objekt bezieht, das heißt, du kriegst mit Augmented Reality in dem Moment was. […] Also man nimmt das Handy als Instrument für diese Augmented Reality und baut dann vielleicht auch so ein kompetitives oder so ein Challenge-Dings eins, wo man dann interagieren kann. Ich glaub, dass was bei dem Weißkunig Quiz so cool war, ist, dass man da wirklich zu dritt - also ich habe das einmal gemacht mit ein paaren, wo es funktioniert hat, und das war wirklich lustig. […] Und da finde ich, könnten wir weiter dran arbeiten. Aber das Handy als sozusagen Guide zu nutzen, so wie wir es geplant haben, das funktioniert glaube nicht wirklich. Weil man dann mit dem Handy durch die Gegend gehen muss und sich nicht mehr zurechtfindet, wo man eigentlich ist. #00:26:51-2#

KB: Man muss es aber glaube ich auch in Frage stellen in die Richtung, dass ich - will ich das tatsächlich - also wer soll mich guiden. Soll mich tatsächlich das Handy guiden oder soll mich nicht eigentlich die Ausstellung guiden und das Handy nur in irgendeiner Weise unterstützen. #00:27:10-9#

I3: Genau, da ist eine wichtige Frage nämlich auch der Audioguides, der ja auch so heißt, der doch noch sehr beliebt ist und eigentlich das besser - also ich glaube, dass das mit dem Hören besser durchgezogen ist. Ich glaub, das Problem beim Handy ist, dass es, genauso wie die Ausstellungsobjekte, auch auf Sehen fokussiert und damit praktisch da Konkurrenz entsteht zwischen zwei Dingen, die die gleichen Sinne ansprechen. Wenn man mir was erzählt, kann ich trotzdem noch aufs Objekt schauen. Deshalb - wenn ich mich selber beobachte, ich lese z.B. auch nie diese Objektbeschreibungen, sondern immer auch nur die Raumtexte. Und die Objektbeschreibung lese ich nur dann, wenn ich wirklich was wissen will oder mitdenke, vielleicht ist da was Spannendes. Und das ist glaube ähnlich beim Handy. #00:28:09-3#

KB: Wenn wir entwickeln, sind wir noch zu stark auf das Sehen - also, dass die App so einen Sinn ergeben muss im Prinzip auch ohne Museum. Und aber auch da kann man sich von den Erkenntnissen her ein bisschen von verabschieden und sagen, die App wird sowieso nur genutzt während der Ausstellung und weder davor noch danach. #00:28:30-2#

I3: Genau #00:28:31-6#

KB: Und gibt es tatsächlich sinnvolle Nutzungsszenarien für davor und danach - in Wirklichkeit gibt es die nicht. #00:28:37-5#

I3: Na für eine Dauerausstellung ist das schon was anderes. #00:28:40-3#

KB: Ja wobei, beschäftigen sich die Leute dann tatsächlich damit? #00:28:47-0#

I3: Also nach einer - ja das stimmt. Aber was mir gerade so einfällt, geht wieder in diese Augmented Reality. Eigentlich müssten wir sagen, das Handy ist ein Werkzeug wie eine Lupe. Ich geh wohin und dann möchte ich was genaues Wissen und dann nehme ich mein Handy raus und verwende es, halte es hin und dann passiert etwas. Also das praktisch, nicht das Handy mich leitet, sondern dass ich das Handy dann zu Hilfe nehme, wenn ich in die Tiefe will. Dann hat man glaube ich die Aufmerksamkeit eher bei der Ausstellung, aber das ist vielleicht auch nur ein Gedanke. #00:29:27-1#

KB: Wenn Du so generell bei interaktiven Installationen für Ausstellungen an Ausstellungen denkst, welche Dinge müssen gegeben sein, damit interaktive Installationen funktionieren? #00:29:54-5#

I3: Vom Ausstellungshandling her? #00:29:59-8#

KB: Alles was dir einfällt #00:29:59-8#

I3: Also, damit sie funktionieren, was ich von Seiten des Ausstellungsbetreibers komplett unterschätzt habe, ist wieviel Aufwand eigentlich das ist, dass das ganze läuft. Es ist ein ziemlicher Wartungsaufwand, es ist ein ziemlicher Betreuungsaufwand. Den Du mit so technischem Zeug hast. […] Was gegeben sein muss, ich glaub, dass es ganz wichtig ist, das ist bei uns leider hat nicht funktioniert von Seiten des Stiftes her - ist, dass man in das Ausstellungsbetreuungsteam vor Ort also, die die dann vor Ort die Ausstellung operativ abwickeln während der Laufzeit, das Verständnis für diese Dinge extrem heben muss. Das heißt man muss sie gut einschulen, man muss die wirklich überzeugen, man muss die motivieren, man muss sagen, was das wirklich bedeutend ist. Das darf man nicht unterschätzen. Ich glaub, dass das das Um und auf ist, dass das Team vor Ort schaut, dass das alles geht. […] Es braucht extrem viel Aufmerksamkeit. […] Und auch die technischen Grenzen. Wenn jetzt eine Schulklasse kommt und das WLAN bricht zusammen. Ich mein wir haben extra eine neues WLAN da unten installiert. Es war jetzt - ich weiß nicht, ob es gut war - aber zumindest mit so Crowd Sachen muss man schauen, wie hoch der tatsächliche Aufwand eigentlich ist. Damit man einmal da gleich 50 Leute bespielen kann. Also das ist auch wichtig sowas. #00:32:03-9#

KB: Die Gegenfrage dazu - woran könnten solche Vorhaben scheitern? #00:32:13-1#

I3: Naja, wenn sich niemand drum kümmert. Wenn man glaubt, es ist so wie die Ausstellungsobjekte. Ich habe ein Bild, das häng ich in die Ausstellung und wenn die Ausstellung vorbei ist, tue ich es wieder runter - oder ein Raumtext. Und an dem scheitert es. Und an dem ist es auch bei uns gescheitert. Weil es einfach ein Wahnsinn war, dass die Leute - aber das ist das Problem von unserem Team - dass die Leute einfach überhaupt kein Bewusstsein gehabt haben oder auch überfordert waren oder what ever. #00:32:43-7#

[…] #00:33:31-9#

KB: Rückblickend, mit Euren Zielen, die Ihr eigentlich hattet, warum machen wir interaktive Elemente, wie erfolgreich war es aus Eurer Sicht bezogen auf Eure Ziele? #00:33:46-2#

I3: Also ich finde, aus meiner Sicht war es schon sehr erfolgreich. Und zwar wenn man die Mittel, die wir investiert haben, und die Ergebnisse, die rausgekommen sind, betrachtet, war das ein unglaublich erfolgreiches Projekt. Also ich bin sehr stolz drauf, dass wir das auch gemacht haben, muss ich sagen. Und es ist auch vom Feedback her sehr erfolgreich, weil wir natürlich auch so kommuniziert haben, dass es eigentlich ein begleitetes Forschungsprojekt ist - also das ist nicht eine Firma, wo man das dann perfekt haben will, sondern da geht es um Forschung und genau das Gespräch was wir jetzt führen geht in die Richtung. Und schauen, was kommt besser und das hat auch super funktioniert mit der Zusammenarbeit mit den Teams. Unsere Leute haben extrem viel gelernt dabei. Ich habe unglaublich viel gelernt dabei. Und wir haben extrem gutes Feedback gekriegt. Also auch wenn was nicht funktioniert hat, das hat sich keiner drüber beschwert. Die Leute haben nur gesagt naja nein mein Handy kann das nicht. Aber ist eh Wurscht. Also es ist jetzt nicht so, dass alle gesagt haben, seid ihr alle verrückt. Und das finde ich, ist wirklich super. #00:35:04-4#

Interview #4

KB: Wie würdest Du Deinen Job im Zusammenhang mit der Ausstellung beschreiben?

I4: Teilkuratorin.

KB: Wie lange bist Du schon im Museumsumfeld aktiv in Jahren.

I4: zwei Jahre.

KB: Und was hast Du für einen Hintergrund (Studium, Arbeitserfahrung)?

I4: Studium der Geschichte der klassischen Archäologie. In meinem ersten Weg wollte ich Kultur- Wissensvermittlung machen und habe deswegen eine Journalismus Ausbildung gemacht und halt Praxis nebenbei immer wieder mal.

KB: Was meinst Du mit Praxis?

I4: Im Museumsbereich also diese Touren, die ich gebe in Klosterneuburg oder eben auch versuchen für Magazine Wissenschaftsthemen verständlich aufzuarbeiten.

KB: Wie würdest du deine Computerkenntnisse einschätzen?

I4: Eher schlecht. Basiskenntnisse vorhanden. Ich kann einen Computer bedienen und einfache Probleme selber lösen. Meistens brauche ich jemand, der mir hilft.

KB: Warst du vorher schon mal in einer interaktiven Ausstellung involviert?

I4: Beim Bau von einer Website, wo Leute auch kommentieren können oder Gefällt mir abgeben können. Eigentlich eine normale Nachrichten-Website aber mit einem Social-Network Gedanken dahinter.

KB: Gut dann kommen wir zu den eigentlichen Fragen. Ich würde mit der Installation mit der Projektion vom Stammbaum starten und dann ein bisschen zurückgehen in die allgemeinen interaktiven Installationen in der Ausstellung. Deswegen als erstes die Frage welchen Mehrwert hat aus deiner Sicht eine interaktive Installation wie die vom Stammbaum in der Ausstellung

I4: [...] Mir ist aufgefallen, dass die Installation zwar sehr interessant für die Leute ausgeschaut hat, aber dass sie Schwierigkeiten gehabt haben, das zu verstehen, was wir damit aussagen wollten.

KB: Kannst Du Dir vorstellen, woran das lag?

I4: Mein Eindruck war, dass das auch für mich wenig intuitiv war oder nicht wenig intuitiv, man hat irgendwie eine Zeit gebraucht, bis man verstanden hat, was passiert, wenn ich was mache. Und auch das zwei Möglichkeiten waren, das zu bedienen nebeneinander, hat die Leute meistens auch verwirrt, weil sie nicht gewusst haben, was sie jetzt machen.

KB: [...] Welche Probleme oder Schwächen hat aus Deiner Sicht diese Installation?

I4: Was auch noch ungünstig war - und das haben wir vorher nicht bedacht - war der Standort. Also der Thron, wo man sich raufsetzen hat können zum Foto machen, war für die Leute das, wo sie sich eher aufgehalten haben. Und dann war schon das Drehkreuz und eigentlich war die Installation hinterm Drehkreuz. Also ich glaub, wenn die besser platziert worden wäre oder günstiger platziert worden wäre, wären die Leute nicht so dran vorbei gegangen. Aber das ist generell blöd gewesen, dass wir diese Stufen rauf hatten. Da hat man irgendwie das Gefühl gehabt, die gehören nicht mehr zur Ausstellung. Das hätte man besser einbeziehen können. Ich glaube, dass voll viele Menschen gar nicht zum Thron raufgegangen sind. Das ist wirklich was, was sich in der Praxis ergibt. Es ist echt eine ungünstige räumliche Situation und wir hätten dort vielleicht mit Plakaten oder Fahnen oder irgendeiner Gestaltung von der Treppe das irgendwie markieren müssen, dass die Ausstellung da oben weiter geht.

KB: Wahrscheinlich hätte die Treppe tatsächlich auch irgendwas transportieren müssen im Nachhinein.

I4: Bei der Führung bin ich immer durch die Ausstellung unten durchgegangen, da hab ich halt nichts erklärt, sondern nur den Weg rauf und da hab ich den Leuten immer gesagt: Ja ok der Thron und die Installation gehört auch dazu, da können sie nachher noch Fotos machen oder sich das anschauen. Dann ist es gegangen, aber es hat ja nicht jeder die Führung gemacht.

KB: Siehst Du für Dich trotzdem irgendeinen Mehrwert mit solchen Installationen vom Stammbaum her?

I4: Also der Mehrwehrt, den ich gesehen hab, war dass wir irgendwie diese Prozesshaftigkeit von Geschichte ein bissel zeigen konnten. Also, das was sich verändert, dass das nicht statisch ist. Also dass man Dinge anders darstellen kann. Und ich glaube, dass generell Menschen immer mehr gewöhnt sind, dass sie irgendwie selbst entscheiden können, was sie sich anschauen und dann ist so eine Installation auch für die Besucher. Also man hat auch das Gefühl man hat dann nicht nur angeschaut, sondern auch was getan und ich glaub das ist wichtig. So ein Erlebnisfaktor vielleicht. [...] optisch war es auch ein Mehrwert. Es hat gut ausgeschaut.

KB: Hast du mitbekommen, wir haben ja in der zweiten Oktoberhälfte die Projektion geändert. Sodass du nicht mehr den Leopold standardmäßig siehst, wenn niemand dran war sondern einen Schriftzug, der die Leute dazu bringen sollte, die Touch-Displays zu nutzen. Hast du da durch Zufall irgendwie mitbekommen, dass die Leute darauf eventuell eher reagieren, die Displays zu nutzen?

I4: Nein, habe ich leider überhaupt keinen Eindruck davon. [...]
Mir ist aufgefallen, dass es anders ausschaut. Also auf mich hat es attraktiver gewirkt, weil es mehr ausschaut wie ein Startbildschirm. Aber ich kann jetzt nicht sagen, ob ich mehr Leute dabei gesehen habe.

KB: [...] Habt generell noch zusätzliches Feedback bekommen von Besuchern oder auch Kollegen aus anderen Museen zu den Installationen.

I4: Also am besten angekommen ist der Table oben beim Stammbaum bei den Besuchern, der war irgendwie das, was die Leute am einfachsten verstanden haben. Ich habe sehr oft die Leute gesehen beim Legenden Spiel und beim Maximilian Quiz aber mit dem Tablet was angeboten wird und weniger mit dem eigenen Handy. Ich habe eigentlich am wenigsten Benutzer bei der Installation oben gesehen, aber aus den besagten Dingen wahrscheinlich vorher.

KB: Was glaubst du so allgemein, welche Herausforderungen siehst du auf Besucherinnen Seite, wenn man die ganzen interaktiven Installationen Revue passieren lässt, wo denkst Du, was sind Herausforderungen aus der Sicht der Besucher?

I4: Ich glaub, dass die Schwelle sehr hoch ist, dass man das eigene Handy benutzt. Man merkt, dass das bei jungen Leuten eher. Also da waren ein paar mit ur cool und probieren das und die vielleicht auch selber in dem Bereich auch arbeiten oder eine Schule machen. Ältere Leute haben das eher super gefunden, dass es das gibt, aber nicht genutzt. Sie können sich entweder mit der App oder den Wandtexten durch die Ausstellung führen lassen. Dann haben sie es super gefunden aber halt nicht benutzt. Also diese Schwelle ist sehr hoch.
Ich glaub, das digitale Vermittlung voll einen Mehrwehrt haben kann für die Besucher, wenn man sich darauf einlässt.

KB: Aus Benutzersicht, was glaubst du, was kritische Erfolgsfaktoren sind?

I4: Nicht das eigene Handy nehmen.

KB: Das heißt, eher Leihgeräte oder doch eher auf mobile verzichten und eher Stand-Installationen zu machen.

I4: Das kann ich mir schon vorstellen, aber das muss dann nicht zwingend ein Handy sein, keine Ahnung oder der eben diese Stehstationen so wie der Tisch oder das Legenden Spiel sind eigentlich ziemlich gut angenommen worden. Wo man sofort anfangen kann ohne, dass man irgendeine Führung hat bevor es losgeht. Ich muss nicht runterladen, muss keine Daten hergeben - ich weiß um das geht es - aber es ist für voll viel Leute eine hohe Schwelle.

KB: Was glaubst du woran könnten solche Vorhaben scheitern?

I4: Wenn man zu viel verlangt von den Besuchern. Also z.B. der Table ist voll gut angekommen bei den Besuchern, da haben eigentlich alle irgendwie versucht das Medaillon groß machen oder irgendwie was anschauen. Weil das ist was, was die Leute kennen, ich klick wo drauf. Bei der Installation war es irgendwie komplexer, da hat man mitdenken oder interpretieren müssen. Ich glaub auch beim Legenden Spiel, dass das einfacher war als das Maximilian Spiel. Weil da die Leite auch gewohnt waren, ich drück auf den Bildschirm und dann passiert irgendwas.

KB: [...] Warum haben wir eigentlich die interaktive Ausstellung bei euch gemacht. Wenn Du rückblickend überlegst die Ziele oder potenzielle Ziele, die damit erreicht werden sollten, sind die erreicht, war es erfolgreich?

I4: Hm auf jeden Fall oben beim Table, weil wir da mal die Leute näher dran lassen wollten. Ich glaub auch auf jeden Fall beim Legenden Spiel. Wir wollten eigentlich diese trockenen Inhalte für zeitgenössische Besucher attraktiv gestalten. Und ich glaube, dass ist uns beim Maximilian Quiz gelungen. [...]

KB: Gibt es noch zusätzlich Anmerkungen?

I4: Gestaltung also die Optik habe ich sehr cool gefunden, dass es so gut zur Ausstellung gepasst hat. Es hat stimmig gewirkt. Es hat nicht so gewirkt, wie eine Ausstellung und dann sind da digitale Elemente einfach hineingepappt, sondern es hat wirklich ein stimmiges Bild ergeben.

APPENDIX H

Guidelines for Interactive Exhibition Design

H.1 Mobile App

H.1.1 Incentivize the use of the mobile app.

Recommendation: Visitors have to be invited to use the running mobile app. They can receive suggestions from the museum, which can offer users promos or extra information if they have the app. In addition, users should see the benefits of installing the app. They can, for example, use the app to contribute to the experiences created by each installation. You can even consider maintaining the same app for multiple exhibitions of the same museum, or even exhibitions from different museums.

A web-based app should be easier to access in comparison to a mobile app. You can run on a browser with no need for installation. Such a web application can even be used as an entry point (e.g., the visitor starts interacting with the web app and moves to the mobile app for more advanced features).

Own experience: Our app was communicated at the museum's website and in the entrance area of the exhibition but without demonstrating a clear benefit. We thought the curiosity of the visitors was enough to convince them. Our evaluation showed that is was not. In our interviews, most visitors reported using our app for curiosity and mainly due to a friend's recommendation rather than the museum's. Although a friends' suggestion positively affects the acceptance of new technologies (Venkatesh et al., 2016), the museum needs to promote and facilitate access to the app as a tool offered by them to complement their exhibition.

When asked about the most positive aspect of the app, visitors reported its playful and interactive characteristic, the access to further information and content, the use of

AR, the possibility of constructing their coat of arms, and the availability of content in multiple languages. Therefore, integrating interactive and playful content in the app can also attract visitors. A gamification feature (such as collecting items to compose your coat of arms) should also incentivize the app's use.

H.1.2 Make the use of the app optional.

Recommendation: Do not force the use of the app. Do not block users from accessing the exhibition nor the artifacts and installations if they do not have the app or a device to interact with it.

Own experience: During the exhibition, we observed the creation of 667 app accounts. Out of these app users, 384 (57.6%) played with the Weißkunig Quiz using the app on their own devices. On the other hand, there were 650 accesses to the Weißkunig Quiz using the stationary tablet. The number of accesses through the stationary device was almost double the number of accesses by visitors using their own devices. Without an alternative to access the content, these users would be excluded from participation.

H.1.3 Allow for a smooth start.

Recommendation: Allow the visitors to access the main content quickly. Do not demand much attention or information from the visitor when setting up the app, especially when it comes to registration and permission.

Own experience: Reflective interviews showed that there is a preference for an instant start, without having to download something or hand over personal data. Observations demonstrated that visitors withhold even a username and a short password in time to create an account, preferring to run a guest login instead. During the exhibition, we observed the creation of 667 app accounts. Only 136 (20.4%) user accounts were registered with a username and password. The remaining users accessed the app with guest accounts (i.e., no need to register).

The need for an instant start is also substantiated by our observation of the users' tendency to skip permission pop-ups. Although it is not only important to ask for permissions in the mobile app but also to explain those permissions to the users (i.e., why those permissions are needed, how the data is going to be stored and processed), we observed that pop-ups were not the proper way of doing so. When first starting the app, users should allow the device to access both Wi-Fi and Bluetooth to access the content from the exhibition properly and to run the location-aware features. However, it was observed that users would quickly skip the permission request without even reading it, as an automatic reaction. To solve the issue, we stopped asking for permission on start and created a small notification bar on the landing page, which appears if permissions are needed. That way, users can quickly land on the main screen and understand what the app has to offer. Then, by tapping this notification bar, the user is redirected to a troubleshooting page, showing what permissions are needed, why, and how to provide them.

H.1.4 Prefer smartphone features that are widely available.

Recommendation: In a BYOD setting, make the app accessible to most devices. However, the more devices and operating systems the development team tries to cover, the most challenging it is. So, pay attention to which sensors and functionalities are fundamental to the application.

Own experience: Opting for a web application running in a web view allowed us to provide support to more operating systems. However, when designing an app that uses Bluetooth for location awareness, not every device behaves the same way. During the design phase, we conceived an app which first displays exhibitions as locked items on the screen. As the visitor navigates the museum and passes by the exhibit, the app's corresponding item unlocks automatically. Even after testing multiple devices and operating systems, we could always find a visitor whose device would behave unexpectedly. Then, to allow for consistent user experience, we stopped conditioning the users to rely on Bluetooth detection to unlock the content. For every user, the content was then available from the beginning. Nevertheless, if the device supported Bluetooth detection, we allowed the app to scroll to the closest exhibition as an smart extra feature.

H.1.5 When using AR, consider the targets carefully.

Recommendation: When using targets from AR tracking, their size, format (2D vs. 3D), and their location in the exhibition should be considered. This should allow many visitors to track the target from afar, and still be able to read and visualize the augmented content.

Own experience: We have used AR for interacting with three different artifacts in the exhibition: an accounting book (by showing its transcription), a panel (by showing its translation), and a coffin (by showing a picture of its content). Both the accounting book and the panel provided texts that required users to be able to get closer to scan the object and read the content. The accounting book was placed behind a glass. So, even if the visitors could closely inspect the object, the specular reflections would sometimes affect the positioning of the AR overlay. On the other hand, the poster was placed on the wall and could be easily scanned by the visitors. Still, not many visitors could get close to the poster concurrently. Having a picture projected over the 3D coffin was shown to be much better than a text. Visitors could scan the object from different angles concurrently and did not need to get close to be able to visualize and understand the AR overlay.

H.1.6 Make the connection between the app and the exhibits clear.

Recommendation: Mark the connection between the app and physical exhibits very clearly. If the app lists the artifacts you can find in the exhibition, then the visitor should be able to correlate physical artifacts and digital elements easily.

Own experience: Our primary solution to establishing the connection between physical artifacts and the content of the mobile app was to automatically scroll the screen and highlight the corresponding item depending on the position of the visitor (location-aware). In addition, we had stickers around the exhibition signaling which artifacts were also displayed on the mobile app. Such stickers carried the logo of the app and the color of the corresponding section. However, when the location-aware features were not available on a device, the sticker was not enough to inform them of where to find information about the physical artifact in the app.

When asked to answer the question "How understandable was the implementation of connecting digital exhibition content with exhibition objects?" on a 7-point Likert scale, users of the app answered the question with an average of 4.9 (SD: 1.7). The average score was barely positive, as users could not understand the link between digital and physical artifacts without the location-aware feature.

H.1.7 Create entry points for the mobile app.

Recommendation: Create mechanisms, such as entry points, in which the user knows exactly when to take the mobile. The user should focus on the exhibits when necessary and on the mobile on-demand. It helps users not to walk around the museum with their eyes only on the mobile app, thus missing the museum experience.

Having a mobile app helps visitors get extra content about different exhibits. It can be a playful tool used by families and school classes to learn more about the topics explored by the exhibition. However, it can easily compete with the exhibition instead of complementing it. Therefore, special attention should be paid during the planning phases to create a dynamic in which the main focus is on the exhibition.

Own experience: By using a location-aware approach, we could understand the position of the users and send push notifications to tell them that there is a piece of information on the app about the exhibit close to them. This feature was intended to allow visitors to turn off their screens and navigate through the exhibition without missing the extra content displayed on the app. However, observations showed that visitors use the app to navigate through the exhibition. They would walk through the museum holding their phones, waiting for the timeline to scroll. When designing and deploying the app, the balance between the attention paid to the digital content and the physical content must be considered.

H.1.8 Offer technical support to visitors.

Recommendation: In a BYOD setting, museums should be able to offer technical support to allow visitors to join the experience with their devices.

When using their own devices, visitors do not have to get familiarized with a new operating system or form factor. However, visitor profiles vary in terms of technology literacy, types of devices available, and special needs.

Moreover, some visitors might not have a device, or, when running the exhibition with the app, their devices can run out of battery. Therefore, if the mobile is essential for the visitors' experience, the museum should be able to provide support in the form of extra components (e.g., power banks, headphones, and spare mobile devices). Museums should also provide staff and instructions to support visitors to get to know the app and an receive support in installing and setting it up.

Own experience: Reflective interviews show that connecting to the proper Wi-Fi was one of the main issues faced by the app users. Multiple networks were available in the museum. In spite of the app's instructions, not every user understood which network was the right one and how to connect to it.

H.2 Digital Artifacts

H.2.1 For positioning interactive exhibits, keep the visitors' walking paths in mind.

Recommendation: Interactive exhibits should be well integrated and not "off the path". The placement of the installation in the exhibition may influence how a digital artifact is perceived. Also, do not place installations in places where users block the way for others or feel observed by passers-by.

Own experience: In the beginning, we did not see, for example, a problem with the intended location for one of our installations. The niche in which the installation was placed was ideal for minimizing distractions by other exhibits or passing visitors. However, the exit with the turnstile was located directly to the left of our niche, which sometimes resulted in visitors leaving before reaching Babenberg GenVis. The reflection interviews consolidated our impressions during the observations. Regularly, people would stand in front of the exhibit looking at the projection, having the choice between going one step forward to interact, or one step to the left to leave the exhibition.

H.2.2 Enter at any state.

Recommendation: In any case, the visitors should be able to enter and leave the installation at any state as smoothly as possible. Define a starting point for the installation and provide a reset function that reverts all changes made by a visitor to this starting point.

Own experience: For all of our exhibits, visitors could enter and exit at any time they wanted. There was no need for a reset function for the quiz in the mobile app as the visitors used their devices. For the stationary device, the visitors had to leave the answer view. For Once upon a time... and Babenberg GenVis, we implemented a reset function to start over. In addition, we implemented an auto-logout for all exhibits, starting a timer when no interaction was detected and resetting to our predefined starting point.

H.2.3 Provide clear onboarding.

Recommendation: Instructions on how to use interactive elements should be visible and easily apprehensible. Optimally, they should be evident when just looking at the installation. The installation should be designed in a way that it affords the necessary interactions (Parker and Tomitsch, 2017). If an installation includes interaction possibilities that might not be intuitive from the beginning, users should be reminded of these possibilities.

Own experience: Vertical scrolling, for example, is a common type of interaction that visitors instinctively used - but the possibility of horizontal scrolling was not noticed by some visitors when using Babenberg GenVis.

Recommendation: In a multi-device environment, when more than one device is part of the interaction process, the connection between these devices must be apparent. Visitors should still know that they are all part of the same installation. Visual or auditory effects, or "call-to-action"-messages, such as "Look at the large screen", can be used to visualize this direct connection.

Own experience: In Weißkunig Quiz, for example, visitors had difficulties recognizing the "bubbles", which represented their answer. This could be solved by an animation of the bubbles flying off the mobile device and landing on the large screen.

Recommendation: For installations with much content, the information should be "layered", so the visitors are not overwhelmed in the beginning but delves deeper the more they interact. This also serves as a motivational factor.

Own experience: In our case, visitors were interested in Babenberg GenVis, but they did not know where to start and needed a comparably long time to understand it.

Recommendation: Onboarding should begin by capturing the attention of the visitors by displaying pictures or exciting facts on the start screen or screensaver ("Did you know that..."). Storytelling can also be used for layered onboarding. Keep in mind that the tutorial should not take too long, as the visitors' attention span decreases over time in the exhibition.

H.2.4 Be aware of different target groups among the museum visitors.

Recommendation: In general, museum audiences are described as diverse, varying in age, interests, and experience with technology (Hinrichs et al., 2013). However, the goal of the app has to be clear and should be focused on specific target users. Content that is interactive, cooperative, or personalizable appeals differently to different groups. Do not include only academic experts, curators, and technicians in ideation workshops, but also teachers, museum visitors, and other end users.

Own experience: When assessing different visualization alternatives for the mobile app, we observed no differences in performance with the exception of user experience. Familiarity with the visualization type and understandability was notably different across different age groups. The better experience reported by middle- and old-aged subjects, which are the primary visitors to the exhibition, was decisive to choose the final visualization.

Reflective interviews also show that the interactive installations are highly attractive to young groups and school classes due to their playfulness. Finally, we also observed different ratings from visitors with different levels of visualization literacy. Therefore, it is always essential to consider visitors with different profiles in a museum exhibition.

H.2.5 Keep in mind the technical requirements of a multi-device setting.

Recommendation: Consider the technical requirements, such as the need for an extensive backend, and the challenges of a multi-device setting (e.g., latency and scalability).

Own experience: During the exhibition, we had different multi-device installations. For example, in Babenberg GenVis, visitors could interact with the projection by using two stationary touch screens. In Weißkunig Quiz, on the other hand, users could join mainly with their own devices, apart from the stationary tablet. In the first example, we have a relatively static setting, in which the devices are already connected when the visitor arrives. The latter example is a dynamic setting, in which multiple visitors can connect and disconnect their devices. This involves infrastructure and usability challenges, as users have to understand how to join the experience, and the system has to support multiple connections from different device types.

H.3 Administration

H.3.1 Digital artifacts should be well integrated into the exhibition.

Recommendation: According to Pujol-Tost (2011), it is not due to information and communication technologies themselves if the technical components fail to serve their purpose, but rather to problems in the exhibition's overall design. Digital and physical elements of an exhibition should be interwoven rather than the result of two distinct efforts - the work of the museum team and that of the (often external) technical team.

Own experience: Although we held regular joint workshops, decisions in time-critical situations were only made within the curator team without involving the development team. Occasionally, the development team would come up with ideas that might have contributed positively to the digital artifacts' visibility but they were overheard by the curator team.

Recommendation: Also, Eschenfelder (2019) states that setting up a separate digital section at the Städel Museum would have resulted in the museum being divided into an analog and a digital section, which is not an appropriate option especially for a small institution. Their solution was to implement an interdisciplinary core team working on the overall strategy and coordinating the individual projects. These projects are subsequently performed by interdepartmental, interdisciplinary teams. Of course, how to set up the teams depends on the size of the museum. However, it is necessary to form one interdisciplinary core team (with curators and developers), which is making decisions thinking about the exhibition as one.

H.3.2 The museum's goals should guide the design process of a digitally enhanced exhibition.

Recommendation: It is essential to define the museum's goals for a digitally enhanced exhibition in the beginning, so that they can be communicated to staff and visitors. Consider the target groups and corporate tasks (e.g., focus on school groups and teachers). Make sure that any idea for digital artifacts supports these goals, validate it against these goals, e.g., by integrating the devil's advocate (Gray, 2013) in the idea evaluation phase during the design process.

Do not jump on the bandwagon and use innovative technology just because it is a trend. Since Augmented Reality (AR) is currently a hype, museums want to have something with AR before they decide on the contribution of AR to the exhibition. Multimedia applications should instead focus on solving specific problems (Bekele et al., 2018).

Own experience: In our case, we tried to make sure that the use of AR in the respective objects adds value to the museum experience.

H.3.3 Involve the exhibition staff through co-design.

Recommendation: The overall aim should be to involve as many stakeholders as possible in the design process. The use of co-design as a strategy of participatory development (Ciolfi et al., 2016) could help integrate the exhibition staff (e.g., cultural mediators, museum guards) to also get a clear overview of their requirements for the entire system and see how the staff will use it later.

Own experience: In our design process, we integrated the curators from the beginning. However, we failed to integrate the exhibition staff. When the exhibition was opened, we noticed a need for an additional explanation of the interactive exhibits. We realized that if they had been integrated, there might have been other, more appropriate options for our installations.

H.3.4 Be aware of technical challenges.

Recommendation: Check the technical constraints in the design phase (e.g., power supply options, range of Bluetooth beacons, Wi-Fi availability and signal strength, phone reception). Be aware that there might be a difference between technical restrictions (technically not feasible) and organizational restrictions (change power supply option, add additional access point). To address these issues, integrate the technical staff early on in the process.

Own experience: We were confronted with those issues during the design process. It was hard to argue that we needed a constant power supply instead of a manual on/off switch, or an additional access point in an area where there was little Wi-Fi coverage. Nevertheless, we were faced with Wi-Fi challenges during the exhibition when a large group entered and used the mobile application. Additionally, the communication with the museum's IT staff was not always easy as they were not familiar with the required technology.

H.3.5 Consider the dynamic of visitors.

Recommendation: Take visitors into account during and outside of guided tours. For guided tours, add possibilities for guides to influence the app content. For example, start an animation that supports the story the guide wants to tell or initiate a quiz. Additionally, consider adapting the tours to the app and vice-versa. Consider fast tours and the time required for interaction with digital elements.

Own experience: Observations and reflective interviews showed that most visitors need a predefined route through the exhibition. So think about how one can control the flow of visitors. For visitors outside of guided tours, remember that they might not visit the exhibits in a particular order. Guide them, let them know where to go and where to focus. Storytelling can be a tool to support guidance and attentional redirection. Give them a challenge or a call to join a different installation when the current installation gets too crowded.

Recommendation: To improve the passive viewing experience of visitors who may not want to interact with digital artifacts is ideal for conveying added value even without interaction.

H.3.6 Involve the staff in the promotion of digital artifacts.

Recommendation: Make sure that the entire staff advertises the installations and the app, but remember that this can also lead to higher costs if, for example, workshops or training courses are held. Consider intensive advertising (e.g., posters, shirts for employees).

Own experience: To involve cultural mediators and museum guards, we performed tours through the museum to explain the digital artifacts. However, we should have done that for the cashiers as they are promoting the mobile application in the first place. Also, cultural mediators reported that when they have interacted with the installation, visitors lost their fear of interaction and were convinced to interact.

H.3.7 Assign the maintenance to the staff.

Recommendation: Train employees to check the battery status, for example, or to see if technical components are still working as intended and to avoid downtime until someone happens to notice that something is not working anymore. In that case, provide the staff with a manual and instructions for troubleshooting and the information whom to call if the problem cannot be solved with these instructions.

Own experience: We followed this directive. However, for example, nobody mentioned that the projector's light bulb should have been replaced. So, it only works as long as the employees feel responsible for it.

H.3.8 Implement remote access and online support.

Recommendation: Instead of traveling because of minor maintenance problems, try to solve them via online support (e.g., if the troubleshooting manual does not help, call a developer who can help remotely). Setting up remote access is only an option when the installations are accessible via the internet.

Own experience: We had internet access for all our installations. Therefore, we accessed the installations remotely with TeamViewer[1]. We also provided telephone contact for assisting with minor issues.

H.3.9 Plan maintenance time.

Recommendation: Do not switch off all devices when the museum closes, but leave a time window of 1 to 2 hours for remote maintenance. On the one hand, it looks strange to the visitors when an interactive exhibit seems to be suddenly steered out of nowhere, and, on the other hand, they might see sensitive data on the screens. Therefore, consider and prepare a maintenance mode for the exhibits, in which the exhibit is not available to the visitors.

Own experience: We had to deal with both options. One installation had a maintenance window, and two others had no maintenance time outside of opening hours. Of course, it was easier to maintain or update the installation that had a maintenance time.

H.3.10 Consider update and maintenance costs.

Recommendation: Digital artifacts have running costs and do not run without the active involvement of humans (e.g., staff, technical support). Do not believe that an app in a BYOD setting is a one-time investment. Be aware that non-foreseeable challenges can arise during the exhibition. Monitoring tools can support you in reacting to upcoming errors at the exhibitions and on the server. Updates, support, and periodic database backups should be already considered in the development plan.

Own experience: In addition to bug fixing, for example, we had to deal with new operating system versions for our mobile app. For iOS, we needed to change the permissions for accessing Wi-Fi data in iOS 13. For Android, the Google Play Store only accepted updates with targetSdkVersion no less than 28 almost at the end of the exhibition. Since we had been targeting an older OS version, we also had to deal with that.

[1] https://www.teamviewer.com/

APPENDIX I

Workshop Questions (Guidelines)

I.1 Administration

- How does the intended path through the exhibition influence the interactive exhibits, and vice versa?
- How far do design, technical, and spatial factors/restrictions of the museum building restrict or enhance the possibilities of the interactive exhibits?
- How can the interactive exhibits (roles of internal and external responsible persons) be maintained?
- How can all stakeholders (goals and roles, e.g., onboarding for guides) be integrated?

I.2 BYOD: Mobile App

- How essential is it for the museum experience that every visitor can use their own mobile device?
- Pros & Cons of BYOD. Is an app the best format (e.g., download, install, setup, update)? What are the best options to make the content available/accessible to different user groups?
- What factors contribute to the visitors' acceptance of using their device in the museum (why should they do it, what do they get out of it, how to engage them)?

I.3 Data Visualizations

- What can be done to make the visitors (usually non-experts and with low visualization literacy) interested in visualized data?
- How can the start be made easy? Leopold could be an entry point for the GenVis. Could Storytelling help?
- How does technical experience affect the understanding of the visualization (its value, benefits, contribution)?

I.4 Multi-Device

- What factors help or prevent visitors from understanding the connection between multiple devices in a setup (e.g., Tablet/Phone & Large Screen)?
- What can be do to make such settings intuitive for the visitors (e.g., engage users, use the devices correctly, affordance)?
- Which location is suitable for multi-device installations?

I.5 Interactive Installations

- How can interactive exhibits keep the visitors engaged (e.g., difficulty levels, content-wise)?
- How can the interactive installations accommodate the visitors' different preferences (e.g., exploring alone, playing in groups, discussing with people)?
- How does the time which visitors are willing to spend in the exhibition influence the interactive exhibits?

I.6 Augmentations

- How can visitors benefit from the augmentation beyond the cool factor?
- What should be done to avoid/minimize the limitations of such technology (e.g., visibility due to lighting and reflections, occlusion of objects by other visitors, augmentation of small objects)?
- Should it be essential for understanding the story of the exhibition, or always appear as optional?

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Education

Since 2014	PhD studies in Computer Science at Vienna University of Technology, Austria PhD Thesis: *Interweaving Physical Artifacts with Data Visualization on Digital Media in Museums* Supervisors: Wolfgang Aigner, Martin Kaltenbrunner
2010 to 2012	MSc studies in Digital Media Technologies at St. Pölten University of Applied Sciences, Austria Master's Thesis: *Datensynchronisation und Offline-Nutzung für webbasierte mobile Informationssysteme* Supervisor: Grischa Schmiedl
2007 to 2010	BSc studies in Media Technology at St. Pölten University of Applied Sciences, Austria Bachelor's Thesis: *Technische und anwendungsbezogene Probleme und Besonderheiten des mobilen Internets* Supervisor: Grischa Schmiedl

1998 to 2001	Audio-Visual Media Designer Apprentice at DAP Bitterfeld, Germany

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Job Experience

Since 2019	Lecturer and Researcher at St. Pölten University of Applied Sciences, Austria Department Media and Technologies IC\M/T Institute of Creative Media Technologies Media Computing Research Group
2011 to 2018	(Junior) Researcher at St. Pölten University of Applied Sciences, Austria IC\M/T Institute of Creative Media Technologies Media Computing Research Group
2009 to 2011	Assistant at St. Pölten University of Applied Sciences, Austria Institute of Media Informatics
2008 to 2009	Assistant at St. Pölten University of Applied Sciences, Austria Campus TV c-tv
2002 to 2007	Media Designer Audio/Video at Regionalfernsehen Bitterfeld-Wolfen, Germany

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Awards

2019	"Ars Docendi", State Prizes for Excellence in Teaching category "Cooperative Forms of Teaching and Working" with the Interdisciplinary Lab (iLab)
2009 to 2012	Merit scholarship St. Pölten University of Applied Sciences
2009	Golden Wire 09, media prize of St. Pölten University of Applied Sciences category "Interactive" with the project WUP

Publications

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