Casual Information Visualization on Mobile Devices considering the Museum Context

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Wien, 8. März 2018

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David Schnitzhofer

Danksagung

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Kurzfassung

Mit 79% waren Smartphones 2016 (Eurostat, 2016) die am häufigsten genutzten Geräte für den Internetzugriff. Schnelle Datenverbindungen selbst in abgelegenen Regionen, steigende Rechenleistung und Displaygrößen ermöglichen eine komfortable Nutzererfahrung. Mobile Visualisierungen, welche von diesen Umständen profitieren, sind jedoch heutzutage kaum verbreitet. Probleme von Visualisierung auf mobilen Geräten sind die begrenzte Displaygröße und die teilweise ungenaue Toucheingabe. Vorteile mobiler Geräte sind deren große Verbreitung und eine breite Palette an eingebauten Sensoren und Eingabemöglichkeiten. Das macht mobile Geräte wie Smartphones besonders geeignet für den Einsatz im Museum. Dabei ist es notwendig, die Bedürfnisse von Gelegenheitsnutzern zu berücksichtigen und geeignete Visualisierungstechniken zu finden. Die vorliegende Diplomarbeit gibt einen breiten Überblick des State of the Art mobiler Visualisierungen und beschreibt den Vorgang vom Design, der Implementierung bis hin zur Evaluation der Visualisierung einer Museumssammlung. Dazu wird auf die Sammlung des Museums für moderne Kunst *mumok* über das *Open Data Portal Österreich* zugegriffen. Diese Daten werden mithilfe von D3.js, Google Maps und ngx-charts visualisiert. Für das Frontend der Applikation wird das mobile Framework Ionic benutzt. Zum Schluss wurde die mobile Anwendung mit 21 Teilnehmern im mumok getestet.
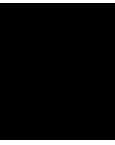
Abstract

With 79%, smartphones were the most used devices for accessing the internet in the EU in 2016 (Eurostat, 2016). High-speed mobile data connectivity reaches even remote locations. Increasing computational power and display size provides users a comfortable user experience. However, mobile visualizations which profit from those circumstances are hardly widespread these days. Problems of visualizations on mobile devices are the limited screen size and inexact touch input. Benefits of mobile devices are the high availability and the broad palette of built-in sensors and input options. This might make mobile devices, for example, smartphones, great devices in the museum context. Keeping the needs of casual museum visitors in mind when finding appropriate visualization techniques is a critical task. The present work gives a broad overview of the state of the art of mobile visualizations and the design, implementation, and evaluation of a visualization of an art museum's collection. Therefore, the collection of the museum of modern art *mumok* located in Vienna is accessed through the *Open Data Portal Österreich*. This data is visualized with the libraries *D3.js*, *Google Maps* and *ngx-charts*. For the frontend of the application, the mobile framework *Ionic* is used. At the end, the application was evaluated in mumok with 21 participants.

Contents

Introduction

Today, many museums hold an enormous amount of digitalized objects which are often only accessible by keyword search. This makes it, especially for novice users with no specific goal in mind, hard to explore a museum's collection. Outside of science, the rapid rise of mobile devices resulted in an increased distribution of mobile information visualization in domains like healthcare, fitness or finance.

However, it seems that the research community largely ignored this trend for museums and considered mainly desktops and stationary devices. In this thesis' literature review contributions with the focus on the design, implementation and evaluation were collected and categorized. Of the 20 collected scientific resources presented in chapter 3, only one (Roccetti, Marfia et al., 2013) can be categorized as a mobile museum visualization. The gathered 15 non-scientific works visualize data like music (McKinney, 2016), film (Bear, 2015) or artworks (Klingemann, 2016). Found non-scientific museum applications only give a spatial overview of the museum and the exhibited artworks (Rijksmuseum, 2017), (Louvre, 2017). Besides, these museum applications mostly target either the usage from remote or in the museum. Only (Rogers, Hinrichs & Quigley, 2014) target both usage scenarios.

The present work gives an overview of the mobile and museum visualization field and explores the process of visualizing museum data on mobile devices. Therefore, the 35 collected resources are described and categorized by different characteristics. Additionally, in an iterative process, a mobile visualization prototype of the collection of the modern art museum mumok, located in Vienna, was created. This prototype was evaluated in mumok with 21 visitors. It has shown that visualizations on mobile devices work well in most cases. In general, visualizations which scale vertically, like horizontal bar charts or dendrograms, suit the mobile environment better than techniques like graphs or scatterplots, which grow equally in both directions. During the usability tests, it became evident that simple single finger interaction is preferred over more complicated methods like double tap or holding touch.

1.1   Research Questions

The thesis should answer the following questions:

- *How suitable are mobile devices for visualizing information?*

  - *Which visualization and interaction techniques are working well on the rather small screens?*

- *How can visualizations on mobile devices be used in the museum context to support the user's understanding of a specific topic?*

  - *If and how do visualizations encourage users to explore the museum's exhibits?*

1.2   Research Methodology

In order to answer the research questions stated above the following steps were performed.

1. **Literature Review and Research:** The research process started with the collection of relevant scientific resources. The considered topics are mobile visualization, museum visualization, museum applications, and visualization evaluation. To broaden the findings, non-scientific applications were also added to the collection.

2. **Design:** For the design of the application it was first looked into the mumok dataset. Therefore, a simple visualization prototype helped to examine exciting data fields. Later, with the focus on interaction, different mockups of the application's user interface were tried out. The decision was made in favor of a flat app structure with a navigation bar at the bottom and different charts on the home screen as an entry point. It became evident early that a gallery filled with images of the artworks is an essential part of a museum application. Besides, a graph visualization and a geographic map were added.

3. **Implementation:** Data Wrangling was the starting point in this step. After nesting the initial artworks data by the selected data fields, it was connected stepwise with the different visualizations and the gallery.

4. **User Tests:** During the design and implementation phase the application was tested at regular intervals with three participants. Based on the found usability issues the application's design was updated iteratively. Found bugs were collected and fixed in the implementation phase.

5. **Evaluation:** The application was evaluated in the modern art museum mumok with 21 participants. This process consisted of an interaction log during the usage and open questions in combination with a System Usability Scale (SUS) questionnaire afterwards.

1.3   Thesis Structure

In this Chapter 1 the thesis' topic with the research motivation is introduced. Additionally, the research questions are stated and the research methodology is outlined. Chapter 2 Problem Description describes the addressed problem with a focus on the museum context and mobile interaction.

The Chapter 3 describes the state of the art. As a starting point, the section 3.1 Related Work presents works which also focus on the state of the art. In the following section, the research method is described. Afterwards, in section 3.3 Results, mobile visualizations, museum visualizations, and museum applications are presented. The next section 3.4 shows the characteristics of the findings in a table. Section 3.5 Visualization Design presents visualization design guidelines of different papers. Section 3.6 Evaluation describes papers which mainly focus on evaluation.

Then chapter 4 Prototype outlines the design and implementation of the prototype. The results are described and presented with screenshots. In addition, the design and implementation process is described. Chapter 5 Evaluation reveals the evaluation process and the results. This chapter starts with a description of the usability test followed by observations made in mumok. 5.3 presents the evaluation approach and the results of the evaluation in mumok.

Chapter 6 Discussion and Future Research answers the stated research questions, outlines potential future work and presents ten design recommendations for the design of mobile museum visualizations. The final chapter 7 Conclusion sums up the problem and this thesis' findings.

Problem Description

Card et al. define information visualization as a computer-supported, interactive, visual representation of abstract data with the aim to amplify cognition (Card, Mackinlay & Shneiderman, 1999). Through visual forms, users can understand the data more easily and quickly than wading through a mass of numbers (Roberts et al., 2014). The area of mobile information visualization is a rather new scientific field. This is particularly shown by the small number of available papers. Due to the rapid technological progress of mobile devices and visualization tools in the last few years, many of the papers seem outdated.

An important part to consider is the users' needs in the design phase. Therefore, the focus of this thesis lies on casual users. To not overwhelm the users, not too many visualization methods should be used (Few, 2013, p. 46). For intuitive interaction, commonly used visualization techniques should be considered.

2.1   The Museum Context

The museum context is characterized by a diverse audience and short, one-time interaction with museum exhibits (Hinrichs, Schmidt & Carpendale, 2008). The audience reaches from casual users, which do not have a specific goal in mind, to target-oriented experts. During the in-situ exploration, visitors' focus lies on the artifacts (Rogers et al., 2014). Bridging the physical and digital information is an important task.

Since the visualization should also be usable from remote, some points need to be considered. In contrast to exploration in the museum, remote exploration is highly open-ended (Rogers et al., 2014). Important for remote exploration are overview visualizations, which trigger curiosity. To provide an overview of the collection, suitable types of metadata were selected. Interesting are for example year, tags, material, description, size, and artist of an artwork. Additionally, every artwork is linked to an image. The
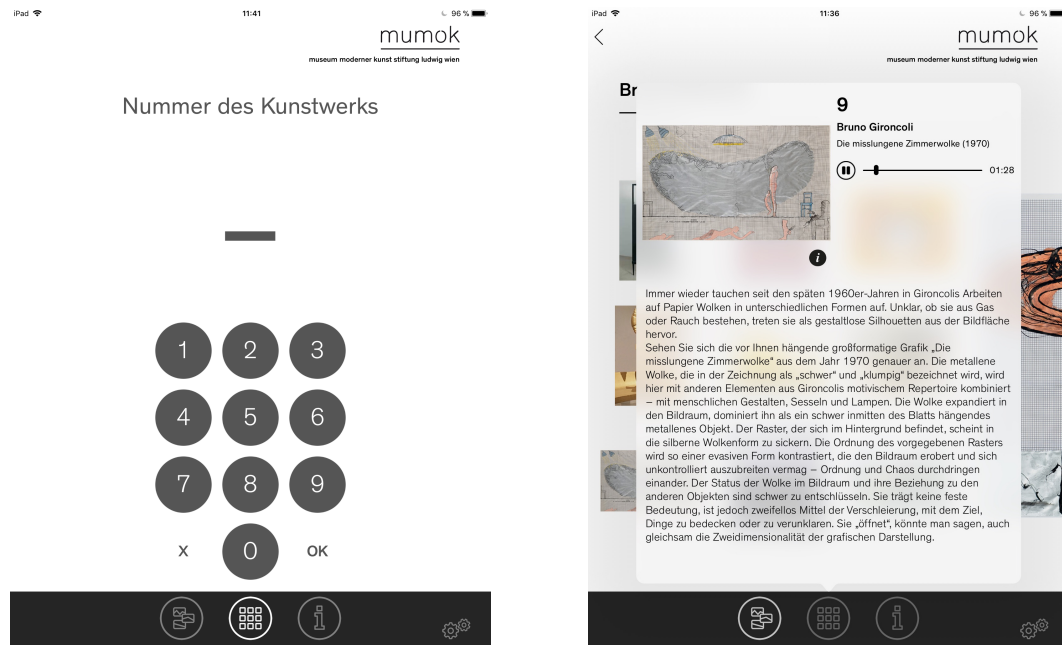
Figure 2.1: Screenshots of mumok's audio guide application

exhibition status of the artworks is available and can be used for the in-situ exploration. In relation to the artist, the place and year of birth and death are interesting data fields. Apart from the artwork description, the mumok dataset is fairly complete.

The usage of mobile devices like smartphones fits the museum context because usually museum participants have their own device with them. A benefit of visitors bringing their own device is that there is no need for museums to provide devices for showing information. Instead, visitors can use their own device or, if not available, borrow a mobile device like a tablet from the museum. This saves the museum costs and resources since no devices need to be bought every few years. Thinking about the wave of influenza, which also correlates with the increased visitor frequency in the winter months, visitors using their own devices also brings hygienic advantages.

The mumok was visited to get insights into the conditions like available labels and WIFI connection. Except for the staircase area, most of the museum is covered by the in-house wireless network. Cellular reception was not available beyond the ground. During the visit, the Android version of the multimedia guide application (Mumok, 2014) was used. A tablet with the installed multimedia guide can also be rented in the museum. If available, the user can access the artwork by typing in the audio guide code. As an alternative, the exhibition view should show nearby artworks using iBeacons and the device's Bluetooth. However, this feature was not working. Since artwork numbers or iBeacons are necessary for accessing most of the exhibits, the application focuses on an in-situ usage. During a meeting with the mumok staff, it was mentioned that the iBeacon

support was discontinued because of the high maintenance effort for new exhibitions. Additionally, it was stated that because of the high ceilings, the results were bad and often the signals from other floors overlapped.

2.2 Mobile Interaction

Stephen Few mentions that smartphones like the iPhone are too small for information visualization (Few, 2013, p. 67). However, since 2013, display size and resolution of smartphones grew significantly and the share of devices with a screen size of 4 inches or smaller are disappearing. At the same time, the amount of smartphones with screen sizes from 5 to 7 inches increases (IDC, 2016).

In comparison, input methods of desktops and mobile devices differ a lot. Instead of a single precise cursor, there are multiple imprecise fingers, which also overlap parts of the content. Factors like different orientation, screen size, and resolution are more critical compared to the domain of traditional computers. These aspects have to be considered while designing and developing visualizations for mobile devices. Compared to clicking, touching is not that accurate, therefore, elements should not be too small. Additionally, invisible touch areas around elements or algorithms detecting the nearest element should be considered when implementing a mobile visualization. Another problem which occurs is, that mobile devices do not support hovering (Few, 2013, p. 68). Hovering in visualizations is often used to show details in a tooltip. A mobile alternative is an always present information area, which presents the information when touching an element.

Even with the mobile devices' downsides, the benefits like intuitive touch input should not be ignored. Touch can be used for tasks like scaling, panning, or selecting elements. Additionally, the orientation of the device should be used to present the data in the best possible way. Finding the right interaction techniques with the needs of casual users in mind is part of the thesis. Furthermore, there might be scenarios where it makes sense to use the device's sensors.

State of the Art

In this chapter, the state of the art of visualizations on mobile devices and visualizations in museums are presented. The Related Work section provides an overview of other contributions which also present the state of the art of a specific domain. In the Method section, the research process with used keywords and search engines is described. The section 3.3 Results presents the found works divided in *Information Visualization on Mobile Devices*, *Museum Information Visualization and Applications*, *Nonscientific Visualizations*, and papers about design and evaluation.

3.1 Related Work

In *Casual Information Visualization* Pousman, Stasko & Mateas (2007) give a good overview about different types of casual information visualization. The four categories introduced by the authors are ambient, social, artistic, and persuasive InfoVis. The work shows the boundaries between casual visualizations and traditional visualizations. Four main differences are the user population, usage patterns, data types and gained insights. Different types of insight are distinguished by analytic insight, awareness insight, social insight and reflective insight. In addition, the paper describes challenges in the design and evaluation phase of casual information visualizations.

Blumenstein et al. (2016) give a structured overview of the commonly used approaches for mobile visualization. Additionally, gaps and challenges in the evaluation of mobile visualizations are discussed in detail. In comparison to this thesis, the work also considered non-casual areas like disaster management and healthcare.

Economou & Meintani (2011) evaluate 64 mobile museum apps with interactive and multimedia features. 54 of the apps presented are guided tours of exhibitions and general information about the museum. Many of them are audio guides with additional features like an overall plan or opening hours. The remaining 10 apps focused on a single object,

content creation or manipulation and games. Almost all the presented applications can be used before, during, and after the museum visit, however, the content, distribution, and design of the apps encourage specific use cases. The authors describe how specific usage scenarios are addressed by the apps, for example, with location tracking, tagging of artworks, photography in the museum or social interaction. Techniques besides direct representation of artworks are not addressed in this work and the presented apps.

In *Visualization on Interactive Surfaces* P. Isenberg & Isenberg (2013) collect papers from the main visualization conferences like IEEE InfoVis, SciVis, EuroVis and the conferences for interactive display research like ACM ITS and Smart Graphics. From a pool of over 1000 publications, the authors extracted 111. The found publications were categorized by data, visual representation, type of display, input, research focus and users. Seven mobile and 26 tablet visualizations are presented, in comparison 98 of the visualizations use large displays like tabletops, drafting tables or vertical displays. The publications were also categorized by research focus, 54% of the papers emphasize on interaction, followed by the development of applications. Topics addressed less often are collaboration, the development of software environments and the technical setup. Isenberg et al. state that mobile visualizations are very rare, which points to a still under-explored research area.

Huang et al. (2015) describes works of a new field called personal visualization (PV) and personal visual analytics (PVA). Personal visualization is about visual data representation in a personal context, in personal visual analytics the science of analytical reasoning is added. They systematically identified 59 relevant papers from publications like TVCG, CHI, UBICOMP, and EuroVis. Based on the findings Huang et al. developed a taxonomy of PV&PVA dimensions which focus on design attributes like data scope or explorability. The design dimensions are listed in a table with definition, levels, and examples. Afterwards, the publications are presented with a parallel plot visualization with the design dimensions as parallel axes. Similar to the field of my work the personal context implies non-professional situations. In contrast to professionals, these users have different goals, backgrounds, and expectations when looking into their data. Huang et al. state that analytical tools need to be accessible and easy to use because the vast majority of people are not visualization or data analytics experts. This publication is also of relevance since many of the personal visualizations target mobile devices.

Good collections of mobile visualizations which were mentioned in a presentation at JSConf 2014 by Baur (2014b) are mobilev.is (MobileVis, 2014) and mobileinfovis.com (Mobileinfovis, 2015). Mobile Infovis structures the visualization by chart type and differentiates between smartphone and tablet. At MobileVis the visualizations are not structured but presented by their added date.

Blumenstein, Breban, Taucher, Thür & Seidl (2017) present 42 museum applications and installations and categorizes them in a matrix visualization (Blumenstein, 2017). The research document presents the museum's name and location, the developers, functionality with bullet points and images of the system. The matrix visualization presents the target audience, the devices, and the user experience through tags. Tablets with 25 and smartphones with 18 occurrences are the most used devices. According to the introduced

user experience tags bring your own device, personalization, location, and games are the most frequent.

Windhager, Federico, Mayr, Schreder & Smuch (2016) give a structured overview of information visualization approaches for cultural heritage. The authors distinguish principles for visualizing cultural heritage in close up views, (multi)linear overviews, spatial encoding, and temporal encoding. They collected 25 information visualization approaches of cultural heritage collections and presented properties like used encoding, data focus, and type of project in a table. Unfortunately, there is no information presented about which device types are targeted.

Levkowitz & Kelleher (2012) give a good overview of the topic mobile visualization in combination with web technology. The paper surveys fundamental technologies like cloud computing, HTML5, SVG and WebGL and presents their features, capabilities, strengths and weaknesses.

In *Information Visualizations with Mobile Devices* Langner, Horak & Dachselt (2015, p. 1) describe three promising aspects of information visualization on mobile devices. Those aspects are "the development of a consistent multi-touch interaction framework that can be applied to a variety of visualization techniques; the combination of common touch input with advanced spatial input techniques; and the usage of the spatial arrangement of multiple, co-located mobile devices". They also mention advantages of mobile devices like their ubiquitousness, and the fact that they are usable almost anywhere and at any time. The authors note that the broad success and the availability in the consumer market make them the ideal platform for bringing information visualizations to even inexperienced users.

Roberts et al. (2014) give a good definition of what visualization is and what opportunities it holds for the future. It is mentioned that only few papers of the IEEE Information Visualization Conference use computer hardware other than desktop or laptop computers. The increasing variety of computer hardware from small hand-held smartphones to immersive multi-wall display systems brings new possible applications even to casual users. Especially for mobile technology the user's context is getting more important. A smartphone has many use cases, it is not only used for work like an office computer. Therefore, the smartphone has to adapt to the user's current context. According to Roberts et al. important Human-Computer Interaction paradigms for the future of visualizations are fluid interaction, the integration of input and output technology in our environment, integrated sensory interaction like head-mounted displays for enabling virtual reality and mixed reality where computer-generated and physical objects coexist.

In the research process, no books with the focus on mobile information visualization were found. The cover of Stephen Few's *Information Dashboard Design* which shows a smartphone with a bullet graph visualization seemed promising. Unfortunately, mobile devices are only covered superficially on a single page (Few, 2013, p. 67). However, the chapter Fundamental Considerations of (Few, 2013, p. 65) seems like a helpful resource for the design process. In this chapter considerations like update frequency, user expertise,

audience size, technology platform, screen type and data type are discussed. Other promising books especially for the design process are *Visualization Analysis & Design* (Munzner, 2014) and *Beautiful Visualization* (Steele & Iliinsky, 2010). In comparison to Few (Few, 2013) this book's focus lies more on the explorative part and not so much on dashboards.

3.2 Method

To narrow the findings of this chapter some works were ignored. Visualizations excluded were for example those designed to support professionals (Sydow, Kassel & Rohs, 2015), domain experts or analysts in their daily tasks. Instead, the focus lies on visualizations usable by novice users which want to get insights into a specific topic. Systems which seemed outdated, for example those with physical keyboard input (Buering, Gerken & Reiterer, 2006), (Dunlop, Elsey & Masters, 2007) were excluded. 3D Visualization of cultural heritage (Benedetto et al., 2014) was not considered in this thesis. Revealed results about virtual and augmented reality visualizations were also left aside. Publications which mainly focus on system architecture, system optimization or algorithms were excluded (Junior et al., 2012). Second screen applications were ignored, instead, the whole information should be presented on the device itself.

The search started on Google Scholar with the keywords *Mobile Visualization* which led to the often cited (Chittaro, 2006) and (Hao & Zhang, 2007). Papers with topics like 3D visualization (Benedetto et al., 2014), virtual or augmented reality, and system architecture descriptions were excluded. To get mobile applications in the museum context the query *Museum App* revealed (Economou & Meintani, 2011). *Tablet Information Visualization* revealed (Sadana & Stasko, 2016).

In the next step ACM with the keywords *Mobile Information Visualization* revealed (Blumenstein et al., 2016), (Escobar, Prato, Bustos-Jimenez & Lucero, 2016), and (Fan, Forlizzi & Dey, 2012). (Drucker, Fisher, Sadana, Herron & schraefel, 2013). To take tablets into account the keywords *Tablet Information Visualization* brought (Baur, Lee & Carpendale, 2012) and (Drucker et al., 2013).

Using *Mobile Information Visualization* on IEEE revealed (Craig, 2015). (Junior et al., 2012) was left aside because it focuses mainly on the architecture of client-server visualization. Since many of the works were for experts, the query was changed to *Casual Information Visualization.* Thereby (Pousman et al., 2007) and (Roberts et al., 2014) was found. With *Museum App* the (Roccetti, Marfia et al., 2013) which discusses the design, and implementation of the *Versoverdi* app. This work led to (Roccetti, Varni, Marfia & Zanichelli, 2013) which discusses how the outreach of museums can be increased with apps. Changing the keywords to *Museum Smartphone* revealed (Tehrani, Zainuddin & Takavar, 2014), found papers about indoor navigation were excluded.

While searching for recent books with the keyword *Mobile Visualization* on CatalogPlus, the paper (Zhu, Zhang, Chen, Xia & Maciejewski, 2015) was found. Since there were

no specific books about mobile visualizations, the query was updated to books with the keyword *Visualization* since 2010. This revealed the books (Munzner, 2014) and (Steele & Iliinsky, 2010).

After an extensive set of scientific material was collected, relevant references were searched from the papers of the related work section. (Blumenstein et al., 2016) for example revealed (P. Isenberg & Isenberg, 2013), (Kay, Kola, Hullman & Munson, 2016), and (Rzeszotarski & Kittur, 2014). (P. Isenberg & Isenberg, 2013) referenced the visualizations (Thudt, Hinrichs & Carpendale, 2012) and (Block et al., 2012). (Windhager et al., 2016) cites (Rogers et al., 2014) which discusses the difference of remote and in-situ exploration in museums.

To broaden the findings, nonscientific visualizations were also considered in this thesis. The search started on mobilev.is (MobileVis, 2014), where many of the entries were mobile-friendly websites of newspapers that visualized aspects of an article. Applications which stuck out were the *Reporter* app (Felton, 2014b) and (Baur, 2014a). On mobileinfovis.com (Mobileinfovis, 2015) the music visualization (McKinney, 2016) was found. Many other entries were about visualizing finances, the weather and fitness aspects like heart rate or steps per day.

The visualization archive of flowingdata.com (Yau, 2007) with the selected tag *App* brought me to the applications *Gyroscope* (Innovations, 2015) and *Flyover Country* (Minnesota, 2015). On the *Google Arts & Culture* website the mobile-friendly *X Degrees of Separation* (Klingemann, 2016) were found.

Searching in the Googles' Play Store for *Museum Visualizations* the (Louvre, 2017) and (Rijksmuseum, 2017) was found. The same keywords brought no results in Apples' Appstore, changing it to *Visualization* revealed many tools for creating own visualizations and dashboards. Visualizations are often used to discover new content, therefore the query *Discover* in combination with *Movies* was tried. This brought the iOS application *Solyaris* (Bear, 2015). *Discover Music* revealed the iOS application *Discovr* (McKinney, 2016). Searching for *Wikipedia* revealed (FTW, 2014).

The non-mobile visualizations (Glinka, Pietsch & Dörk, 2017), (Dörk, 2014), (Miller, Walloch & Pattuelli, 2012), (Jenkins, 2013), (Hinrichs et al., 2008), (MoMA, 2012), (Museum, 2015), (Barrett-Small, 2014), (Research, 2014) were already known from a previous seminar and are considered in this thesis.

3.3 Results

In this section, the relevant results for the thesis' topic are shown. The section 3.3.1 presents InfoVis on mobile devices, followed by museum information visualizations and applications, and visualizations which are not scientifically grounded. These three sections are considered in the categorization table 3.1 where properties like target device and used visual representation are encoded. This section also presents papers in relation to the design and evaluation of information visualizations and mobile applications. In

section 3.5 Visualization Design the extracted key designing considerations of information visualizations are presented in list form.

3.3.1   Information Visualization on Mobile Devices

Drucker et al. (2013) compare traditional WIMP interfaces which consist of point and click menus, icons and other widgets with the gesture-centric touch-based direct manipulation of data objects which they call FLUID. The two approaches are compared by the actions selection, choose categories, filtering & focusing, order, and zoom. Two user interface versions of a bar chart visualization following the WIMP and the FLUID approach were implemented and evaluated in a user study. The questioning showed that 13 of 17 participants preferred the FLUID approach. Besides users were faster and made significantly fewer mistakes when using the FLUID visualization.

Chittaro (2006) describes a sample map visualization which presents points of interest on a mobile device. The POIs are shown with icons that indicate how many constraints are fulfilled. The constraints can be manipulated through sliders. With a click on an icon, additional information, like met constraints, is shown. The paper seems partly outdated. For example, it is stated that low resolution and fewer colors of mobile devices need to be considered. On the other hand, there are statements which still apply, for example, that simply porting desktop visualization to mobile is impossible. Described reasons are the compact size of mobile devices and the varying usage contexts where the user's focus is not solely on the device. According to Chittaro, available research has not addressed mobile visualizations. However, universal recommendations such as avoiding visualizations that are impressive but difficult to read still apply. A checklist with six major steps for creating a visualization contains mapping, selection, presentation, interactivity, human factors, and evaluation. In the end, the author describes problems and presents ways of visualizing text, pictures, maps, physical objects and abstract data on mobile devices.
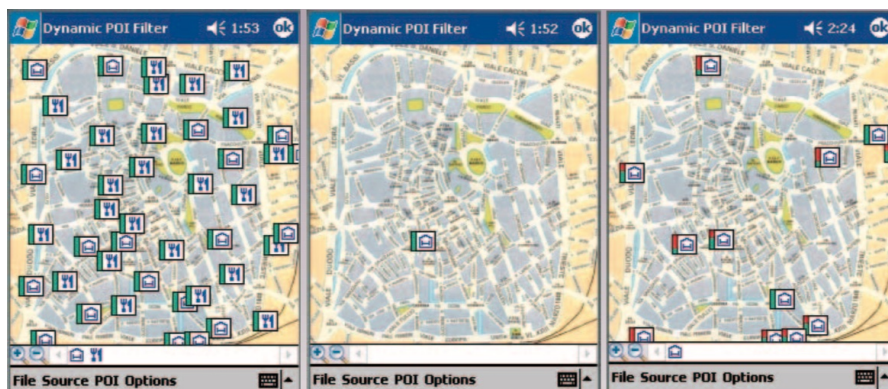
Figure 3.1: Too many icons (left), not enough icons (middle) and a refined visual encoding based on the selected constraints (Chittaro, 2006)
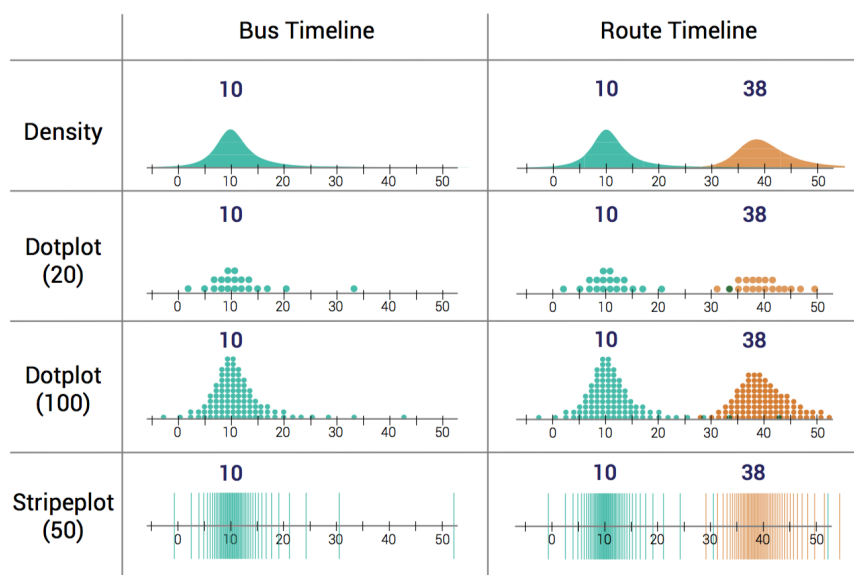
Figure 3.2: The evaluated visualizations of *When (Ish) is My Bus?* (Kay et al., 2016)

In *When (Ish) is My Bus?* Kay et al. (2016) present and evaluate methods to visualize uncertainty on mobile devices. They present a novel discrete visualization the quantile dot plot and compare it with density, stripe plots, and a combination of them. Therefore, they developed candidate visualizations for public transit predictions which were tested in an online survey. The target was to assess how well people can interpret the probabilistic predictions and to detect the users' preferences in how the data should be visualized.

With *Kinetica* Rzeszotarski & Kittur (2014) introduce physics-based affordances like magnets and barriers and multi-touch interaction and explores how those post-WIMP interactions might improve multivariate data visualizations. They developed a generative framework and implemented some affordances in an iPad application. Afterwards, they conducted a comparative study between the physics-based visualization and a traditional WIMP spreadsheet tool with charts and tables. Potential benefits of physics-based visualization are for example minimal training, outlier detection, and the awareness of distribution.

Sadana & Stasko (2016) describe challenges and design principles of creating a Multiple Coordinated View (MCV) for tablets. Key challenges mentioned are the usability, the consistency and the scalability of the visualization. The key design principles for MCV are to provide views-on-demand, employ single-finger operations, prevent occlusion and promote standard gestures and consistency. They produced a prototype with the identified interactive operations linking, brushing, selecting, zooming, filtering and viewing of the data. The used visualization techniques are scatterplots, bar charts, line charts, and parallel coordinates plots.

Escobar et al. (2016) present and evaluate the *Adkintun* mobile app which lets users check

	Forces	Layouts	Mutations	Barriers	Filters	Queries & Overlays
Forces	*Magnets* Points are pulled to a finger					
Layouts	*Force plots* Points are pulled to their place in a chart	*Fixed charts* Points snap to their place on a chart				
Mutations	*Group by vector* Group points that are moving similarly	*Group by layout* Group points by their place in a chart	*Groups* Put points into abstract groups			
Barriers	*Jelly walls* Points need an extra push to pass a wall	*Layout walls* As points pass, put them into a layout	*Collision to data* Points that hit a wall are assigned values	*Walls* Block points from a region of space		
Filters	*Query magnet* Attract points that meet specific criteria	*Detail view* See point details in a layout popup	*Group by filter* Group points based on specific criteria	*Sieves* Walls only permit certain points	*Show/hide* Display points by criteria	
Queries & Overlays	*Query fields* Visualize the pull of different forces	*Area details* See details for points that meet criteria	*Group zoom* Zoom in and manipulate points	*Lens* Highlight certain points in a region	*Selective overlay* Highlight/select points by criteria	*Overlays* Color/scale points by data dimensions

Forces - Act on points to move, attract, or accelerate
Layouts - Place points into meaningful locations
Mutations - Mutate, combine, or change points
Barriers - Prevent points from occupying a region
Filters - Selectively include or exclude based on criteria
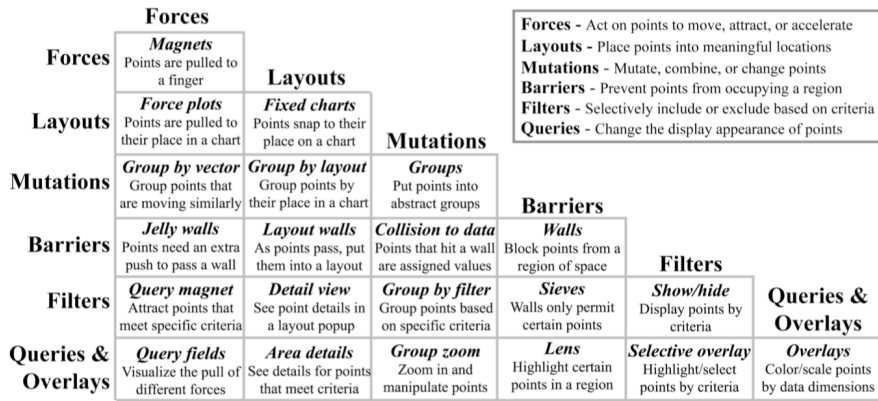**Queries** - Change the display appearance of points

Figure 3.3: *Kinetica*'s (Rzeszotarski & Kittur, 2014) generative framework that combines different physics-based affordances

Figure 3.4: Interface of *Designing Multiple Coordinated Visualizations for Tablets* Sadana & Stasko (2016)
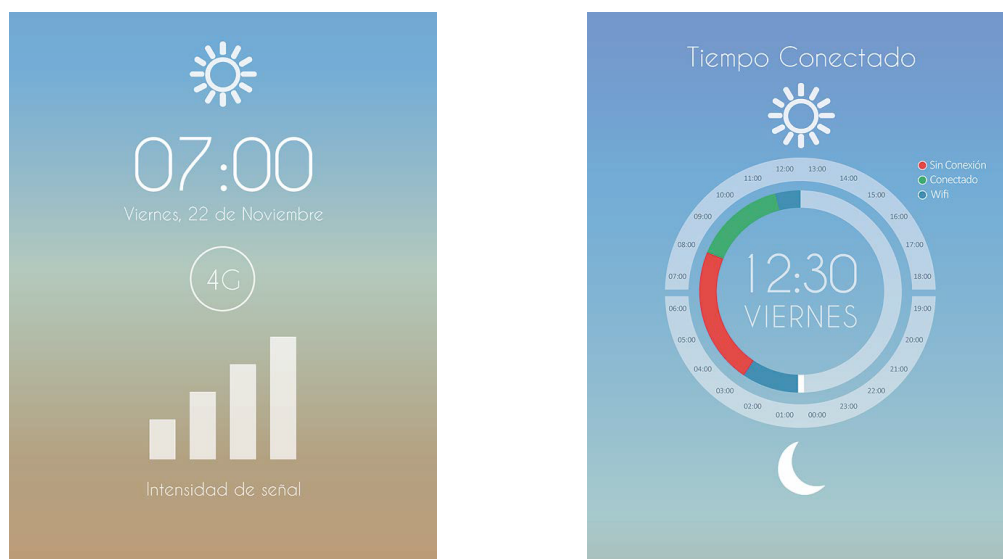
Figure 3.5: Signal quality (left) and connection time visualization in the mobile *Adkintun* app (Escobar et al., 2016)

their mobile internet connectivity through information visualization. The visualization is shown directly on the mobile device and presents values like connection time, connection type, and signal quality. Therefore, they used established interface design guidelines and familiar metaphors like traffic lights. It is mentioned that when designing visualizations for mobile devices, cluttering the limited screen space should be avoided and to make the cognitive task easier all the essential data should be presented. The application was evaluated quantitative with a questionnaire and qualitative with semi-structured interviews.

With *The Mobile Tree Browser* Craig & Huang (2015) present a new space-filling visualization for visualizing labeled hierarchies on displays with limited display space. The transitions between the screens are animated, to make browsing of long lists easier, fisheye distortion is used. It is mentioned that those techniques decreased the cognitive load of having to interact with the data directly. This space-filling visualization was compared with a table view and a tree view. Twelve users rated the three alternatives according to different metrics which relate to the usability and effectiveness. They gave *The Mobile Tree Browser* higher ratings for usability and legibility. Additionally, it was mentioned that it gives a better overview of larger, more challenging datasets on mobile devices.

ShotVis by Zhu et al. (2015) is a mobile application which lets users take images of texts or tables, extracts the information and visualizes it. Available visualizations are for example scatterplots, bar charts, line charts or word clouds. For visualizing tables, the user can map the data with sketching gestures and by assigning data labels to the selected data. After the data is organized, a visualization is automatically generated.
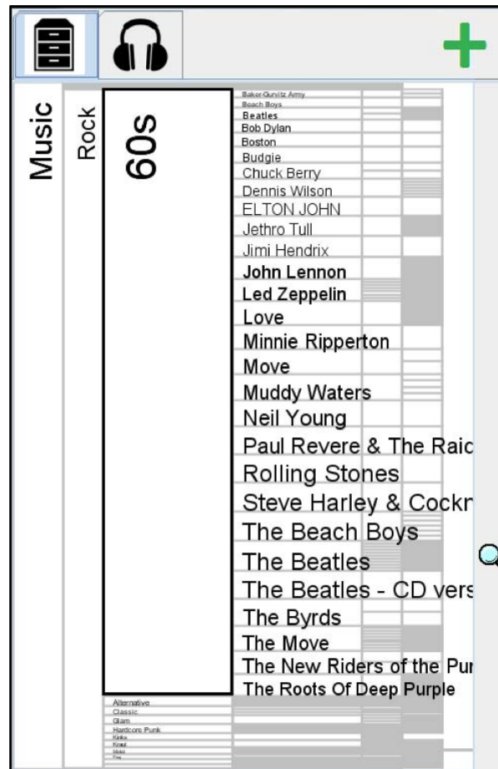
Figure 3.6: *The Mobile Tree Browser* (Craig & Huang, 2015) with applied distortion

Users can switch between different visualization types, change the title or colors of elements. To visualize texts, the authors used word clouds that map the frequency of a word to the font size. Again the user can customize the visualization by changing the font type and the title. The application was evaluated with four participants in a user study with a focus on usability and effectiveness. ShotVis was compared with desktop visualization tools familiar to the participants. After finishing specific tasks the attendees answered questions about the usability, efficiency, usefulness, and satisfaction with results of ShotVis. It has shown that ShotVis can achieve equal or better results faster and in a more intuitive way. In contrast, the satisfaction with the visualizations was relatively low.

With *TouchWave* Baur et al. (2012) present an extension of stacked graphs for multi-touch devices. It provides flexible layouts, interactive querying, and the possibility to switch seamlessly between visualizations. Besides the adaptions on stacked graphs, the authors are focusing on multi-touch interaction techniques. The datasets presented in the prototype are a music listening history and movie box office revenues. The visualizations were developed for Apple's iPad 3. It is not mentioned whether the visualization also works for smartphones.

Figure 3.7: *ShotVis*' (Zhu et al., 2015) word cloud and scatterplots of Anscombe's data

Figure 3.8: Multi-touch gestures of *TouchWave* (Baur et al., 2012)
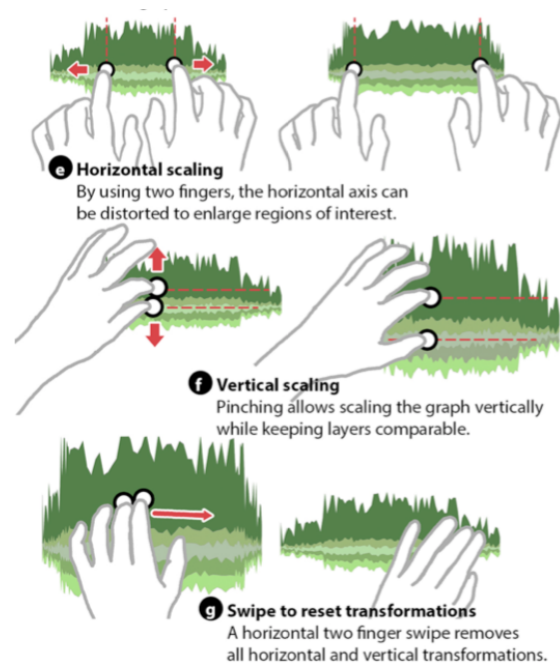
3.3.2 Museum Information Visualization and Applications

Rogers et al. (2014) ask how mobile visualizations can enhance the exploration and experience of museum collections in-situ in comparison to remote browsing of collections. Therefore, a tablet-based visualization prototype was studied during remote and gallery use. The paper describes that compared to the item-centered in-situ exploration the remote exploration of the collection is highly open-ended. The findings show that in-situ visualizations need to bridge the digital and physical information space to support the museum exploration. Relevant for this thesis' prototype is the fact that participants found the search for an artifact with keywords frustrating.

Hinrichs et al. (2008) present a visualization about the life of the Canadian artist and writer Emily Carr. *EMDialog* does not run on mobile devices, instead, visitors of Glenbow Museum in Calgary were able to explore the visualization via a large touchscreen. One of Emily Carr's favorite motives were trees, so the creators of the visualization used a tree diagram combined with a cut section visualization. Those synchronized visualizations are shown at the same time, in the cut section every decade is one ring. In every ring, there are several explorable data points like images or notes. The tree diagram categorizes the data with color using one of the five predefined tags.
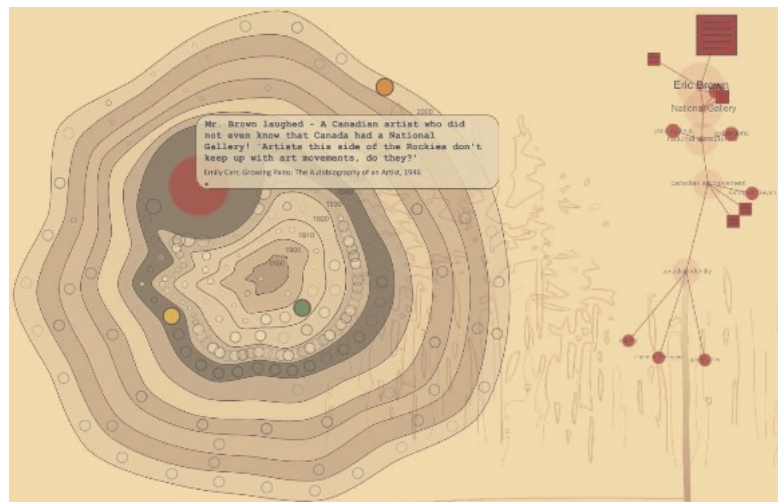
Figure 3.9: *EMDialog*'s (Hinrichs et al., 2008) combined cut section and tree diagram visualization

Versoverdi (Roccetti, Marfia et al., 2013) is a mobile application that supports the navigation of Giuseppe Verdi-related cultural sites. Visit suggestions are based on the user's mood which is detected through binary emotion recognition. Relating the two moods, happy when smiling and unhappy when not, fitting content is presented. Besides the mood browsing capabilities, the application links between different museums. As a metaphor, every museum is presented as a planet which suggests routes to other related planets. The universe of planets can be browsed by simply moving the device around.
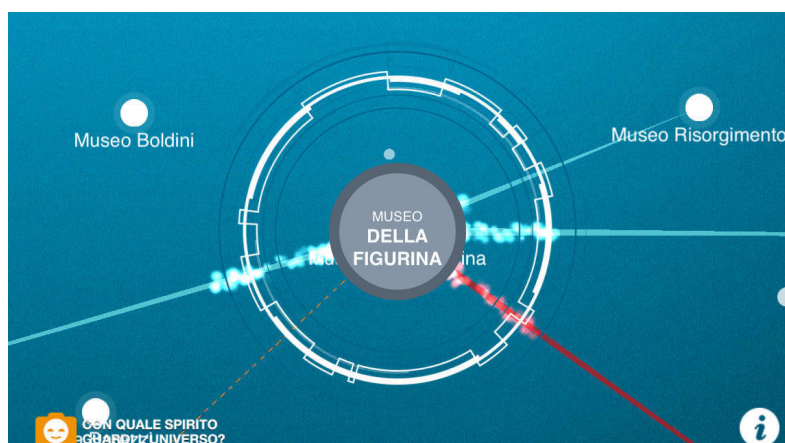
Figure 3.10: Planetary visualization of the *Versoverdi* app (Roccetti, Marfia et al., 2013)

The detected mood determines which content is presented. In contrast, the links are not influenced by the facial expression.

Another mobile application by Roccetti et al. is *Marsili's Spirit* (Roccetti, Varni et al., 2013). This paper focuses more on gamification and improving the outreach of a museum. Outreach affects how wholly unknown people can be connected and attracted by institutions. To improve the outreach, they mention that stories behind the artifacts or exhibits should be interesting and appealing to the visitors which move outside. Therefore, the app shows artistic and rewarding content when a visitor is close to any of the involved institutions. Rewards are for example motion comics, high definition versions of exhibits or timelines of periods.

Rehm & Jensen (2015) present a study about a digital companion agent for tablets which tries to change children's engagement with the presented artworks. The challenge for the young visitors is to find the artworks eaten by a monster. The monsters texture changes to the artwork which should be found. Visitors can point the tablet's camera towards a found artwork. If the implemented image processing detects the artwork, visitors are awarded with points and additional information about the artwork and the artist is presented playfully. The application was evaluated with 57 Danish children between 6 and 12 years. To measure the degree of engagement, the participants were recorded with an action camera mounted on a chest harness. In comparison to an implemented paper version of the game, it has shown, that children interacted more with the cultural heritage. Additionally, the retention rate for details of the involved artworks was higher.

With *The Bohemian Bookshelf* Thudt et al. (2012) present a visualization for yet unexpected book discoveries in digital library collections. In five interlinked visualizations serendipity should be encouraged by multiple different access points, highlighted adjacencies, and flexible pathways for exploring the collection. For evaluation, the Bohemian Bookshelf was installed in form of a tilted 36-inch touch display for eight work days at the University of Calgary library. They took field notes of the visitors' interactions and

Figure 3.11: The user interface of *Marsili's Spirit* app (Roccetti, Varni et al., 2013) with the initial page (left) and interface at Palazzo Poggi

Figure 3.12: Teaching agent (Rehm & Jensen, 2015) with wrong artwork (top) and right artwork (bottom)
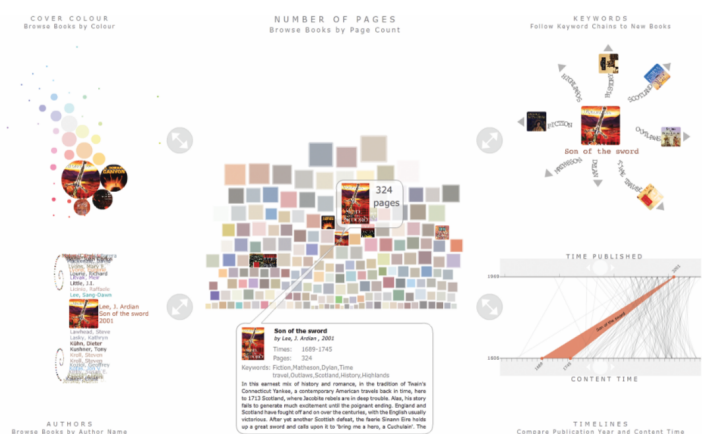
Figure 3.13: *The Bohemian Bookshelf*'s (Thudt et al., 2012) five interlinked visualizations presenting a book collection

Figure 3.14: *The DeepTree Exhibit*'s (Block et al., 2012) main view (left), three kids collaboratively exploring the DeepTree (middle), and special learning activity

interviewed 11 users. It has shown that people appreciate the Bohemian Bookshelf's interaction techniques for finding new books.

Block et al. (2012) published with *The DeepTree Exhibit* an interactive multi-user, multi-touch visualization of the Tree of Life. Therefore, the problem domain was analyzed, they designed and implemented a fractal tree layout algorithm and present insights from designing, testing and evaluating the visualization. Since the focus of different stakeholders varies three challenges are stated, which are: Users are not domain experts, domain experts are not users, and guidance for novices and depth for experts. For evaluation, the conversations of 18 visitor groups were recorded. The authors observed users during free exploration and asked post-test questions afterwards.

Past Visions (Glinka et al., 2017) directly visualizes the drawings by Friedrich Wilhelm the 4th. Therefore, the works of Friedrich Wilhelm are aggregated per year whereby his drawings form a bar chart. The user can filter the collection by combining different topics. When hovering over one of the topics, non-corresponding sheets are grayed out. After a click, the bar chart is reorganized, matching and non-matching drawings form a

Figure 3.15: *Past Visions* (Glinka et al., 2017) with selection Potsdam

Figure 3.16: The Epochen view at *Deutsche Digitale Bibliothek visualisiert* (Dörk, 2014)

bar chart above and beyond a line. This allows the user to gain insight on which topics concerned Friedrich Wilhelm at different times.

At *Deutsche Digital Bibliothek visualisiert* Dörk (2014) displays the collection of several libraries using different techniques. The platform consists of the four different modes called *Epochen*, *Stichworte*, *Orte* and *Netzwerk*. In the first view, the size of the collection per epoch is visualized with a stream graph. The absolute size is shown in a bar chart on the right side. The second section summarized the heritage with a tag cloud, popular tags are at the top and have a bigger font. The *Orte* view shows the distribution of heritage types for each of the 63 libraries in ring charts, the collection size is mapped to the size of the ring. In the *Netzwerk* section the distribution of the data providers is shown in a network graph which uses bubbles for nodes. The bubbles vary in size depending on the amount of provided data, additionally, the circle's color distinguishes individual persons from organizations and libraries. With a timeline on top of the network chart, users can filter the providers by time period.

Figure 3.17: The whole network of *Linked Jazz* (Miller et al., 2012)

In *Linked Jazz* (Pattuelli, 2014) connections between jazz musicians are visualized. The musicians are shown in a network graph. In the paper, the underlying technology of the necessary linked open data for this project is described (Miller et al., 2012). The implementation consists of 1000 nodes and 3000 edges which can be organized in three different modes. Standard is the *Fixed* mode in which artists are placed inside of an ellipsoid, the *Similar* mode organizes the artists in cliques based on their shared connections. In the *Gender* view the gender of the artists is mapped to red for female and blue for male. The graph can be moved and scaled with the mouse. A click at one of the musicians highlights the connected artists and shows a text from Wikipedia and if available a piece of music from YouTube.

The Library Project (Kurgan, 2014) was initiated at the Spatial Information Design Lab of the Columbia University and shows the collection of their University library. Therefore, the visualizations *Catalog* and *Crossing Disciplines* were developed. In the catalog view, the user gets an overview of the collection. The libraries holdings are categorized and color mapped into twelve different sections. Every section has four circular layers, outside are the more specific subcategories. The amount of objects is mapped to the size of a bubble. When hovering the bubbles, additional statistics about the category are provided. The crossing disciplines view is for exploring multidisciplinary works. Five interleaved rings are used, in the outermost large ring, documents which cover two disciplines are highlighted. The smaller a ring is, the more disciplines are connected. In the center of the visualization only works with six different linked fields are shown. When hovering over a point, the connections are shown, with a click the related works are displayed in the top right corner.

Kindred Britain (Jenkins, 2013) published by Stanford University in 2013 shows the connection of nearly 30 000 British individuals through family relationships of blood, marriage, or affiliation. Many of those persons are iconic figures in British culture. The
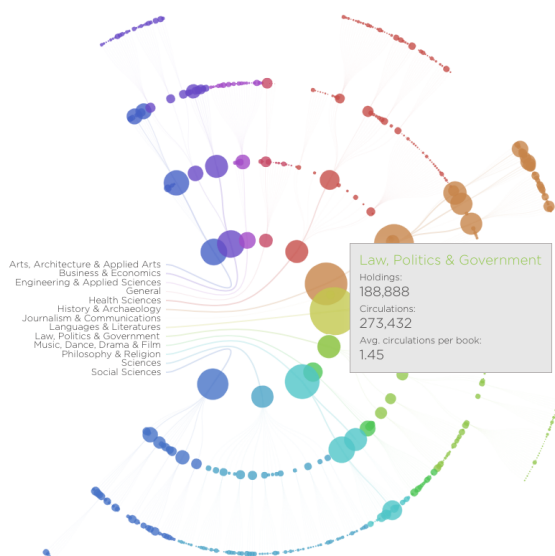
Figure 3.18: The Catalog view of *The Library Project* (Kurgan, 2014)

persons are represented by a color mapped bubble for their gender and are positioned in a circle. The bubbles can be moved and reorganized with the mouse. After one of the persons is released over another the relation between them is revealed. To distinct between marriage, lineage, and sibling edges between persons are color mapped. Besides the network view, there is also a timeline and a geography view with a world map. If the mouse hovers over one of the elements, the corresponding persons in the other visualizations are highlighted. In addition, a tooltip shows the name and the lifetime of the person. The visualizations are not scalable, because of that a large screen is necessary, this is especially the case if the additional timeline and map are opened.

Inventing Abstraction (MoMA, 2012) was realized for the Museum of Modern Arts (MoMA) in New York and shows the connection of contemporary artists between 1910 and 1925. In the network graph artists are presented unorganized, the name of every artist is written in a rectangle. Rectangles of persons with a large network are colored orange, others are colored white. The graph can be manipulated and explored with the mouse. A click on a node opens the associated network. Corresponding artworks, information about the artist and a summarizing text is displayed on the right side.

In the 3D visualization *The Museum of the World* (Museum, 2015) which was created in a collaboration between the Google Cultural Institute and the British Museum, the user can navigate through collections using the keyboard. The collection's items are placed on a timeline sectioned by the continent. This view starts in the present, with the up key the user can go back in time. Sound is used to give the user additional information about the density of the collection. When hovering over a data point, an image of the heritage is displayed.
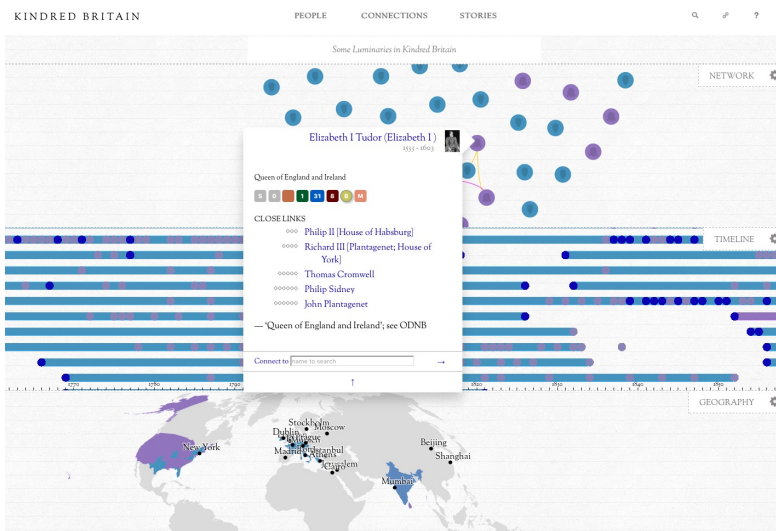
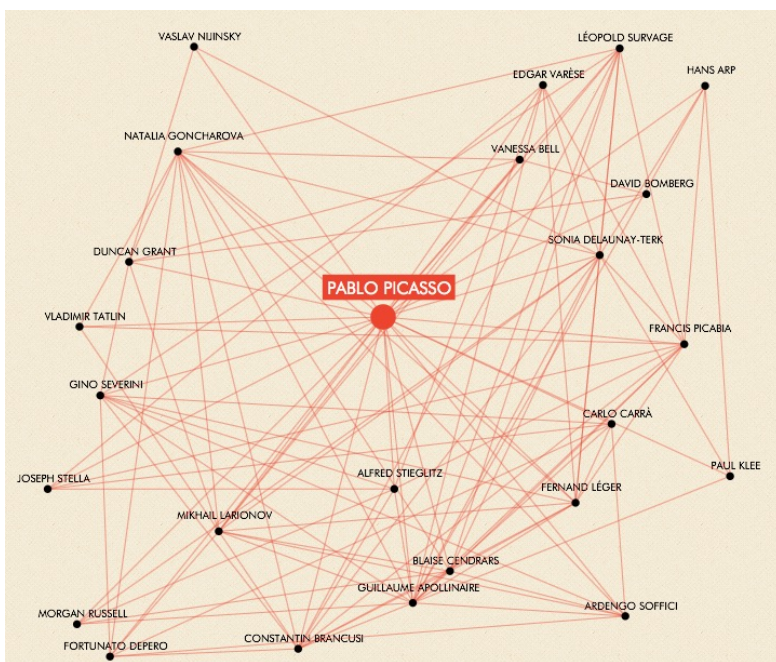Figure 3.19: *Kindred Britain*'s (Jenkins, 2013) network, timeline, and geography view

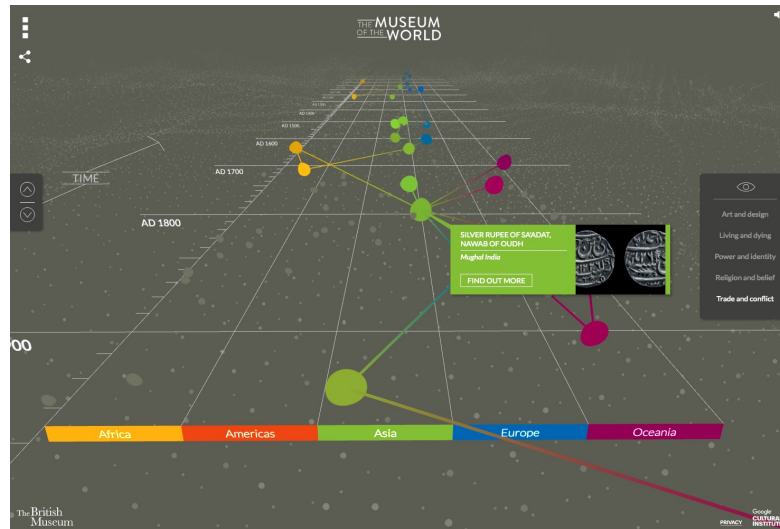Figure 3.20: *Inventing Abstraction* (MoMA, 2012) with the network of Pablo Picasso

Figure 3.21: *The Museum of the World* (Museum, 2015) with a selected exhibit
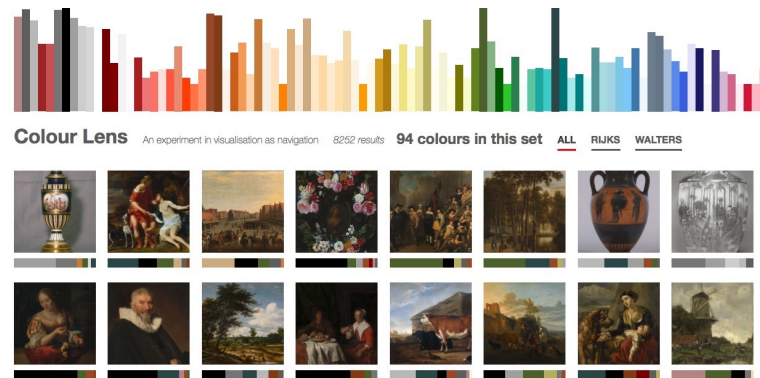

Figure 3.22: *Colour Lens* (Barrett-Small, 2014) with color distribution and artworks

The website *Colour Lens* (Barrett-Small, 2014) lets users select from 94 different colors to find artworks from the Rijksmuseum and the Walters Art Museum with matching colors. The colors are organized by color-tone in bars which also map the count of fitting artworks with their height. After a color bar is clicked, matching cultural heritage is presented and available color bars are shown. This way colors can be combined until the set of colors is exhausted. With a click on an image, the museum's website with additional information is opened.

3.3.3 Nonscientific Visualizations

Solyaris (Bear, 2015) is an iPhone and iPad application which helps users to find and discover movies, TV shows or persons with a force directed graph. Around every entity is a circular area with related elements. After clicking an element, a tooltip with brief information is shown, with a click on a button in the tooltip further details like the storyline, film posters or a link to the trailer are shown. Through a click on the bottom navigation bar, it is possible to switch to the cast list, the IMDb or Wikipedia entry.

Figure 3.23: *Solyaris*' (Bear, 2015) force directed graph (left) and the general info screen

Reporter (Felton, 2014b) is a self-tracking application for iOS which infrequently asks different questions about the current status. The application was created by the designer Nicholas Felton in 2012 for collecting data for an annual report (Felton, 2014a). To visualize the measured data such as eating, sleeping, or social behavior, the application sticks to simple charts like line charts and bar charts.

X Degrees of Separation (Klingemann, 2016) is a desktop and mobile visualization which lets users select two different artworks. After the selection, the visual connection of those two images is shown with other artworks. The images between are selected with a computer vision algorithm. Every item shows the name of the artists, the year, the title and the corresponding exhibition site. With a click on the item, the image of the artwork is presented in a zoomable view, if available, a description of the artwork is shown.

In *Music Timeline* (Research, 2014) music genres and their popularity over time are visualized with an interactive flowchart. With a click on one of the areas, sub-genres are
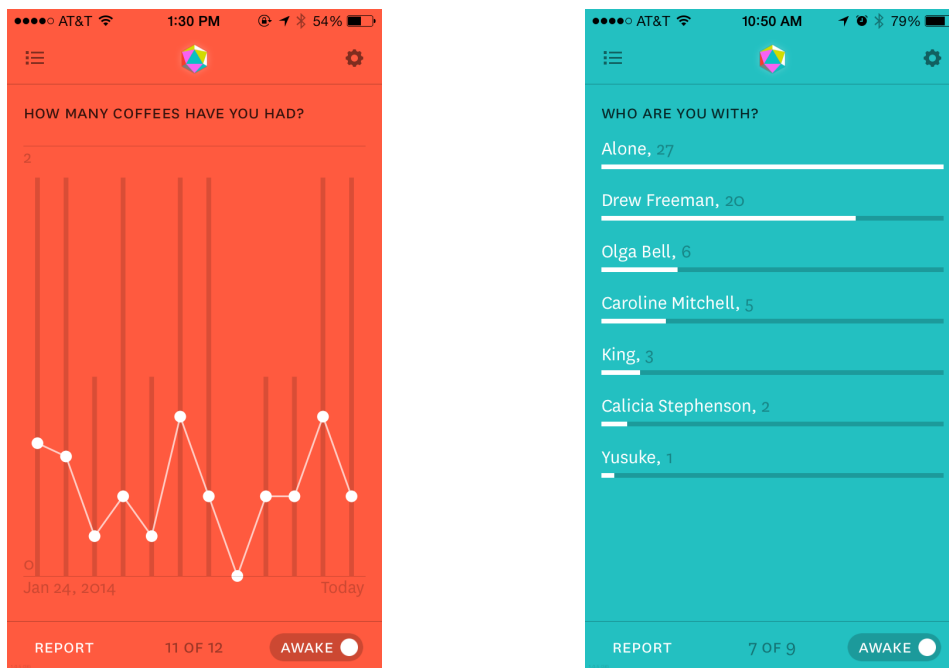
Figure 3.24: *Reporter*'s (Felton, 2014b) coffee consumption (left) and social environment visualization
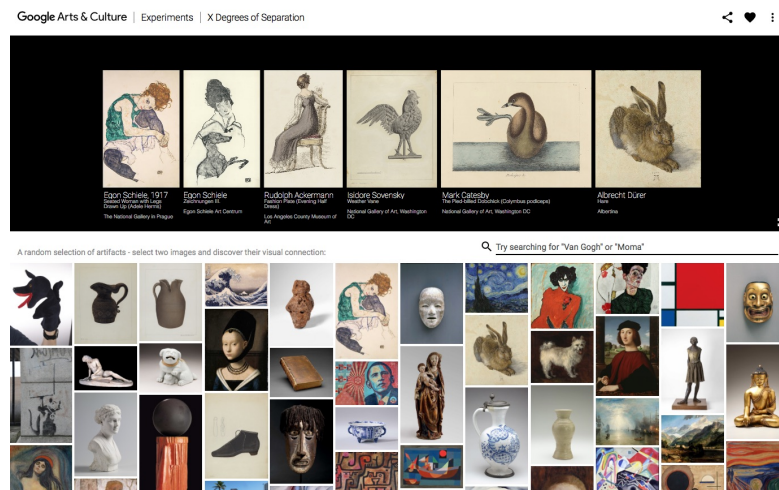

Figure 3.25: *X Degrees of Separation* (Klingemann, 2016) with the connection between an image of Egon Schiele and Albrecht Dürer
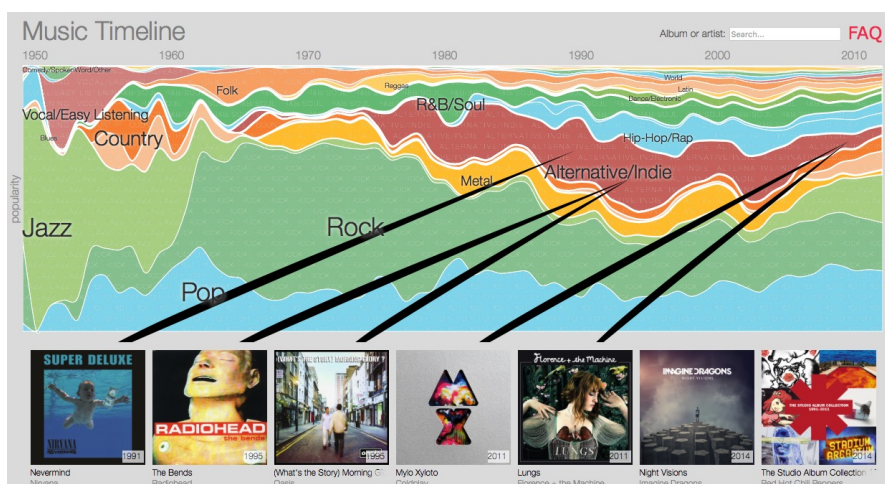
Figure 3.26: *Music Timeline* (Research, 2014) while hovering over genre
Alternative/Indie

shown, an additional click shows the distribution of artists in this subsection. Underneath
the flowcharts matching records are shown. With a click on an artist, the corresponding
Wikipedia article is displayed. The popularity data for this visualization is generated by
statistics from Google Play Music. The popularity is computed by the number of users
having an artist or an album in their library.

Wikiweb (FTW, 2014) is a mobile Wikipedia reader for iPhone and iPad which visualizes
connections between articles. Therefore, a force directed graph with the article's title in
the center and the linked articles around is used. The articles can be read directly from
the application, the article's structure is presented in a list view.

My Visit to the Louvre (Louvre, 2017) is an Android and iOS application which helps
users finding the way through Louvre with a 3D space model and by following the
itinerary suggestions. Additionally, information about the museum like opening hours,
exhibitions, or provided workshops is shown. It is also possible to buy audio guides or the
ticket in the application. In total there are 600 descriptions and 600 audio commentaries
about the artworks and museum rooms.

The *Rijksmuseum* application (Rijksmuseum, 2017) for Android and iOS offers different
guided tours through the collection. It combines maps to show the location of an artwork
and audio guide features. The provided *Family Quest* is a scavenger hunt where groups
of two to four can play together.

Discovr (McKinney, 2016) is an iOS application which visualizes connections between
musicians. Therefore, a force directed graph visualization based on the previously entered
artist names is shown. Nodes are presented by round images of the artists, and if enough
space is available, the artist's name. After an musician is selected, information about the
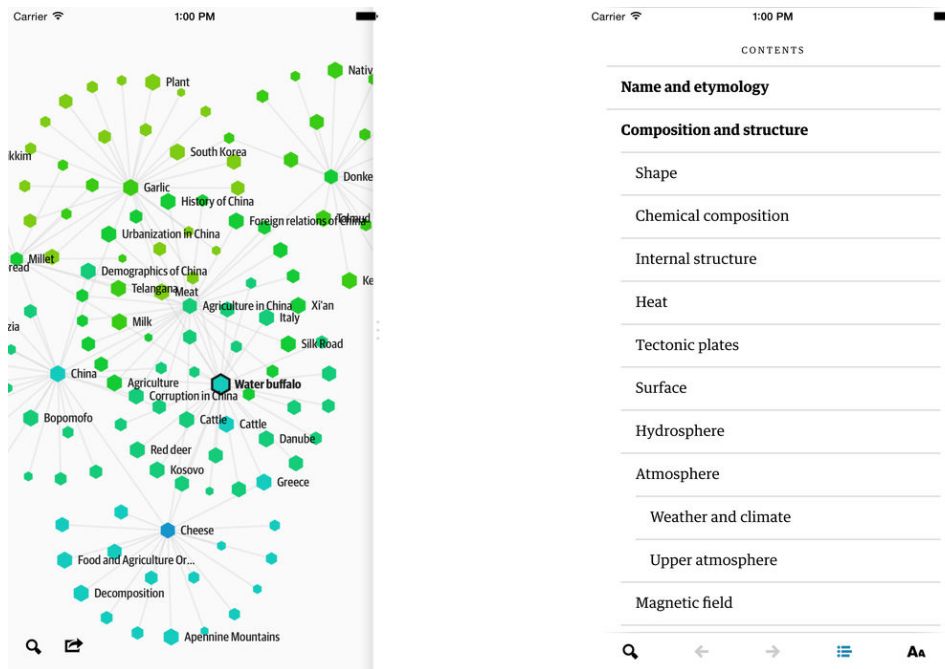artist, songs from Spotify, and videos are presented.

Figure 3.27: *Wikiweb*'s (FTW, 2014) force directed graph of Wikipedia articles (left) and a list view of an article's structure
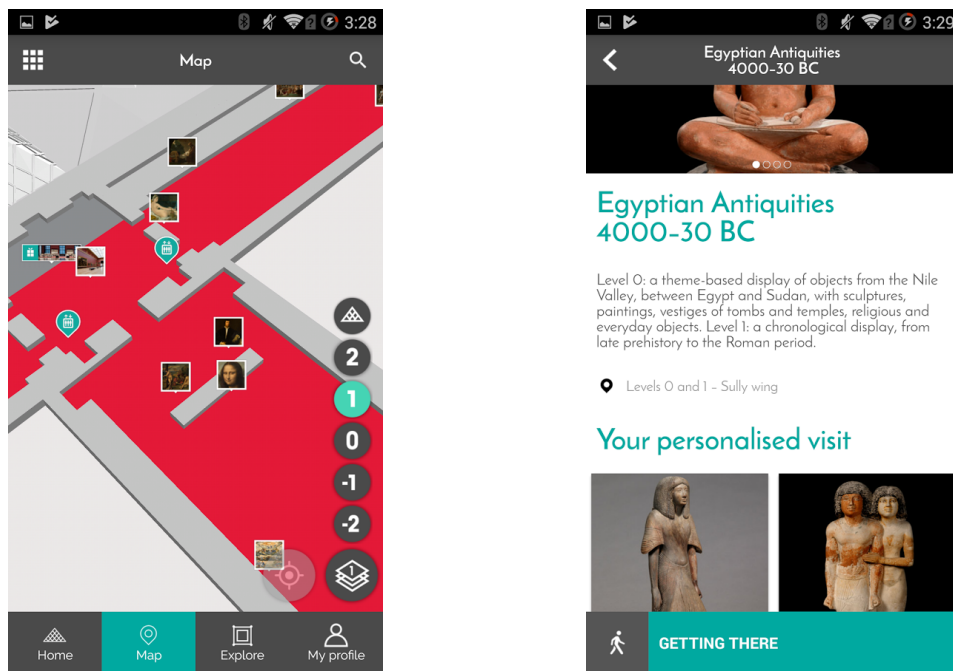

Figure 3.28: *My Visit to the Louvre* (Louvre, 2017) with the 3D space model (left) and the description of an exhibition
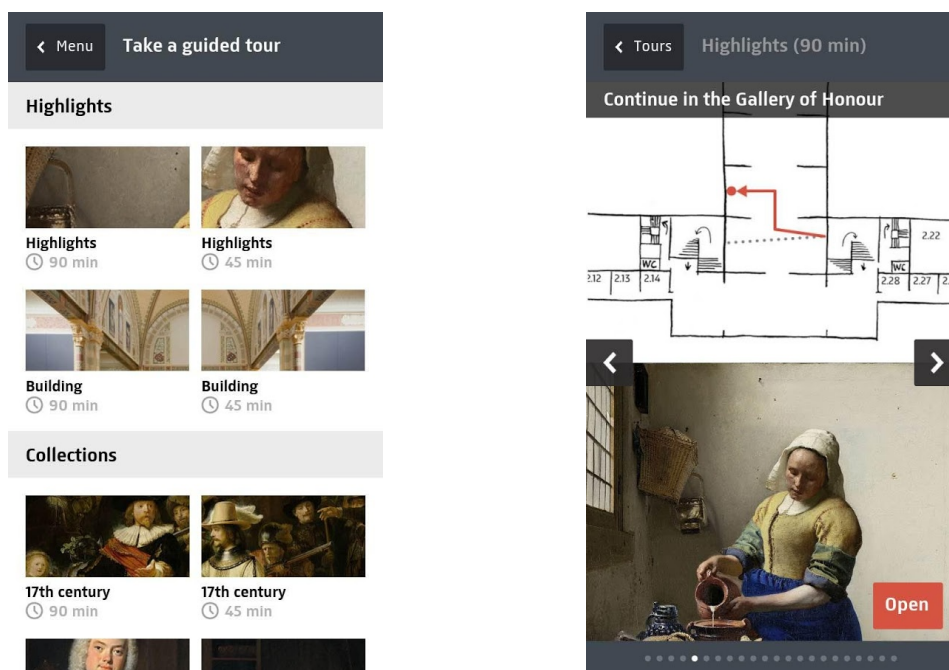
Figure 3.29: The *Rijksmuseum* app (Rijksmuseum, 2017) with the selection of tours (left) and a guide through the museum
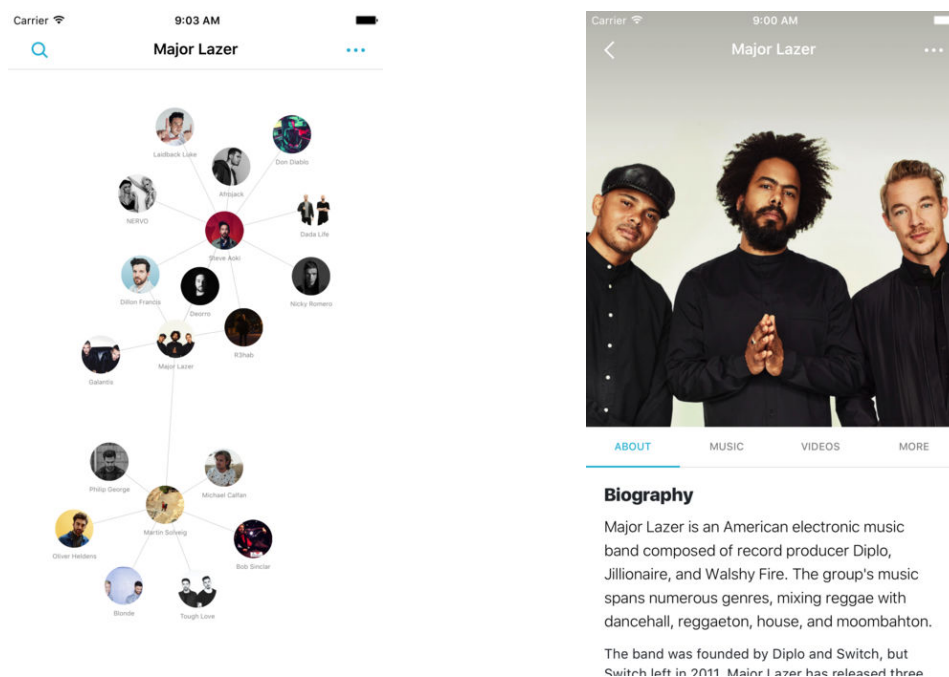

Figure 3.30: *Discovr*'s (McKinney, 2016) force directed graph with artists (left) and additional information about an interpreter
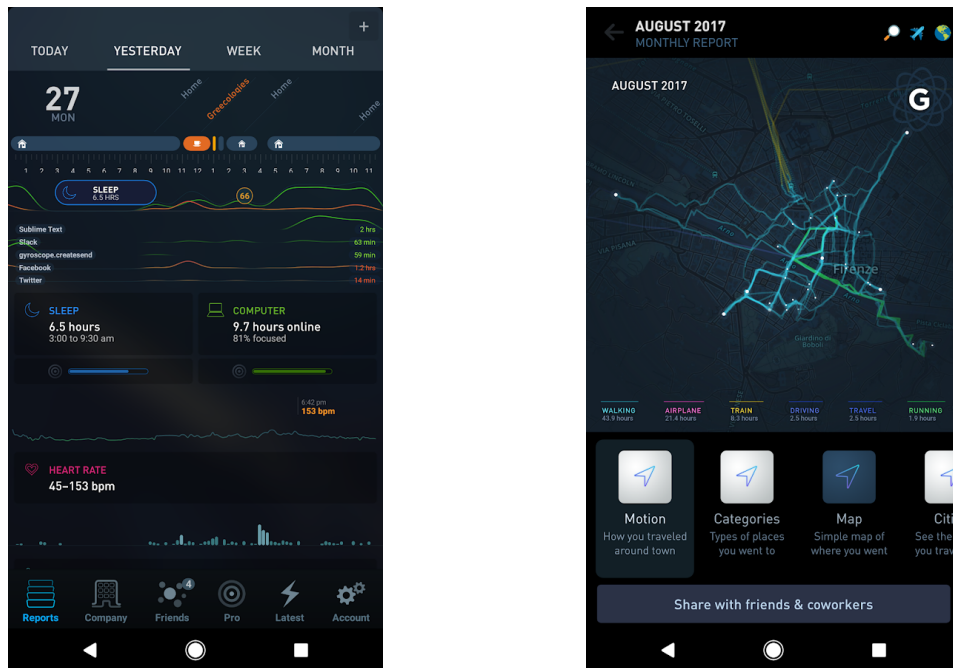
Figure 3.31: *Gyroscope*'s (Innovations, 2015) daily report (left) and a map view with the movement profile

Gyroscope (Innovations, 2015) visualizes measured data like steps, heart rate or weight with different reports. The application for example contains a visualization which combines a map with a calendar that shows when and where most steps were made. Other used visualizations are bar charts for comparing the own achievements with friends or timelines which show progress over time.

Flyover Country (Minnesota, 2015) is a smartphone application which tracks plane flights with GPS and shows geologic information like fossil locations on the path. The points are clustered and shown on a map. With a click on a point, additional information like a georeferenced Wikipedia article is shown.

OECD Regional Well-Being (Baur, 2014a) is a mobile-friendly visualization of well-being across different OECD regions. Topics considered are for example education, jobs, environment, or safety. The different regions are presented by circles on a world map. After an element is selected, a visualization of the eleven well-being topics is shown with circularly arranged bars. Regions with a similar well-being profile are presented beyond. Detailed information and comparisons of a region with others are shown in bar charts and dot plots.
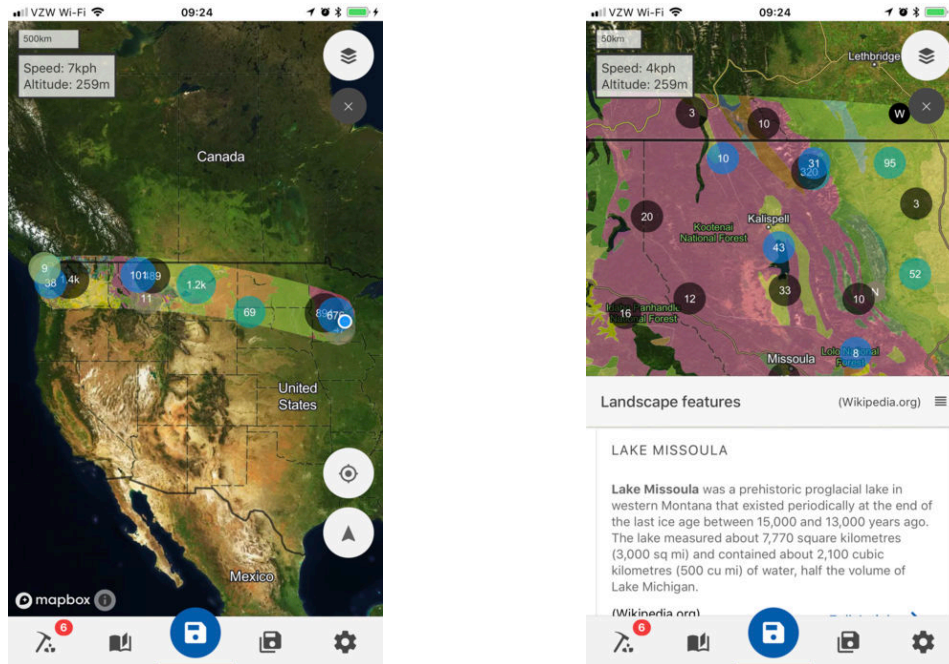
Figure 3.32: *Flyover Country*'s (Minnesota, 2015) map with clustered locations (left) and shown information after selection
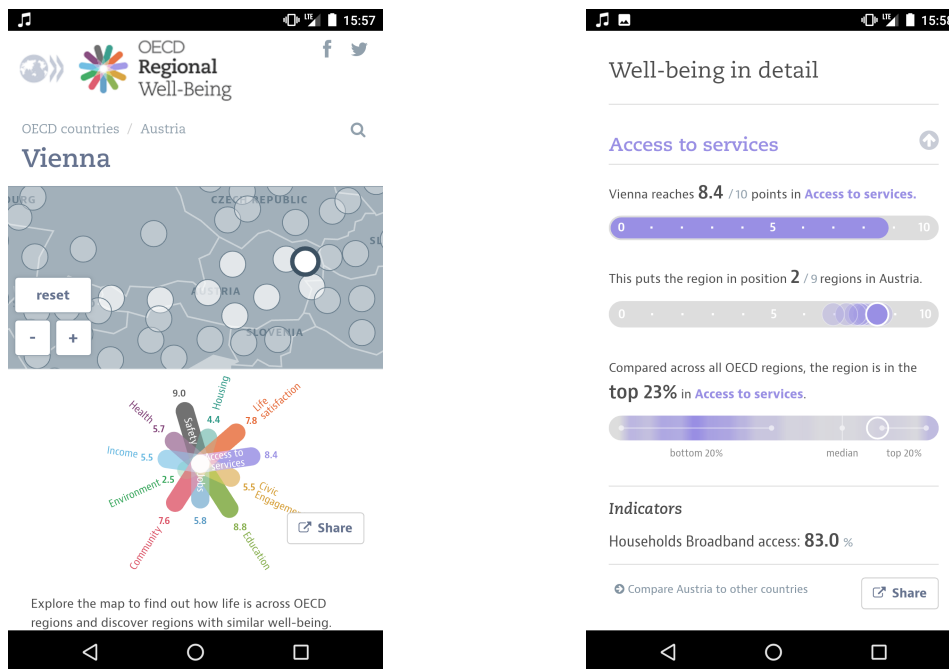

Figure 3.33: *OECD Regional Well-Being* (Baur, 2014a) with map and glyph (left) and access to service in comparison to other regions

3.4   Categorization of Findings

In the following table 3.1 the findings of the 35 different visualizations and applications are presented. Papers which solely focus on the design or evaluation were excluded. For selecting fitting categories (P. Isenberg & Isenberg, 2013), (Windhager et al., 2016), and (Blumenstein et al., 2016) were a good starting point. The categories are aligned at the top of the table. References to the findings are shown along the y-axis. A check mark indicates that a specific property applies.

Regarding the visual representation with one work (Museum, 2015) 3D is distributed the least. It seems that the low popularity of 3D information visualizations on desktops also appears for the mobile domain. In comparison, representations like spatial (14), temporal (17), network (14) and text (20) are more common.

Scientific papers with the focus on visualization techniques or interaction often were not precise about the used dataset. It appears that from the 14 contributions settled in the museum context all rely on images. In contrast, film was only used once (Dörk, 2014). In general, the least used data types were audio (9) and film (7).

Since this thesis targets mobile devices, it is no surprise that tablets (18) and smartphones (17) are the most common device types. However, considering only the 14 works situated in the museum context, tablets are targeted five and smartphones four times. From the eleven desktop contributions only two (Baur, 2014a), (Klingemann, 2016) support mobile devices.

As mentioned above purely theoretical papers are ignored in this table. Instead, all the works are at least implemented in the form of a prototype. Of the 35 works 20 have a scientific background. Of those scientific contributions, 14 conducted an evaluation.

With the focus on exploration, it reveals that only four works clearly target group interaction (Hinrichs et al., 2008), (Rehm & Jensen, 2015),(Block et al., 2012), (Rijksmuseum, 2017). Of the 14 museum visualizations three are used from remote and nine can be used in the museum. Only one application (Rogers et al., 2014) targets both usage scenarios.

Visualization	Visual Representation						Dataset					Target				Project			Exploration			
	Spatial	Temporal	3D	Network	Text	Other	Artifacts	Film	Images	Audio	Persons	Phone	Tablet	Desktop	Stationary	Scientific	Prototype	Evaluation	Group	Museum	Remote	In-Situ
Drucker et al. (2013)	✓	✓				✓							✓			✓	✓	✓				
Chittaro (2006)	✓											✓				✓	✓					
Kay et al. (2016)		✓										✓	✓			✓	✓	✓				
Rzeszotarski & Kittur (2014)					✓						✓					✓	✓	✓				
Sadana & Stasko (2016)		✓			✓		✓						✓			✓	✓					
Escobar et al. (2016)		✓			✓							✓	✓			✓	✓	✓				
Craig & Huang (2015)				✓	✓					✓	✓	✓				✓	✓	✓				
Zhu et al. (2015)	✓			✓	✓		✓					✓				✓	✓	✓				
Baur et al. (2012)		✓						✓		✓			✓			✓	✓					
Rogers et al. (2014)				✓			✓		✓				✓			✓	✓	✓		✓	✓	✓
Hinrichs et al. (2008)		✓		✓	✓		✓		✓		✓				✓	✓	✓	✓	✓	✓		✓
Roccetti, Marfia et al. (2013)	✓			✓	✓		✓		✓	✓	✓	✓	✓			✓	✓	✓		✓		✓
Roccetti, Varni et al. (2013)				✓					✓			✓				✓	✓			✓		✓
Rehm & Jensen (2015)									✓				✓			✓	✓	✓	✓	✓		✓
Thudt et al. (2012)		✓		✓	✓	✓	✓		✓		✓				✓	✓	✓	✓		✓		✓
Block et al. (2012)		✓		✓	✓				✓						✓	✓	✓	✓	✓	✓		✓
Glinka et al. (2017)	✓	✓		✓	✓	✓	✓		✓					✓		✓	✓	✓		✓	✓	
Dörk (2014)	✓	✓		✓				✓	✓	✓	✓			✓		✓	✓			✓	✓	
Miller et al. (2012)			✓	✓				✓	✓	✓	✓			✓		✓	✓	✓				
Kurgan (2014)				✓		✓	✓							✓		✓	✓					
Jenkins (2013)	✓	✓		✓	✓				✓		✓			✓		✓						
MoMA (2012)				✓	✓		✓	✓	✓		✓			✓		✓				✓	✓	
Museum (2015)	✓	✓	✓	✓	✓		✓		✓					✓		✓				✓	✓	
Barrett-Small (2014)						✓	✓		✓					✓		✓				✓	✓	
Research (2014)		✓								✓	✓			✓		✓						
Bear (2015)				✓	✓			✓	✓		✓	✓	✓			✓						
Felton (2014b)	✓	✓									✓	✓	✓			✓						
Klingemann (2016)						✓	✓		✓			✓	✓	✓		✓						
FTW (2014)				✓	✓				✓			✓	✓			✓						
Louvre (2017)	✓	✓		✓			✓		✓	✓		✓	✓			✓				✓		✓
Rijksmuseum (2017)	✓	✓		✓			✓		✓	✓		✓	✓			✓			✓	✓		✓
McKinney (2016)				✓	✓			✓	✓	✓	✓	✓	✓			✓						
Innovations (2015)	✓	✓				✓							✓			✓						
Minnesota (2015)	✓			✓				✓				✓	✓			✓						
Baur (2014a)	✓			✓		✓					✓	✓	✓	✓		✓						
This thesis	✓	✓		✓	✓	✓	✓		✓		✓	✓	✓	✓		✓	✓	✓		✓	✓	✓

Table 3.1: Categorization of the found visualizations and applications

3.4.1 Discussion of Findings

In the last row, the solution proposed in chapter 4 Prototype is categorized. Besides of 3D, video, audio, stationary and group, all the characteristics are fulfilled. Works with great correspondence are (Roccetti, Marfia et al., 2013) and (Glinka et al., 2017).

In summary, the state of the art revealed that mobile visualization in the museum context is still a barely explored field. Especially the combination of remote and in-situ interaction, for example, with tagging of specific pieces, can increase the learning and connection with the presented topic. Another potential research area is the seldom considered interaction in groups. Since museums are visited most of the time in groups of two or more, social features, for example in form of games, could increase the participants' engagement. The popularity of image representation shows that the presentation of the initial object is very important. This also concludes with this thesis' field study that revealed that the gallery was a frequently used feature.

Positively highlighted can be the fact that most of the scientific works were evaluated. However, sometimes the evaluation was only conducted in a lab environment with experienced users. Besides, going into the field and understand the users' context should bring deeper insight. The exposed strict separation of desktop and mobile needs to be reconsidered. It is likely that the trend of supporting both platforms is also adopted by the visualization community.

3.5 Visualization Design

This section presents resources which focus on the design of an information visualization. Besides of a description of the publications, some papers' guidelines are presented.

In *Generous Interfaces for Digital Cultural Collections* Whitelaw (2015) argues for more generous alternatives to text search and presents good examples. Confronting non-expert users which do not have a specific target in mind with text search shows little promise. Instead, Whitelaw promotes rich and browsable interfaces which can reveal the scale and complexity of cultural heritage collections. The paper focuses mainly on web-based desktop visualizations. However, issues with text search affect mobile devices stronger since text input is less comfortable in comparison to desktop computers.

Lee, Isenberg, Riche & Carpendale (2016) reflect about more natural interactions for information visualizations. This Natural User Interfaces (NUI) which use for example touch, gesture, speech or sketch interaction promise to reduce the barriers of computer usage. The traditional WIMP (Windows, Icons, Menus, Pointer) approach is criticized for the unnatural tasks, the high level of complexity for simple tasks, and the fact that they are not suitable for new contexts like museums, public spaces, or handheld devices. Instead of a task-driven approach, they propose a human-centric alternative where the individual, the technology and, social aspects are considered. The authors describe the following five opportunities and challenges for the InfoVis community:

- *Go Beyond Mouse and Keyboard*

- *Provide High Freedom of Expression*

- *Take Into Account Social Aspects*

- *Reduce the Gap between a Person and the Technology*

- *Gain a Better Understanding of People's Behaviors*

Craig (2015) presents mobile information design guidelines. The tenor in the visualization community is that mobile visualizations should be limited to simple operations and small-scale data. With a case study, the author shows that a mindful usage of existing information visualization techniques can help to overcome many mobile devices' limitations. The formalized design guidelines are:

1. *Be aware of the situations in which the application is likely to be used and adapt the interface accordingly for sporadic, hands-free or one handed use.*

2. *Use techniques that make more efficient use of available screen space or do not require accurate selections.*

3. *Keep text and selection targets above a constant device specific minimum size and scale other elements to fit these constraints.*

4. *Don't display too much information on the screen at the same time.*

5. *Use virtual buttons to switch between different types of selection.*

6. *Don't allow important information to be hidden by the user's finger during interaction.*

The key design principles stated by Sadana & Stasko (2016) in *Designing Multiple Coordinated Visualizations for Tablets* are:

- *Provide views-on-demand*

- *Employ single-finger operations*

- *Prevent occlusion*

- *Promote standard gestures and consistency*

In the previously described *Bohemian Bookshelf* (Thudt et al., 2012) the authors present design guidelines which allow serendipity through visualization. The five points to enable coincidental discoveries as an alternative for directed search stated are:

- *Multiple Visual Access Points*

- *Highlighting Adjacencies*

- *Flexible Visual Pathways*

- *Enticing Curiosity*

- *Playful Exploration*

The Rules of thumb chapter of *Visualization Analysis and Design* by Munzner (2014, p. 117) gives a good overview of important topics when designing a visualization. The eight rules of thumb presented are:

1. *No Unjustified 3D*

2. *No Unjustified 2D*

3. *Eyes Beat Memory*

4. *Resolution over Immersion*

5. *Overview First, Zoom and Filter, Detail on demand*

6. *Responsiveness Is Required*

7. *Get It Right in Black and White*

8. *Function First, Form Next*

3.6 Evaluation

In *Evaluating Information Visualizations* Carpendale (2008) describes different types of empirical methodologies for evaluating information visualizations. Different quantitative and qualitative methods are presented and discussed in relation to their generalizability, precision, and realism. The author recommends a real-world approach with real users, real tasks and a complete and complex dataset. However, in comparison to this thesis, the mentioned target audience are expert users. In the end the author advocates for more evaluation in general and for a broader variety of different techniques.

Forsell & Johansson (2010) outline the ten most important heuristics for InfoVis. From a pool of 63 heuristics published in six heuristic sets, evaluators judged how well each heuristic explains a usability problem. The top 10 heuristics which provide the widest coverage to explain all problems are:

1. *Information coding*

2. *Minimal actions*

3. *Flexibility*

4. *Orientation and help*

5. *Spatial organization*

6. *Consistency*

7. *Recognition rather than recall*

8. *Prompting*

9. *Remove the extraneous*

10. *Data set reduction*

T. Isenberg, Isenberg, Chen, Sedlmair & Möller (2013) present evaluation practices published at the IEEE Visualization conference from the previous ten years. The findings were categorized by scenarios like understanding environments and work practices, visual data analysis or user experience. The authors state that in the last six years methods that include participants increased. In contrast, the previous dominant evaluation focus was on resulting images or algorithm performance. In the considerations section Isenberg et al. state that process-based evaluation scenarios are important to understand the problems faced by the audience in a real-world setting. Due to the number of participants necessary for evaluation the authors refer to Nielsen and Molich (Nielsen & Molich, 1990), which stated that 80% of all usability problems are found with six people. An alternative is to stop the analysis once the collected data becomes redundant. They criticize that

many of the studies are not reported rigor enough, therefore they encourage reporting who has participated, collaborative details and the study protocols used.

Nayebi, Desharnais & Abran (2012) focus on the state of the art of mobile application usability evaluation and testing. The methodologies for evaluating mobile usability are laboratory experiments, field studies, and hands-on measurement where the defined aspects like display load, clarity, completeness, or display self-adjustment are measured directly. Observations made by Nayebi et al. are that more usability problems are found in non-lab experiments. In the field, users had more negative feelings such as dissatisfaction and difficulty of use and tasks took longer. The authors mention that new mobile interface needs like device orientation changes, location awareness or multi-touch gestures are not addressed in the evaluation process. Other observations are that usability measures are often not properly defined, and that it is often unclear how the data was collected. It is stated that most of the studies rely on a single evaluation methodology. Combining for example a field study with hands-on measurement could bring more information.

Saket, Endert & Stasko (2016) discuss evaluation methods beyond traditional usability goals like efficiency and effectiveness. Instead, the categories of user experience goals memorability, engagement, and enjoyment are introduced.

Chittaro & Sioni (2014) evaluate three versions of a mobile app that uses different visualization for breathing training. For the perceived effectiveness the participants tried out the different designs and filled out a questionnaire afterwards. In addition, values like the skin conductance level, the heart rate and the power of the recommended frequency band, which indicates how deep participants breath, were measured.

The mobile web-based *Virtual Museum* (Tehrani et al., 2014) application was created with the target to provide information about the Muzium Negara. A definition mentioned in the paper is that virtual museums help users to interact with the virtual environment. Exhibits are presented through images, videos, and 360-degree panorama views. Potential problems were identified through interviews with 17 tourists and two museum officers. To evaluate the application, heuristic evaluation with six experts was used. Reasons for choosing this evaluation method are that it is cheap, popular, fast and that no involvement of end users is required.

Lam, Bertini, Isenberg, Plaisant & Carpendale (2012) present the seven most common evaluation scenarios based on an analysis of 800 papers. The scenarios are *Evaluating Environments and Work Practices* (EWP), *Evaluating Visual Data Analysis and Reasoning* (VDAR), *Evaluating Communication through Visualization* (CTV), *Evaluating Collaborative Data Analysis* (CDA), *Evaluating User Performance* (UP), *Evaluating User Experience* (UE) and *Automated Evaluation of Visualizations* (AEV). For each scenario, the authors present goals and outputs, methods and examples, and evaluation questions. The authors' intentions are to encourage the InfoVis community to reflect about evaluation goals before using a method and to employ a broader set of evaluation methods.

CHAPTER 4

Prototype

This chapter presents the created mobile museum visualization application. In the first section 4.1 the design of the prototype is described and shown with screenshots. The section 4.2 Implementation discusses the data wrangling process, and the technologies used in the application.

4.1 Design

The design of the application followed the mobile first approach. Especially at the beginning, the main target devices were smartphones. Consequently, a sparing use of screen-space was enforced, and it was not necessary to remove elements later because of lacking space. Only minor changes, like structuring the charts in a responsive grid, were required for providing a better tablet and desktops experience. Another reason for this mobile focus was that most of the users have their smartphone with them in the museum. Targeting the museums' rental tablets only, excludes potential users, especially those from remote.

Additionally, Shneiderman's (Shneiderman, 1996) information seeking mantra *Overview first, zoom and filter, then details-on-demand* was followed. The charts on the home screen give an overview of the collection. Zoom is implemented in the map and the gallery. Since the amount of visual elements on the home screen and dendrogram visualization is rather low, zooming was not required. Filters can be applied on the home screen, the dendrogram and the map. In addition, the filtered results can be viewed in the gallery. Due to the restricted space on mobile devices, details-on-demand is an important paradigm which is followed throughout the application in form of an information bar at the bottom. After an element is selected, this bar (4.5) shows corresponding information.

Furthermore, the previously mentioned interaction design guidelines 3.5 from (Sadana & Stasko, 2016) were applied for the design of the prototype. Thus, the whole application
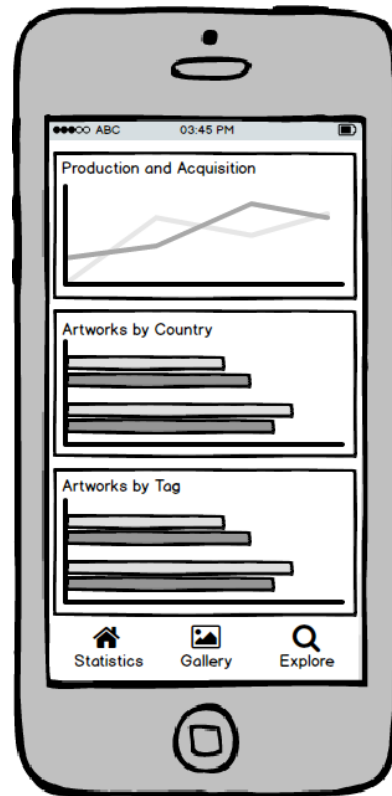
Figure 4.1: Mockup of the application's main screen

can be operated with simple one finger interaction. Consistency is achieved through the uniform design of the interaction elements. For example, the top and bottom bars are available on all the four screens.

A first prototype of the mobile application was created with the software *Balsamiq Mockups* (Balsamiq, 2017). The target of this prototype was not lying on visualization but on finding a fitting user interface for the application. After experimenting with different approaches, the selection fell on a complete flat app structure. Therefore, a bottom navigation bar with the buttons for the different screens was selected. This way the user can navigate with one click to every available screen. During experimentation, the need for a visual differentiation between the charts became clear, therefore a rectangular boundary was inserted.

4.1.1 Home

The six available visualizations on the main screen are *Production and Acquisition*, *Artworks by Country*, *Artworks by Tag*, *Artworks by Material*, *Artworks by Artist* and *Artists by Country*. As visual separation cards with a header on the top and the chart element beyond were used.
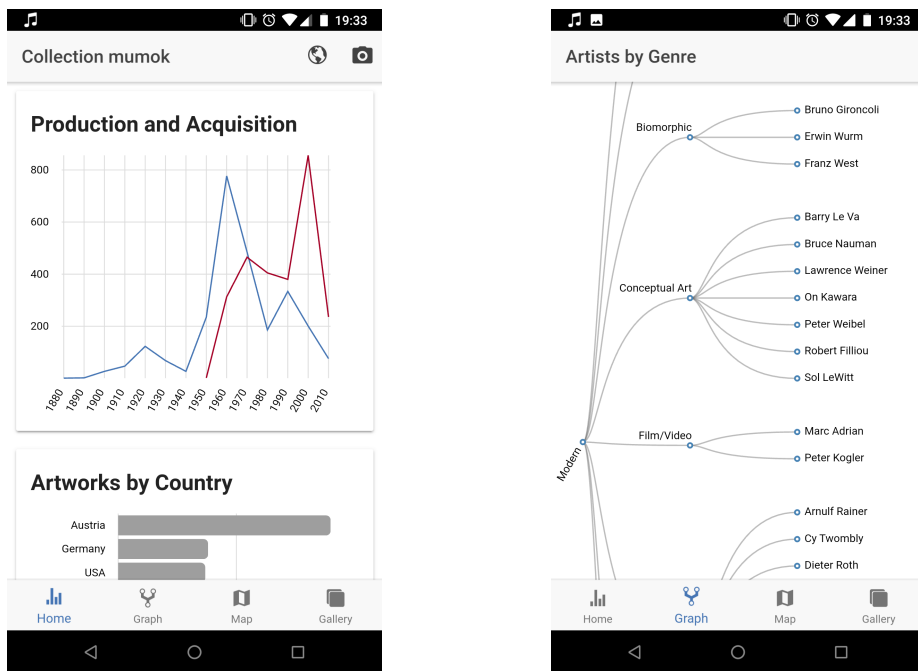
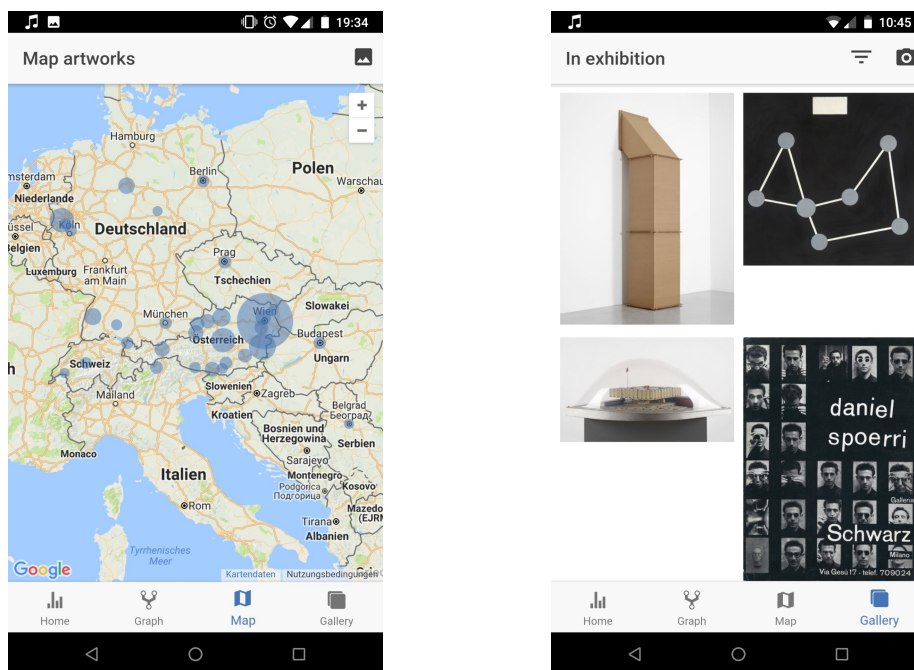Figure 4.2: Home screen (left) and graph

Figure 4.3: Map (left) and gallery

Figure 4.4: Top toolbar bar with the buttons to change the language and scan a tag (left) and bottom navigation bar
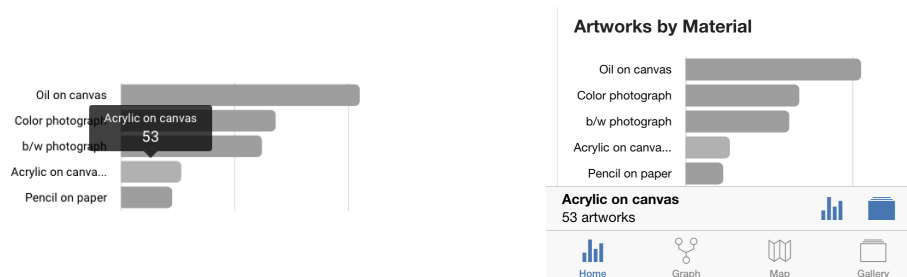

Figure 4.5: The formerly used tooltip (left) and the bottom bar with further information and interaction elements

The top toolbar 4.4 contains a header describing the currently selected items and two icon-buttons. The language button was introduced to change the language based on the user needs during the field study. When distributing the application over an app store, it would make sense to remove the button and show the language based on the device settings. The second button in the toolbar is used to scan an artwork's label. When clicking the icon, the default camera application is opened. After capturing the photo, a circular loading animation (4.13) is shown until the image is processed.

For showing details about a selected chart element tooltips were used for starters. After informal user tests, it became evident that these tooltips were not working well. They were too small and did not provide further interaction with the selection. However, the interaction was necessary since the first two usability tests revealed that long touch gestures are not well known. As a consequence, the tooltips were replaced with a bottom information bar which is shown after a chart element is clicked. This bar, which is one of the main interaction elements, is also available on the other screens. As a visual indication, the selected chart component is displayed brighter. If a click at no element is conducted, the information bar is hidden and the chart element's color is reset.

Besides of the selected element's name and the number of corresponding items, the information bar also contains two icon buttons. The first button, which has a bar chart as an icon, is for filtering the artworks based on the current selection. After clicking this button, all the other charts are updated (4.6), again with an empty click the filter can be reset. By clicking the gallery icon, the gallery with the selected items is opened. The gallery icon in the navigation bar beyond has the same behavior. However, the user tests have revealed that this button does not have the same affordance as the one in the information bar above.

The charts used on the home screen are a line chart with one line for production and one
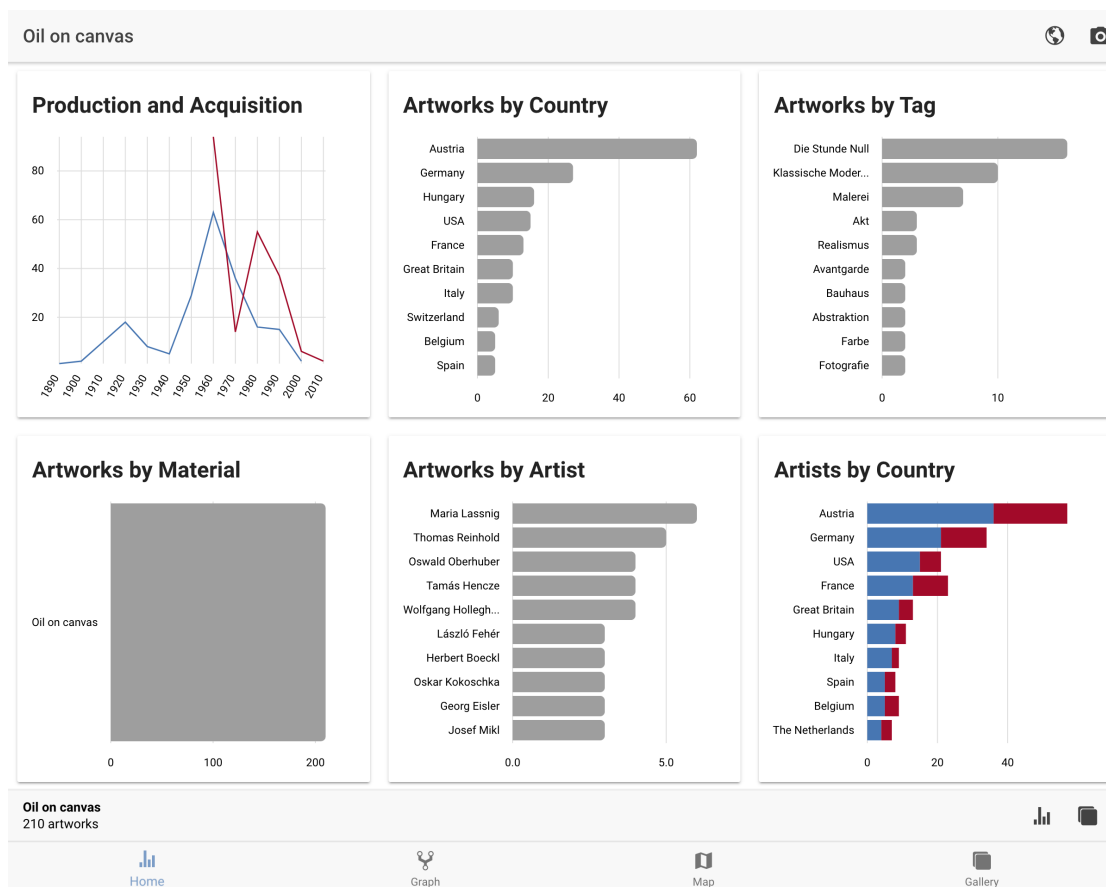
Figure 4.6: Tablet's landscape view with items filtered by *Oil on canvas*

line for acquisition, horizontal bar charts and a stacked horizontal bar chart for birth and death-country of the artists. The horizontal bar charts were used because the labels are more readable and they scale better on smartphones when vertical scrolling is enabled. For the colors of the *Production and Acquisition* line chart and the *Artists by Country* stacked bar chart colorbrewer2.org (Brewer & Harrower, 2017) which was recommended by Munzner (Munzner, 2014, p. 225) was used. The selection fell on blue *#4575b4* and red *#a50026* from the section diverging data with 10 classes. The same colors are also used at the map to visualize either the number of artworks or artists per city.

4.1.2 Graph

On the *Graph* screen the top 50 artists are categorized by genre in a so-called dendrogram. This visualization type scales vertically very well, another benefit is that the category and artist names are constantly present. When one of the nodes or the corresponding text labels is clicked, further details like place and year of birth and the number of artworks are presented at the bottom information bar. A click on the chart icon presents the
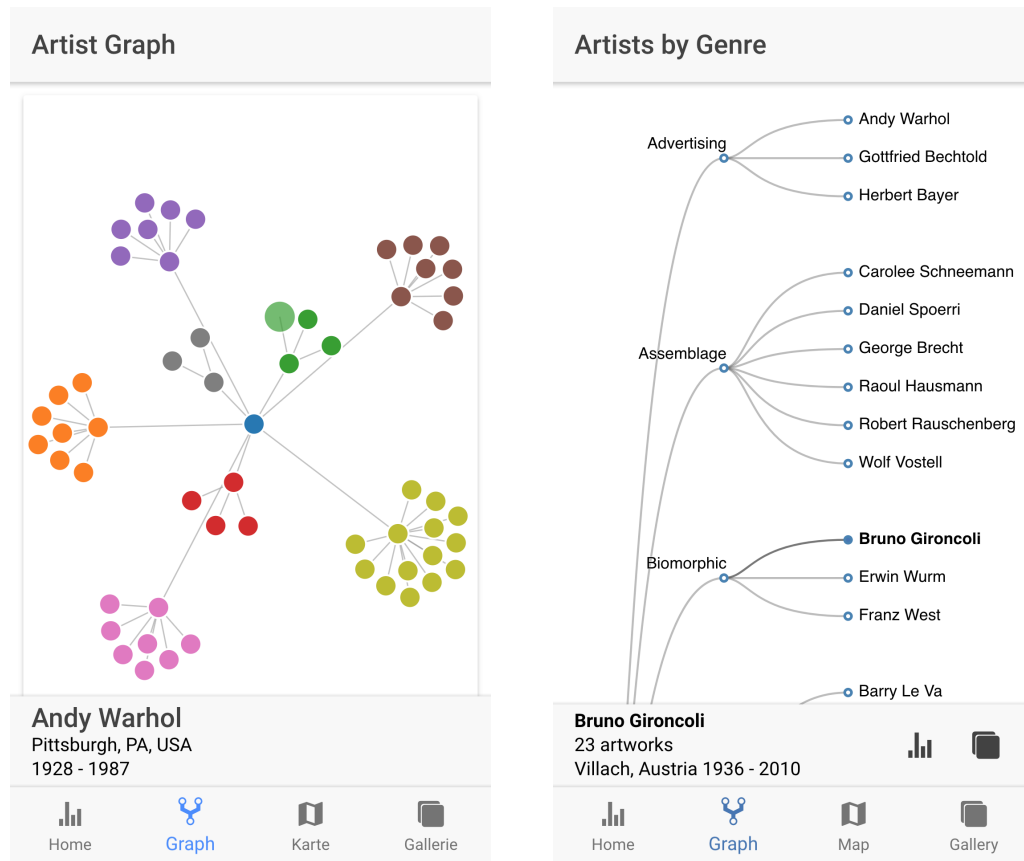
Figure 4.7: Previously used force directed graph with Andy Warhol selected (left) and dendrogram with selected artist

statistics for the selected artist on the home screen. In addition, the gallery icon shows images of the artworks in the gallery.

Before implementing the dendrogram, it was tried to visualize the same data with a force directed graph (4.7). This revealed that despite their popularity those graphs do not perform very well on smartphones. When presenting the names next to the nodes, they are hard to read because of the overlapping text. If the labels are only shown on demand, they require a lot of interaction to find out which artist belongs to which category. Additionally, the graph spans into x and y-axis which does not fit the aspect ratio of smartphones.

4.1.3   Map

At the *Map* screen, artworks or artists are presented by the place of origin on a Google Map. The amount of artworks is mapped to the size of the semitransparent blue bubbles. Again when clicking a visual element, the bottom bar shows additional information and
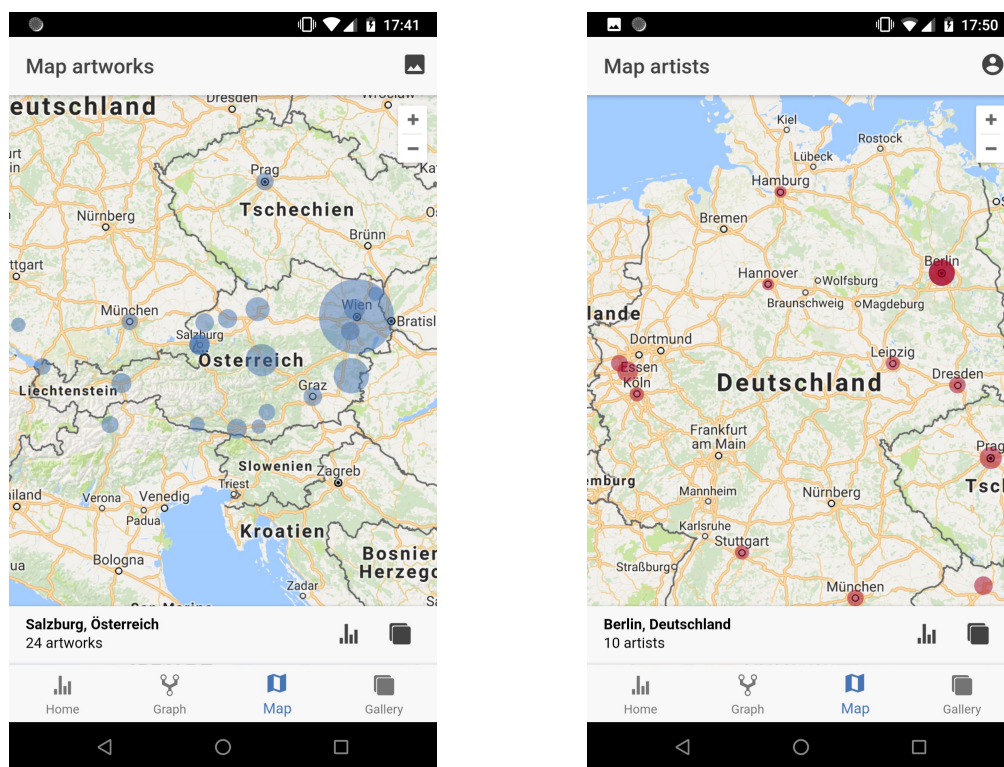
Figure 4.8: Map with the artworks (left) and the artists

buttons to view the corresponding items at the home screen or in the gallery. To highlight the selected bubble the opacity is increased. The map is scalable with multi-touch gestures or the available zoom buttons. When the zoom level changes, the bubbles are rescaled. The top toolbar holds a button to switch between artworks and artists. In the artist view, the number of artists per city is mapped to the bubbles and to separate the different modes the bubbles are colored red.

4.1.4 Gallery

On the gallery page, available images of the artworks are presented. When a chart element is selected, corresponding images are shown in the gallery, otherwise currently exhibited artworks are presented (4.3). After selecting an image, the artists' name, the title and the production year are shown in the information bar. With a further click on this bar, information like year of acquisition, size, material, tags or, if available, a description is presented (4.9). The information bar also holds a heart-button to tag the image and a button to view the image in fullscreen. When the image is maximized, it can be zoomed (4.10) by double tapping or pinching gestures. All other interaction elements besides an arrow for navigating back are invisible. Favorite and exhibited artworks can be viewed with a click on the filter icon in the top navigation bar. Similar to the home
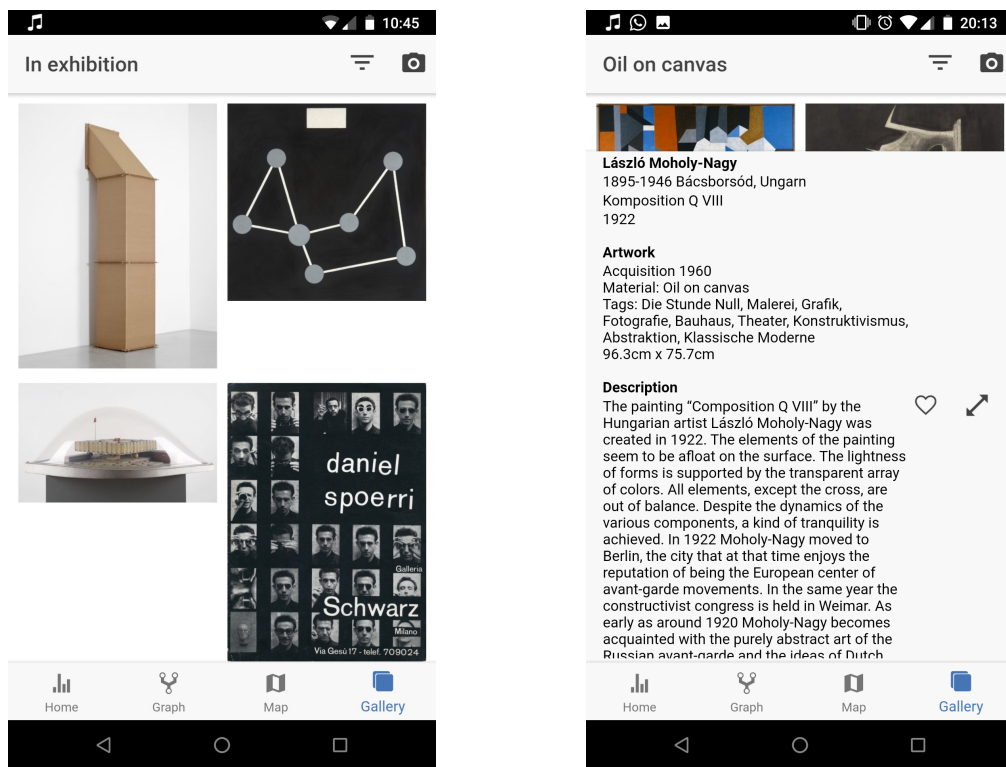
Figure 4.9: Gallery with exhibited artworks (left) and details of a selected image

screen, the camera button opens the default camera to scan an artworks' label. Found corresponding items are afterwards presented in the gallery.

4.1.5 Interaction

The usability tests have shown that simple single finger interaction is very important. Only a few participants used holding touch or double tap gestures. These findings conform with (Sadana & Stasko, 2016), who promote single finger interaction and consistent standard gestures for touch devices. Therefore, the holding touch and double tap gestures were dropped and replaced with single finger interaction. To enable filtering and viewing of artworks' images, buttons were added to the bottom information bar. This bar is available on all screens, only at the gallery screen it provides different functionality with tagging and maximizing an artwork.

In the beginning, the chart with the applied filter was not updated. The fact that on smartphones often only one chart is visible at the same time, made it hard to realize (TP1, TP2) if data changes occurred. For this reason, the currently selected chart is also updated 4.6. As an additional indicator, the title of the top bar is changed.

In the mobile domain, it is important to consider device orientation changes. Thus, the rather restricted space can be used in an optimal way. For example, at the home screen,

Figure 4.10: Zoomed image in fullscreen view

the cards which contain the different charts are in a grid. When the screen width changes, for example after the device is rotated, the grid's columns are stretched to the point where they are moved to another row. This way, every row can contain from one, for example in portrait view on smartphones, up to three charts. The same applies to the gallery where depending on the available horizontal space, two to four different artworks are presented per row.

Since fingers are less precise than a mouse cursor, it is important to make the selectable chart elements or their click area large enough. During the user tests, it became obvious that some elements were too small. Therefore, the bar width on the home screen was increased. At the dendrogram, the users sometimes struggled to hit the text label, therefore, a larger invisible click area was added.

4.1.6 Language

According to mumok's annual report (mumok, 2016), 27.9% of the visitors are from Austria. An employee at the ticket sale stated that around 50% speak German with a more international shift during the holiday season. To reach a broad audience, the app was translated into English and German. Fortunately, apart from the tags, most of the

data fields are available in German and English.

For implementing the language, the library *ngx-translate* (Combe, 2017) was used. This library enables to store the text elements in external text files and reference them by their key in the source code. The corresponding string is then selected during the runtime based on the users' language settings. As already mentioned, for the field test a button to change the language was added to the top navigation bar.

4.1.7   Usage before and after the museum visit

Prior to considering the usage in the museum, the usage before and after the museum visit was targeted. Except, of the tag scanning, all the features can be used outside the museum. According to (Economou & Meintani, 2011) tagging can be used to reinforce the interaction with the artworks and increase the learning effect. Consequently, a feature to like artworks with a click on a heart icon in the gallery was implemented. The liked artworks are persistently stored and can be viewed in the gallery. Usage scenario one might be to browse the collection before visiting the museum and highlight artworks for a closer while visiting the museum. A potential second usage scenario might be to use the tagging while standing in front of an artwork and exploring the details later at home.

4.1.8   In situ usage

To enrich the usage of the application in the museum an artwork-tag scanning feature is provided at the home screen and in the gallery. Users can take photos of an artwork's label and get items from the same artist. When the user clicks the camera icon in the top toolbar, the native camera app is opened. After the image is taken, the text is processed with Googles' cloud vision API (Google, 2017b). At the home screen, corresponding data of an artist is presented. In addition, the gallery shows all available artworks by this artist.

Because of the good light conditions, the object character recognition (OCR) works very well in mumok. Another benefit is that the tags are printed with black letters on a white non-reflecting background. One down-sight, which revealed during the field study, was that the text structure of the signs differed at temporary exhibitions on the top floors. During the first inspection in July 2017, the signs on the top floors were structured exactly like those at the lower floors with the artist's name on top, followed by the artist's country and the title and year of the artwork. However, the tags of the new exhibition *Naturgeschichten*, which started in September 2017, did not present the artworks name in the first line. Therefore, the algorithm which only considered the first line of the scanned text was not able to find corresponding artworks.

4.2   Implementation

In the design and implementation phase finding suited technologies for the system was an important part. The visualizations are implemented with the DOM manipulation library
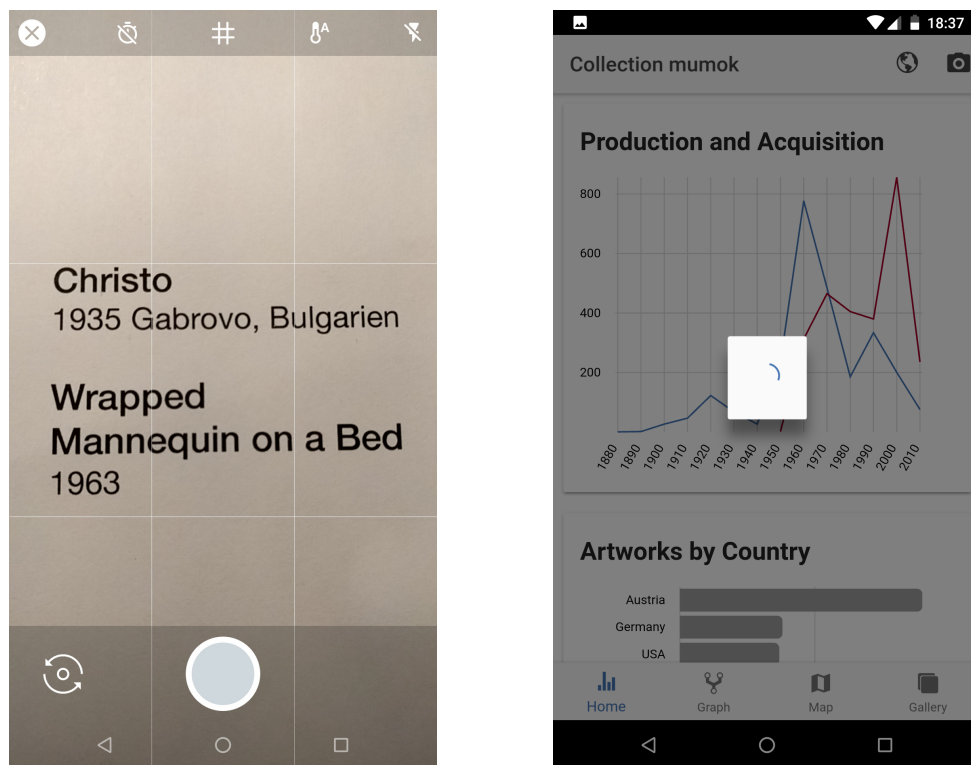
Figure 4.11: Image capturing of a tag next to an artwork (left) and the loading indicator which is shown afterwards

D3.js (Bostock, Ogievetsky & Heer, 2011), and ngx-charts (Swimlane, 2016) which is based on D3.js and provides a set of basic charts. A benefit of using SVG which stands for *Scalable Vector Graphics* is, that scaling of the visualizations works well. Additionally, for showing the data on a world map the JavaScript Google Maps API (Google, 2012) with enabled visualization features is used.

As a mobile front-end framework, Ionic (Ionic, 2013) is used. A benefit of this progressive framework is that besides of hosted instances those mobile web applications can also be compiled and distributed over app stores. Thinking about problems relating to the museum context, like bad WIFI or mobile data, some data can also be stored locally. Due to the focus on mobile devices, those frameworks also provide a variety of input gestures and design patterns like tabs or navigation menus.

Before thinking about a specific design for the application, the available data was examined. Therefore, the collections' JSON (ODP, 2017) was inspected on interesting data fields. In the next step, the potential data fields were visualized in a first simple prototype with d3.js (Bostock et al., 2011). Within this process, the artists' birth years and countries, and the artworks' production years, tags, artists, and the completeness of the descriptions were visualized with bar charts.
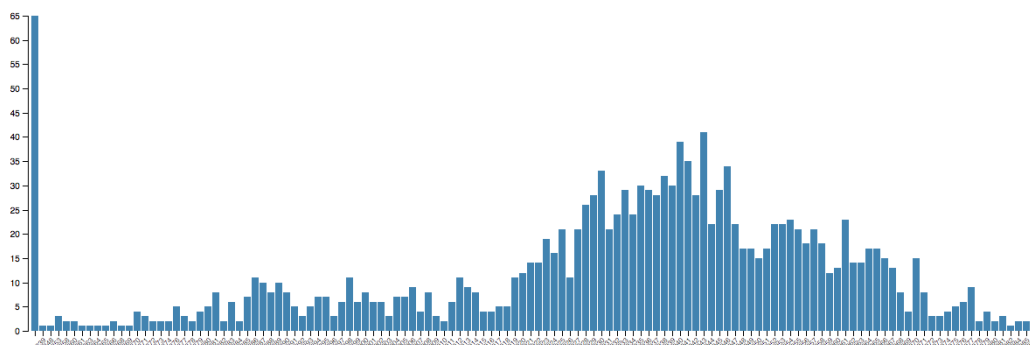
Figure 4.12: Screenshot of the first prototype with artists' birth years

4.2.1   Data Wrangling

Data Wrangling is the process of transforming data into a specific structure. In this case, the target was to bring the data to the structure required for visualizing it. For preprocessing the data, the programming language Python was used. Because of synchronous processing and the great number of packages for data wrangling, Python suites this task very well. The nesting of the data is performed dynamically in the application.

As a starting point, the digitalized artworks of the mumok collection (ODP, 2017) were accessed. The data which is stored in a JSON file is then nested by the selected data fields. Thus, some fields, like the production and acquisition decade of an artwork, or the tags and material in array form, had to be created. For the line chart, the nested production and acquisition data is combined and sorted by decade. For the other charts, the array with the nested artworks is sorted by their length and reduced to the first ten elements.

For the dendrogram the artists genres were processed from Artsy.net (Artsy, 2017). With a Python script, the top 50 artists' genres were fetched and written to a CSV file. For a clear overview, the genres were restricted to the most common ones which are *Film/Video*, *Sculpture*, *Conceptual Art*, *Painting*, *Biomorphic*, *Assemblage* and *Advertising*.

For the right position of the bubbles at the map, it was necessary to link the city names to their geolocation. Since the Google Places API (Google, 2017a) has a restricted amount of usages per minute, it was necessary to preprocess the geolocation. Therefore, the Places API was accessed from a Python script and the corresponding longitude and latitude was written to a CSV file.
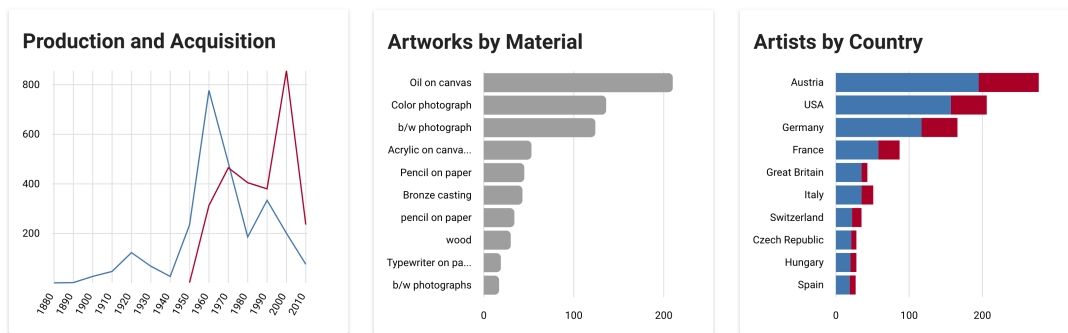
Figure 4.13: Used line chart (left), bar chart(middle) and stacked bar chart

Many of the artworks images are only placeholders and were filtered out in the gallery. In a Python script it was iterated over the whole collection and if the size of an image was equal to the placeholder image, the ID was written into a CSV file. Whenever an array of artworks is passed to the gallery, the list is used to filter out placeholder images.

4.2.2 Visualization

In the next step, an Ionic project was created. For the charts at the home screen the visualization library ngx-charts (Swimlane, 2016) is used. The library provides different preconfigured charts that are rendered in Ionic. Benefits of using this library are the charts' uniform design and the fact that mobile interaction is supported by default. The data is bound to the charts when the data changes. For example, after a filter is applied, the charts are updated with an animated transition.

The implementation of the dendrogram is based on an example from d3js.org (Bostock, 2017). The previously wrangled data is structured on three levels. The root is *Modern*, followed by the seven genres and the corresponding artists. To increase the clickable area of the elements, an invisible layer with larger text elements was added.

The map was implemented with the Google Maps JavaScript API (Google, 2012). In comparison to a native plugin, this web-based service is also available in the browser. For the visualization of the places, the provided tutorial (Google, 2017c) was considered. The amount of artworks or artists per city is mapped to the size of the bubble. Since there are more artworks per place the size is halved. To avoid overlapping, the size of the bubbles is recalculated after the zoom level changes.

The bottom navigation bar (4.4) is provided by the Ionic framework, the currently visible screen is indicated by a blue-colored icon. After another icon is clicked, the screen is changed, the selection of the home and gallery screen is interlinked. This means that after a chart element, for example *oil on canvas*, is selected, the gallery shows corresponding images (4.6).

4.2.3   Gallery

The gallery shows the images in a responsive grid (Drifty, 2017a) with two to four items per row. Therefore, the image URL provided in the JSON object is used. As mentioned before, the placeholder images are sorted out with a filter list. For the fullscreen image view, an external library was used (Riron, 2017).

To persist the favorites, the storage plugin from Ionic (Drifty, 2017b) was used. After an artwork is tagged, the ID is written to the storage. At the app startup, the storage is loaded and favorite artworks can be viewed in the gallery. The data is stored as long as the user does not delete the app or clears the data.

4.2.4   OCR

The scanning of the artworks was implemented with the Google Cloud Vision API (Google, 2017b). Therefore, the Base64 encoded image captured with the camera is sent to the API. After a few seconds, a string which contains the detected text is responded.

Initially, the text recognition was realized locally with Tesseract.js(Kwok, 2017). With around two seconds for text recognition on Android, it worked very well, however, on iOS it took around 30 seconds for the same image. A reason for that might be that Android apps can access more computational power than their iOS counterparts.

CHAPTER 5

Evaluation

5.1 Usability Test

During the design and implementation phase, the application was tested with three users. Therefore, the screen of the mobile device and the speech was recorded. The users were not provided with information how the system is used unless they were stuck. In front of the test, a consent was filled out and it was described which data the application presents.

In the beginning, they were free to explore the application. After a few minutes, they were told to fulfill several tasks on the different visualizations. For the usability, the application was tested on an iPhone 6, an iPad Air 2, and a Nexus 5X. The first test was conducted with the web version of the application, for later tests, the application was compiled for Android and iOS. Since the visualization was tested mainly in the browser before, this revealed some bugs on the different platforms.

During the usability test, some critical usability issues revealed. For example, the assumption that long clicks are a well-known design paradigm was wrong. As a consequence, the application was changed, so that every element can be accessed with a single click. Before these changes, the gallery with specific artworks could be reached by touching a chart element for some time. Instead, it is accessible with a click on gallery icon in the bottom information bar.

It has also shown that some chart elements were too small. Therefore, the height of the bars from the bar charts was increased. Since two of the test persons had problems with clicking the names of the artists in the dendrogram view, the click area was increased.

Another issue found was related to the German translation of the application. The heading *Kunstwerke nach Tag* led to confusion since two test persons thought that the artworks are presented by day. Therefore the label was changed to *Kunstwerke Schlagworte.*

Figure 5.1: Mumok at the first observation in summer 2017

5.2   Observation

To understand the museum context and get insight about the preconditions, the mumok was visited several times. It was observed and noted how the museum visitors interact with the artworks. It has shown that the interaction with single items is usually very short. Many of the visitors do not read the text at the entrance of every platform. Most of the participants visit the museum in groups of two, or in larger guided groups. Several visitors took a lot of photos from the artworks, therefore they mostly used their smartphones which they often held in their hands the whole time. It was observed that visitors usually do not move in a specific pattern. Reasons for that could be that artworks in mumok are not only presented on the outer walls. It revealed that the sitting areas available on some floors are popular. Mumok addresses this preference by providing seated tours where participants sit on folding stools during the guide's explanations.

Beside of the exhibition rooms, some observations were made in the foyer during the user test. Many people who enter the entrance area leave the museum without entering the exhibition halls. Often they leave after visiting the museum shop, watching the price list or the animated screen in the foyer. In comparison to earlier observations, the museum was more crowded. According to a person from the museum staff, it is usually more frequented between Christmas and New Year. It was also stated that the audience during these days is more international than usual. Similar observations have been made during the field study, in comparison to previous visits, the museum was more frequented.

5.3   Field Study

The visualization application was tested at the 29th of December 2017 between 10 am and 7 pm in the mumok. Therefore, the museum provided five iPad mini 2 which are usually used as audio guides. These tablets with the installed app were distributed for

Figure 5.2: Stand in front of the ticket counter from which the tablets were distributed

free to voluntary museum participants. To restrict the usage to the app, the setting *Guided Access* (Apple, 2017) was enabled.

In total, 21 persons tested the application. From these persons, 19 answered the open questions and 16 filled out the SUS Questionnaire. Often, the contact with the participants established because they had questions about the museum or thought that it is the ticket counter. Some people were also contacted while waiting in the queue for buying tickets. Most of the addressed persons were interested in testing the application and usually, they were happy to give feedback afterward. It seemed that the information that the system is developed within a diploma thesis encouraged the participants to help.

The 16 participants which filled out the SUS were 30.3 years old on average, ranging from 16 to 45 years. Five of the participants were female and eleven male. The attendees' came from eleven different home countries. Three participants came from Germany and three from the United Kingdom, interestingly only two participants were from Austria. Other home countries were Japan, Brazil, Belgium, Hungary, Spain, Russia, and Switzerland. From the 17 participants who also entered the exhibition rooms only one person stayed less than one hour.

5.3.1 Open Questions

After the participants returned the device, it was first asked how they felt using the application. Remarks and uncertainties of the participants were noted. Additionally, the participants were asked to fill in their age, gender, and country. The questionnaire was available in German and English. To keep the process short, only the three following open questions were asked:

1. *What did you like about the app?*

2. *What did you not like about the app?*

3. *What general comments/questions do you have about the app in its current form?*

The open questions encouraged the participants to talk about the prototype. Besides the users' likes and dislikes regarding the application, and some desired features were mentioned.

Problems mentioned most often were the non-functional scanning function on the top floors and the sometimes failing WIFI connection. Some persons criticized missing artworks or too little additional information. One participant wished a more playful design and said that the application's appeal is "too business-like". For two participants the application was confusing and not self-exploratory.

In contrast, other persons praised the simplicity, the layout of the data or stated that the application is "clear and beautiful". One participant said, "What it does, it does really good". Relating the usage scenario there were different opinions. It was mentioned that the use before the museum visit would be best. In contrast, another person said, "Best is to use it inside the exhibition". Another participant would really appreciate a similar application in other museums.

The most desired feature was the presentation of the artworks per floor. Two participants expressed a wish for a search functionality. Another participant would enjoy it if artworks nearby are presented automatically.

5.3.2 Questionnaire

After the open questions, the participants were asked to rank the application on the backside of the questionnaire. Therefore, SUS (Brooke, 1995) which stands for System Usability Scale, mentioned by Forsell (Forsell & Cooper, 2012) was used. SUS consists of ten statements which should be rated from one for strongly disagree to five for strongly agree. It has shown that this rather short questionnaire suits the museum context very well. Probably more participants would have denied to fill out a longer questionnaire. For German-speaking participants the translation *System Usability Scale (SUS) – An Improved German Translation of the Questionnaire* (Lohmann, 2013) was used.

1. *I think that I would like to use this system frequently*

2. *I found the system unnecessarily complex*

3. *I thought the system was easy to use*

4. *I think that I would need the support of a technical person to be able to use this system*

Questions	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	SUS Score
Aim	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑
Person 1	5	3	5	4	5	1	5	2	4	3	77.5
Person 2	1	4	2	3			1	3	2		40.0
Person 3	2	4	2	4	2	3	1	5	1	4	20.0
Person 4	5	2	4	1	5	2	5	1	5	1	92.5
Person 5	4	1	5	2	5	2	5	1	4	1	90.0
Person 6	3	4	2	2	3	2	4	4	3	2	52.5
Person 7	4	2	5	2	4	1	3	1	3	1	80.0
Person 8	3	1	4	3	3	2	4	2	3	2	67.5
Person 9	4	1	5	5	4	2	5	1	5	1	82.5
Person 10	4	1	3	3	5	1	4	2	4	2	77.5
Person 11	3	2	4	3	4	1	4	2	4	3	70.0
Person 12	5	1	4	1	5	1	5	1	5	1	97.5
Person 13	3	1	4,5	1	5	1	5	1	5	2	91.3
Person 14	2	3	2	4	4	3	2	3	2	3	40.0
Person 15	4	1	5	1	3	1	5	1	5	1	92.5
Person 16	4	1	5	1	5	2	5	1	5	2	92.5
Average	**3.5**	**2.0**	**3.8**	**2.5**	**4.1**	**1.7**	**3.9**	**1.9**	**3.8**	**1.9**	**72.7**

Table 5.1: SUS ratings of the 16 participants

5. *I found the various functions in this system were well integrated*

6. *I thought there was too much inconsistency in this system*

7. *I would imagine that most people would learn to use this system very quickly*

8. *I found the system very cumbersome to use*

9. *I felt very confident using the system*

10. *I needed to learn a lot of things before I could get going with this system*

Four of the participants who filled out the English version of the SUS did not know the word cumbersome, therefore it was described as difficult or a pain to use. As a

consequence, it might make sense to replace cumbersome with a more widespread word. However, the other questions were understood without problems.

According to Bangor, Kortum & Miller (2009) the achieved SUS score of 72.2 out of 100 indicates a good usability. A working scan functionality on the top floors might have improved the result. However, the fact that the prototype was implemented for a diploma thesis might have led to a more generous rating. Bottom outliers visible in the table 5.1 are participants three (20), two (40) and 14 (40). Six participants rated the prototype with a score of 90 or more.

5.3.3 Interaction Log

Besides of a questionnaire, the screen changes and clicks on elements were logged with Google Analytics (Google, 2015). During the test 701 screen changes were made in total, the home screen was accessed 282 times, the gallery 198 times, the dendrogram 111 and the map 110 times. From the 756 interactions with elements like charts or buttons 403 happened at the home screen, 263 in the gallery, 52 at the dendrogram, and 38 at the map. Of those interactions 184 fell on the selection of chart elements, 151 were clicks at artwork images and 80 times the optical character recognition (OCR) feature was used. There was no crash recorded during the app usage.
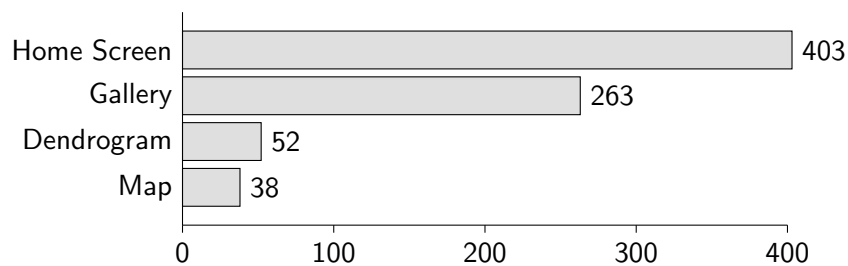
Figure 5.3: Distribution of interactions per screen

These results show that the collection of visualizations on the home screen and the gallery are most important for the users. The fact, that most of the events were about selecting chart elements indicates that casual users do not shy away from using visualizations. However, it is also important to show the artworks directly and provide additional information about them. The scan feature of the label next to the artworks was often used. Some participants mentioned that the feature was not working on the top floors (4.1.8).
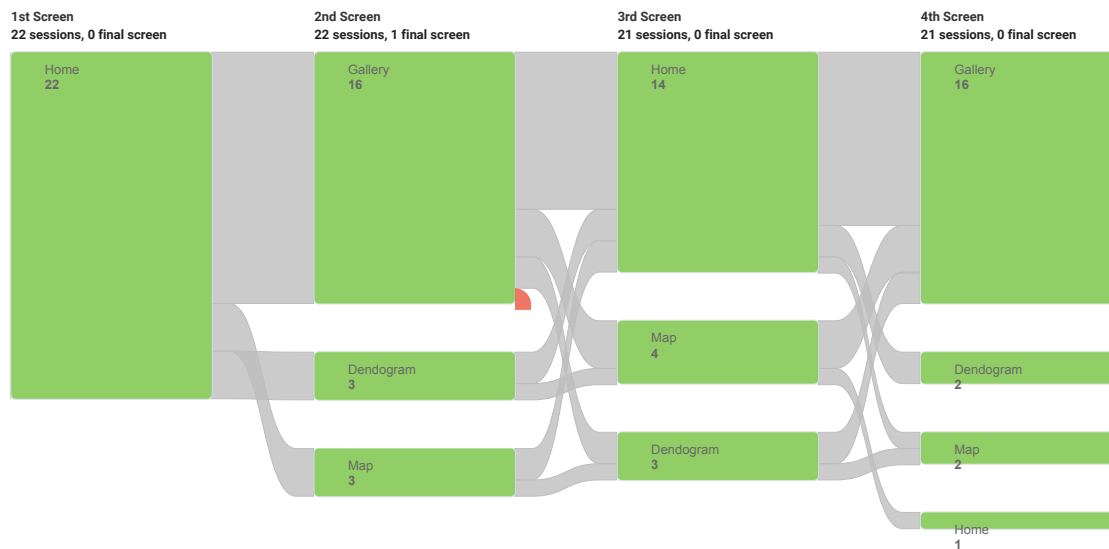
Figure 5.4: Sankey diagram with the behavior flow for the first four screens

The Sankey diagram 5.4 indicates that users were most often switching between the home screen and the gallery. From the started 22 sessions only 3 participants accessed the dendrogram or the map afterwards. The most viewed third screen was again the home screen (14) followed by the map (4) and the dendrogram (3). It reveals that the later interactions are more evenly distributed. For example, the tenth screen viewed was eight times the home screen, the dendrogram or the gallery and five times the map.

Discussion and Future Research

Since the museum and its visitors are a constantly changing, some evaluation's findings might not be generalizable. The mumok, with its collection of modern art, might attract a younger audience than other museums. From a subjective point of view, it seemed that there is a tendency that younger persons liked the application better. Some older participants had problems with the interaction and stated that the application is too complex.

During the evaluation in the museum, some limitations of the visualization application revealed. An issue that particularly occurred for temporary exhibitions, were missing artworks in the dataset. The participants' most desired feature is the presentation of artworks per floor, unfortunately, this data is not available in the open dataset. Instead of a quantitative study to decide which visualization techniques work best, it was mostly instinct driven with user tests between. However, the constraints of mobile devices and the low number of well-known charts by the general public were helpful in the decision process.

The design and implementation revealed that the interaction with the visualization plays a significant role. Through the conducted user tests at an early stage, some major usability issues appeared. Thus, with each iteration of the prototype the quality, increased significantly. Relating to the occurred label scanning issues it would have been wise to conduct a pretest in the museum.

Thankfully, it was easy to establish a collaboration with mumok and they were open for an evaluation. Finding the right addressee played a significant role. The first email was directed to mumok's art education, though the received answer came from the head of technical department and operations. Perhaps, for projects like this thesis, it is better to first get in contact with technology interested persons. An additional possible success factor was the presentation of the prototype's current state in the meetings with the technical head and staff from the art education.

It was tried to keep the effort for mumok as low as possible. Besides of the open source data from ODP and the rental devices, no additional material or installations were required from mumok. This made the outcome more generic and enables an easier adoption for other museums. For example, the label scanning should work in all museums which provide text labels next to the exhibits.

6.1   Answers to Research Questions

Q: *How suitable are mobile devices for visualizing information?*

A: Through the design, evaluation, and implementation of a prototype this thesis has proofed the applicability of information visualization on mobile devices. Concerns regarding the screen size were addressed with design considerations mentioned beyond.

– **Q:** *Which visualization and interaction techniques are working well on the rather small screens?*

– **A:** In general, it has shown that visualizations that scale vertically suit the mobile domain. If an application is vertically scrollable, adding data to a horizontal bar chart or a dendrogram does not require any additional actions. Due to the widespread use of vertical scrolling in applications or on websites, this also helps users to adapt quickly. The ease of use should also be achieved by providing well-known visualization techniques.

Q: *How can visualizations on mobile devices be used in the museum context to support the user's understanding of a specific topic?*

A: For the usage of mobile visualization in the museum it is necessary to bridge the physical with the digital realm. Simplifying the task of information gathering is critical and requires knowledge about the user's context. This thesis demonstrates an approach in which the labels next to the artworks are scanned and processed through object character recognition (OCR). Based on the scanned artist's name corresponding content is displayed on the home screen or in the gallery. Since no installations need to be done a benefit of this approach is the low maintenance effort.

With the used qualitative approach, the question if the developed prototype supports the users' understanding cannot be unequivocally answered. This question would require costly methods like A/B testing. However, some participants were very involved and enjoyed the provided information.

– **Q:** *If and how do visualizations encourage users to explore the museum's exhibits?*

– **A:** The interaction logs of the field study revealed the importance of overview visualizations and images of the objects. Those elements can especially arouse interest at the beginning. The behavior flow 5.4 revealed that after some time users want to access the data from another perspective. This indicates that multiple visual access points are probably encouraging a more extended and exciting usage.

As already stated, for the in-situ use this thesis' prototype implemented tag scanning to provide further information about an artist. Other contributions use scavenger hunts (Rehm & Jensen, 2015), (Rijksmuseum, 2017) to motivate participants for exploration.

6.2 Design recommendations for mobile museum visualizations

Based on this thesis' findings the following key design recommendations were generated. The first five recommendations focus on mobile visualizations in general. The points six to ten emphasize on museum applications.

Recommendations for Mobile Visualization

1. *Start with a design focus on smartphones*: Thus, it is not necessary to remove elements when adapting visualizations for tablet or desktop systems.

2. *Enable standard single finger interaction*: Users probably do not want to learn fancy interaction techniques for a relatively short period of use.

3. *Offer multiple access points*: The all-in-one visualization solution does not exist, different visual representations can communicate various types of information.

4. *Use visualization techniques that scale vertically*: Vertical scrolling is a well-established interaction paradigm in the mobile domain and works fine with content that scales in the y-direction.

5. *Use the device's sensors*: Present the data in the best possible way for example by reacting to orientation changes or by perceiving the user's context.

6. *Present images of the exhibits*: The literature review and field study indicate that pictures of the exhibited objects play an essential role.

7. *Support in-situ and remote exploration*: A combination of both can increase the user's involvement in the presented topic.

8. *Try to capture the user's context*: There are several options to get the user's context, this work for example, introduces label scanning.

9. *Establish collaborations with cultural institutions*: The collaboration between science and museums generates a win-win situation for all.

10. *Conduct tests in the field*: Without knowledge about the field's characteristics, the location's constraints and potential user's needs might be missed.

6.3 Future Work

Future work could elaborate alternative techniques for the in-situ usage. The presented label scanning approach is rather robust, cost-effective and easy to implement, however, it takes a few moments until the museum visitor receives results. Maybe augmented reality solutions where the exhibits are overlaid with visualizations are the way to go.

Another field of work is located in the area of visualization tools and libraries. With most of the available desktop offerings, it is quite easy to display the visualizations on mobile devices. However, for the interaction part, some major problems like the difference between clicking and imprecise touch gestures occurred. Small changes in the available solutions which are mostly open source would simplify the mobile visualization process a lot.

With the decreasing speed of innovation in the development of mobile devices and their operating systems, it might be time for a textbook about mobile information visualization. Ideally, this book should reflect about the design and implementation of visualizations on smartphones and tablets. Additionally, the important interaction part should not be forgotten.

Since museums are often visited in groups, the social component plays a significant role. Future work could focus on this and elaborate methods to enhance the social interaction in the museum context.

Conclusion

Prior scientific work sometimes focused on visualization in the museum context. However, mobile devices like the almost ubiquitous smartphones and tablets were most of the time ignored or not combined with visualizations. This thesis starts with a broad overview of the field presenting 35 papers with the focus on mobile visualization and museum visualizations. Afterwards, in an iterative user-centered process a prototype was designed, implemented and evaluated in the museum.

The conducted field study with 21 participants from eleven countries revealed that the museum context is international, changing and has an audience with diverse targets. These findings correspond with (Hinrichs et al., 2008) and (Rogers et al., 2014) who state that the museum context is characterized by a diverse audience and short, one-time interaction with museum exhibits. In comparison to other studies, the evaluation was conducted directly in the museum where participants explored the collection with the application installed on a tablet. A benefit of field studies is that mainly persons interested in the topic are reached in a real-world setting. After usage, the users answered open questions and a system usability scale (SUS) which indicated a good usability of the visualization. Based on the collected experiences during the design and evaluation, ten design recommendations were collected (6.2).

Due to its generic design, the developed application could be used in a variety of museums with digitalized exhibits. Since text labels are widely used in the museum context, the scanning feature is not limited to mumok. The field of mobile information visualization is still at the very beginning. This is reflected particularly in the sometimes only rudimentary support of mobile devices in visualization tools or libraries. This is revealed to an even greater extent in combination with the museum context. Future research areas mentioned in 6.3 are about improving the in-situ usage, consider the museum's social component, better mobile support of visualization tools or libraries, and the realization of a mobile information visualization textbook.

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