FAKULTÄT
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Tactile Multi-Media Guide

Interaction design on tactile reliefs

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Wien, 18. August 2020

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DIPLOMA THESIS

submitted in partial fulfillment of the requirements for the degree of

Diplom-Ingenieurin

in

Media Informatics

by

Daniela Stoll, BSc
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to the Faculty of Informatics

at the TU Wien

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Vienna, 18th August, 2020

Daniela Stoll	Werner Purgathofer

Erklärung zur Verfassung der Arbeit

Daniela Stoll, BSc

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

Wien, 18. August 2020

Daniela Stoll

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I would also like to say a heartfelt thank you to my family, especially to my Mum and Dad, for always believing in me.

Thank you!

[1]VRVis, Research Centre of Virtual Reality and Visualization, is funded by BMVIT, BMDW, Styria, SFG and Vienna Business Agency in the scope of COMET - Competence Centers for Excellent Technologies (854174) which is managed by FFG. (https://www.vrvis.at/)

[2]ARCHES has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 693229. (http://www.arches-project.eu/)

Kurzfassung

Diese Diplomarbeit war Teil des dreijährigen ARCHES-Projekts. Wir haben uns zum Ziel gesetzt, ein integrierendes kulturelles Umfeld zu schaffen. Der Hauptbeitrag dieser Arbeit ist die Entwicklung eines neuen Tactile Multi-Media Guide (TMG). Der TMG ist ein Interaktionsdesign auf taktilen Reliefs, das Kunst für Besucher mit unterschiedlichen visuellen, akustischen und kognitiven Präferenzen zugänglich macht. Über 200 Menschen mit verschiedenen Behinderungen aus partizipatorischen Forschungsgruppen in London, Madrid, Oviedo und Wien trafen sich in den Museen, entwickelten Ideen, testeten und halfen bei der Gestaltung der Prototypen. Diese Diplomarbeit erstellt einen *Design for all* Mixed-Reality Prototypen, bei dem die Benutzer sechs Kunstwerke mit ihren Händen erkunden und Informationen mit spezifischen Gesten auslösen können. Der TMG stellt Informationen in Form von Audiodateien, Untertiteln, Gebärdensprachvideos sowie Texten zur Verfügung. Es unterstützt auch Besucher mit Lernschwierigkeiten mit einer leicht lesbaren Version. Diese Diplomarbeit zeigt, dass das Erleben von Kunst für jeden interessant und zugänglich sein kann.

Abstract

This thesis was part of the three year ARCHES project. We have set ourselves the goal to create an inclusive cultural environment. The main contribution of this thesis is the development of a new Tactile Multi-Media Guide (TMG). The TMG is an interaction design on tactile reliefs, which makes art accessible for visitors with various visual, hearing and cognitive access preferences. Over 200 people with diverse disabilities from participatory research groups in London, Madrid, Oviedo and Vienna met in the museums, developed ideas, tested and helped shape the prototypes. This thesis establishes a *Design for all* mixed reality prototype, where users can explore six artworks with their hands and trigger information with specific gestures. The TMG provides information in form of audio files, subtitles, sign language videos, as well as texts. It also supports visitors with learning difficulties with an easy read version. This thesis shows that experiencing art can be interesting and accessible for everyone.

Contents

CHAPTER 1

Introduction

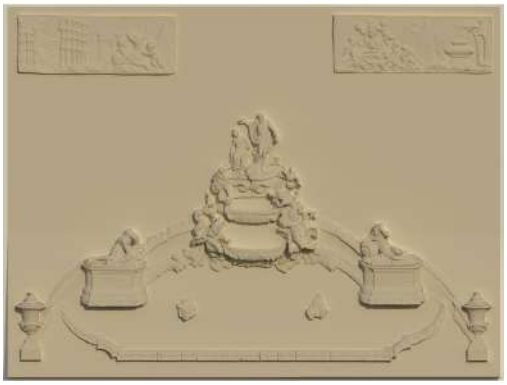
It must be a touching feeling to stand in front of a masterpiece and immerse oneself in all the details, to dive into a sea of colours and figures and scenarios that the artist brings to life. Blind people are excluded from this joy because of the loss of the most important of our senses – but are they really excluded? When art mediators lend their eyes and put their vision and knowledge into words, a picture gradually emerges in the mind that, of course, can never equal the original. Nevertheless, scenarios take shape, moods become receptive and alive - almost as if one could see the picture. In addition, tactile reliefs convey a precise idea of the location of the objects and their relationship to each other. Finally, comprehensive verbal descriptions of the building and tactile graphics help to convey an impression of the location of the gallery rooms, make it easier to orientate oneself and help to become familiar with the surrounding. In this way, even blind people can experience and enjoy the art of painting. However, this overall concept can only succeed if all those involved know which steps are necessary to make a "museum for seeing eyes" accessible and perceptible to blind people as well. The ARCHES project tries to build this bridge of understanding on the one hand in common workshops and on the other hand in individually adapted activities. The tours under expert guidance and together with people who are able to see, but sometimes have other limitations when enjoying art, are like "seeing through the eyes of the others" and do not offer only a very special quality studying a work of art. But these tours also convey a feeling of togetherness and thus broaden the horizon of one's own perception. I therefore consider it as a privilege to be able to contribute a small part to the success of this courageous project.

Eva Papst
Participant of the participatory research group
Kunsthistorisches Museum in Vienna

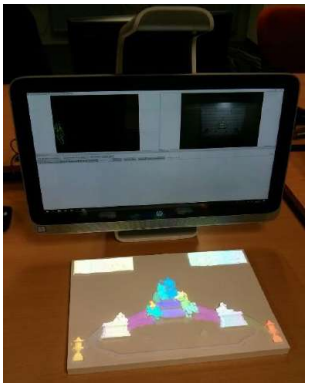
1.1 Motivation and Problem Statement

As part of the *Accessible Resources for Cultural Heritage EcoSystems* (ARCHES) project, six museums and seven research institutions have set themselves the goal of creating an inclusive cultural environment, especially for visitors with various visual, hearing and cognitive access preferences. Blind and visually impaired (BVI) visitors traditionally explore the art in museums using audio guides, live audio described tours or tangible objects.[RCW+18] The Interactive Audio Guide (IAG) in combination with a tactile relief version of artefacts enables BVI people to have a new perception of art objects in museums.[RCW+18, RCT18] The relief conveys spatial information and the verbal description supplements additional information such as colour, distribution, background story and more.[RCW+18] As shown in Figure 1.2a, a 2.5D tactile relief is created by means of a 3D scan and the frontal view and top view of the Meissen table fountain "The Triumph of Amphitrite", Figure 1.1. As illustrated in Figure 1.2, the tactile relief is positioned under the projector, where differently coloured interactive sections are projected onto it. Audio guide content is played when a user interacts with a highlighted section through a single pointing gesture on the relief.[RCT18]

Figure 1.1: Meissen table fountain *The Triumph of Amphitrite* exhibited at the Victoria and Albert (V&A) Museum in London.



(a) 2.5D tactile relief of the Meissen table fountain *The Triumph of Amphitrite*. In the left and right corners are enlarged versions of the reliefs of the left and right stonebases.



(b) Setup of the interactive audio guide (IAG) with the tactile relief under the HP Sprout projector. The coloured interactive sections are projected onto the relief.

Figure 1.2: Tactile relief and Setup

1.2 Aim of the Work

To ensure easy access to all information for people with impairments like BVI or hearing impairments, the IAG's features [RCW+18] will be extended and enhanced with multimedia content.

This thesis will discuss the following research questions, as part of a multi-national and multi-disciplinary research project:

- How to make art accessible for visitors with various visual, hearing and cognitive access preferences?
- How to process multi-media data of selected artwork to ensure access for the audience?
- How to design a user interface to be accessible for the audience?

Planned tasks include designing interactions, their implementation in the audio guide software, and the development of an appropriate data-authoring tool. The IAG was originally developed for BVI people. Further improvement of the combination of IAG and HP Sprout should enhance the experience for people with hearing or cognitive impairment. The integrated touch screen adds multi-media data such as animation, video or sign language to the auditory information playback. In order to adapt the multi-media content to the different needs, the visual representation (user interface, projection on the relief, etc.) has to be redesigned.

The following points need to be considered during redesigning the concept of the IAG for people with different impairments:

- Projection on the relief (variation of the object, filters... etc.)
- Adaptation / simplification of interaction
- Modes for people with different needs
- User recognition
- Make colours perceptible
- Tutorial mode

1.3 Methodological approach

To get a detailed picture of the state-of-the-art, this thesis will discuss similar projects and review the relevant literature, consisting of computer science papers and papers specific to designing for people with disabilities. The core of this thesis will be a design-study following the findings of Reichinger et al.[RCW+18], Palani et al.[PTGG18], O'Modhrain et al.[OGGL15], Blöchl and Götzendorfer[BG17]. As the development of a Tactile Multi-Media Guide (TMG) for people with various disabilities is a relatively new field, information about the provided multi-media data are collected. A prototype implementation is used to evaluate needs and wishes of the participative research group, which represents the future users. With the gathered information, we were able to develop an interaction design. After creating the new concept and a prototype, this thesis utilises a user-driven design approach for further development. At the end of each iteration, expert feedback from the ARCHES participative research group and cooperating museums is gathered, to enhance the visual representations and interactions. The participative research methodology requires that all the newly developed parts be regularly tested with the user groups, so that their specific needs can be addressed. In addition to the feedback received within the ARCHES project, this thesis evaluates feedback about the acceptance and interaction with GUI with other interface studies worldwide.

1.4 Structure of the Work

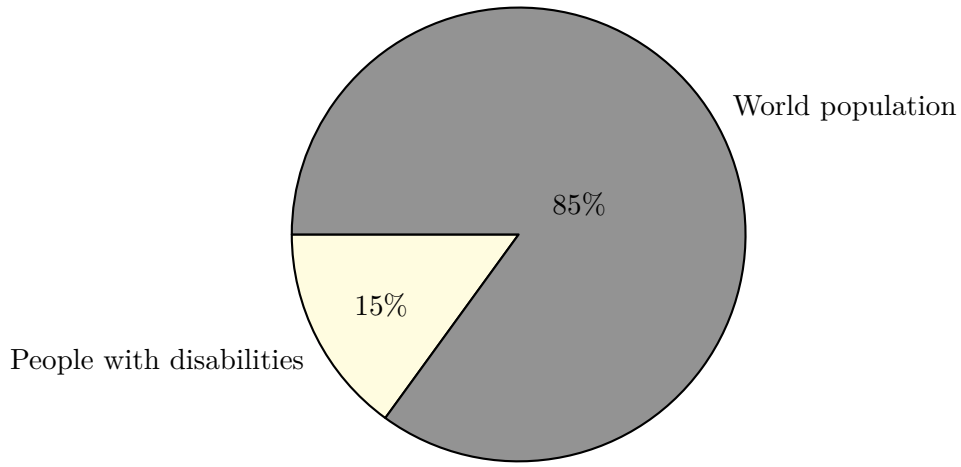
The following Chapter 2 (Related Work) gives an overview of the related work and how it has influenced our design. Chapter 3 (Setup and Data) described the used software and hardware components, as well as how the data is generated, prepared and managed. In Chapter 4 (Tactile Multi-Media Guide) the results are explained in detail. Chapter 5 (Design Process and User Evaluation) explains how our participatory research groups through the design process have tested the application.

CHAPTER 2

Related Work

Disabilities is an umbrella term, covering impairments, activity limitations, and participation restrictions. An impairment is a problem in body function or structure; an activity limitation is a difficulty encountered by an individual in executing a task or action; while a participation restriction is a problem experienced by an individual in involvement in life situations. Disability is thus not just a health problem. It is a complex phenomenon, reflecting the interaction between features of a person's body and features of the society in which he or she lives.

World Health Organization[Org18]



Currently about 15% of the world's population has some form of disability. The rates of disability are increasing due to ageing populations.[Org18]

Disabilities can affect people in different ways, even with the same type of disablement. Some may be hidden (invisible disability). There are many types of disabilities: Vision, Hearing, Thinking, Learning, Movement, Mental health, Remembering, Communicating and Social relationships.[Wor19]

At least 2.2 billion people have vision impairment or blindness. One billion people have moderate or severe distance vision impairment or blindness due to unaddressed refractive error, as well as near vision impairment caused by unaddressed presbyopia, loss of elasticity of the lens of the eye.[Org19]

Visual impairments are not only sight restrictions caused by illness, e.g. cataract (vision through a veil), but can also be inherited, e.g. colour blindness. Colour blindness is not a form of blindness, it is rather a deficiency to perceive colours. The best-known colour deficiencies are red-green and yellow-blue blindness. People affected by red-green blindness have problems with discriminating red and green hues.[Won11, NN11] Yellow-blue blindness impacts the discerning between blue and green hues, as well as yellow and red hues.[Won11, NN11] Monochromacy (total colour blindness) only allows seeing in black and white tones (grayscale).[Won11, NN11]

As our Tactile Multi-Medida Guide was initially started as an artwork *Tactile Audio Guide* for blind and visually impaired people, we collected a lot of data about people with visual disabilities and their museums experiences.[RCW+18, Kha16, CDS] In the follow up project ARCHES our participatory research group consists of people with various disabilities. Through the working process with our participants, the ARCHES team discovered that we want to change the phrase "Design for people with disabilities". We design with and for people with various access needs. This reformulation is connected with the fact that one begins to see the world through the eyes of the participants and connects with them. We want to make the whole museums experience accessible for everybody. Our ARCHES partners published a *How-to-Guide on inclusive activities*: *Towards a participatory museum.*[CDS] More about the participatory research is discussed in the Chapter 5, Design Process and User Evaluation.

We can agree with the colleagues from the *Eye to Ear* project: People with disabilities "want to participate in cultural life just like everyone else. After all, the lasting impression of a visit to a museum is not only created by looking at works of art, but also by the feeling of being physically in a culturally important place, soaking up its aura, perceiving the soundscape or being impressed by the structural size of an exhibition building."[BG17]

The app **Eye to Ear - Gallery of Audible Images**[BG17] shows an excellent example of how visually impaired people can experience art in a new and independent way. The users interact with a touchscreen and get verbal descriptions and sound interpretations of the presented visual art. The Eye to Ear team works together with the *Austrian Association of the Blind and Visually Impaired* to design the app.

Figure 2.1: The Eye to Ear App: The Gallery and an Artwork.[BG17]

Further design research and conversations with our participants, museum partners and experts have drawn our attention to two Austrian organisations. The *Austrian Federation of the Blind and Partially Sighted (BSVÖ)*[BSV] and the *Austrian Association for the Blind and Visually Impaired (Hilfsgemeinschaft)*[Hil] support the following colour concepts, Figure 4.23. The project *Eye to Ear - Gallery of Audible Images* for BVI people, also successfully uses the high contrast two colour (black and white) concept, as seen in Figure 2.1 the left image.[BG17] With their novel sound concept they change the perception of the artworks.

Several studies are concerned with the accessibility of electrical devices for blind and visually impaired people.[PTGG18, OGGL15, BLG15, BG17] Our conducted user evaluation unveiled problems like with navigation through app content or as mentioned above choosing the high contrast two colour concept for better visibility.

Research on data preparation, device handling and user experience has led to guidelines and pitfalls for designing interactive interfaces.[PTGG18, OGGL15, BLG15, CCR$^+$08] In order to be able to ensure accessibility, individual adjustments need to be made.[BLG15] We've considered various access needs and wishes of the participative research group. Therefore, we have evaluated the application with every design iteration and adjustments to the individual settings of the app. A detailed description of the Design Process and User Evaluation is located in Chapter 5.

Museums are full of amazing paintings and sculptures, but it is extremely difficult to create a mental image just from a verbal description. Andreas Reichinger is researching on tactile models for over ten years now. In various publications, he explains the difficulty and importance to create tactile models for blind and visually impaired (BVI) people. Every painting and sculpture has its own design challenges. Important pictorial information must be prepared in such a way that it is easy to understand, but as much information as possible can be conveyed.[RCT18, RCW$^+$18, RMP11, RNR$^+$12] More about the individual steps from high quality original photographs of the painting to a layered depth diagram and the finished 2.5 D tactile relief can be found in these papers: *Designing an interactive tactile relief of the meissen table fountain* [RCT18], *Pictures in your mind: Using interactive gesture-controlled reliefs to explore art* [RCW$^+$18], *Computer-aided design of tactile model* [RNR$^+$12] and *High-quality tactile paintings* [RMP11].

"Tactile reliefs offer many benefits over the more classic raised line drawings or tactile diagrams, as depth, 3D shape, and surface textures are directly perceivable. Although often created for blind and visually impaired (BVI) people, a wider range of people may benefit from such multimodal material."[RCW+18]

The additional texture on the 2.D tactile relief helps to identify various parts and feel more details of the painting like embroideries on the sleeve of the Laughing Cavalier or the "stars" in the sky of the Noche de Frio Espeso. The paper *"Designing an Interactive Tactile Relief of the Meissen Table Fountain"* describes the creation of a tactile relief based on the 3D sculpture.[RCT18]

The master thesis of Khan et al.[Kha16] describes the used design practices of Reichinger et al.[RCT18] to create 3D haptic images out of 2D artworks. Khan et al. uses the Science Technology (STS) learning approach to research "how the users were involved in the process of development, how the context of disability influenced the design process and how the designer overcomes the obstacle of designing for a user group that they are not a part of."[Kha16] The results provided more insight into the user experience and helped to develop the Tactile Multi-Media Guide (TMG).

The project *Designing Interactive 3D Printed Models with Teachers of the Visually Impaired* shows the benefit of using 3D Printed Models to close educational gaps from students with visual impairments.[SLZA19] Through our research, we have both identified the following important points:

- Areas or important segments in 3D objects, or in our case 2.5 D reliefs, must be well distinguished, whether tactile or auditory.
- The combination of auditory and visual processing (like animations) of the content is beneficial.
- An overview description is necessary.

These results support the combined use of 3D objects with multi-media content, instead of the standard number triggered audio guide. An important step in data preparation is the illustrative text description, e.g. "Bird thief: A young lad is climbing the oak tree. He wears red pants and a gray-blue jacket. With both legs he clings to the trunk, so as not to fall down.". As blind people can not touch art, Bartolome et al. [BQK+18] have tried to find a different way to conserve their aesthetics and value. In their work *Exploring Art with a Voice Controlled Multimodal Guide for Blind People* they designed a voice interactive multimodal guide to improve the accessibility of artworks, Figure 2.2.

Figure 2.2: Interactive multimodal guide with 2.5D artwork model and during a test.[BQK+18]

This thesis will not describe in detail the design process of the tactile reliefs and the predecessor project AMBAVis, as well as the software of the Interactive Audio Guide (IAG). More information about the project is published in the following papers:

- High-Quality Tactile Paintings (2011)[RMP11]
- Computer-aided design of tactile models (2012)[RNR+12]
- Gesture-Based Interactive Audio Guide on Tactile Reliefs (2016)[RFMP16]
- Spaghetti, sink and sarcophagus: design explorations of tactile artworks for visually impaired people (2014)[RSL+16]
- Pictures in Your Mind: Using Interactive Gesture-Controlled Reliefs to Explore Art (2018)[RCW+18]
- Designing an Interactive Tactile Relief of the Meissen Table Fountain (2018)[RCT18]
- Tactile Photography: The Routledge Companion to Photography and Visual Culture (2018)[Neu18]

The next Chapter 3 (Setup and Data) described the used software and hardware components, as well as how the data is generated, prepared and managed.

CHAPTER 3

Setup and Data

In cooperation with six museum partners in four cities (London, Madrid, Oviedo and Vienna) of the ARCHES project and the research group participants the following artworks (see Figure 3.1) has been chosen: (title, artist, type of art, period of creation, museum partners, content language).

(a) *The Peasant and the Nest Robber*, Pieter Bruegel the Elder, Painting (Oil on panel), 1568, Kunsthistorisches Museum (Vienna, Austria), German.

(b) *Triumph of Amphitrite (Meissen Table Fountain)*, Johann Joachim Kaendler, Table Fountain made from porcelain, 1745-1747, the Victoria and Albert (V&A) Museum (London, England), English.

(c) *Laughing Cavalier*, Frans Hals, Painting (Oil on canvas), 1624, The Wallace Collection (London, England), English.

(d) *Hotel Room*, Edward Hopper, Painting (Oil on canvas), 1934, Museo Thyssen-Bornemisza (Madrid, Spain), Spanish.

(e) *The Adolescent Savior*, Giovanni Antonio Boltraffio, Painting (Oil on panel), 1490-1495, the Museo Lázaro Galdiano (Madrid, Spain), Spanish.

(f) *Noche de Frio Espeso*, Aurelio Suárez, Painting (Oil on canvas), 1954, Museo de Bellas Artes de Asturias (Oviedo, Spain), Spanish.

The *Peasant and the Nest Robber* (German: *Vogeldieb*) of Kunsthistorisches Museum will be used as an example artwork in further explanations. In order to support the various access preferences such as visual, listening and cognitive, content was specifically prepared and several interaction options were created.

(a) ©KHM-Museumsverband

(b) ©V&A Museum

(c) ©The Wallace Collection

(d) ©Heirs of Josephine Hopper - Licensed by VAGA, New York, NY

(e) ©Museo Lázaro Galdiano

(f) ©Museo de Bellas Artes de Asturias

Figure 3.1: All six selected artworks.

3.1 Technology

The TMG consists of four technology components, as shown in Figure 3.2. The hardware upgrade of the Interactive Audio Guide (IAG) with the HP Sprout and the addition of mutli-media data laid the foundation for the TMG.

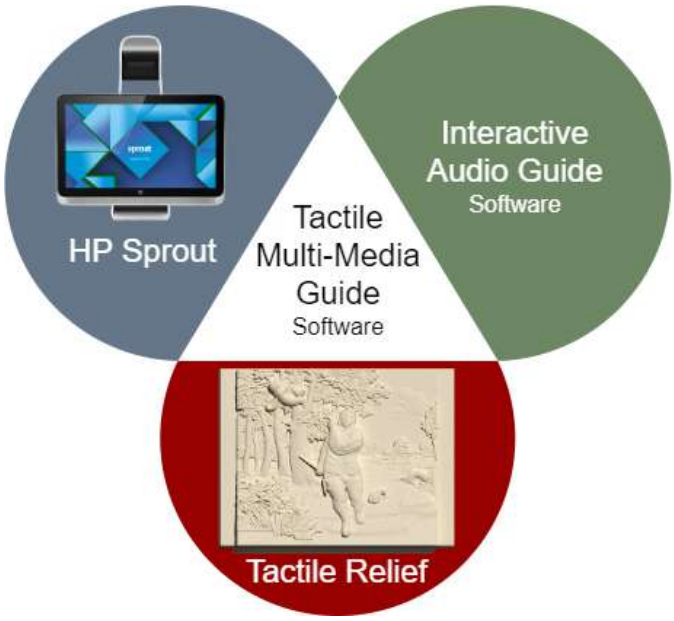


Figure 3.2: Technology Components: HP Sprout (Hardware), Tactile Relief, Interactive Audio Guide (Software) and Tactile Multi-Media Guide (Software).

3.1.1 HP Sprout (Hardware)

The IAG's original hardware setup consisted of a depth camera sensor, a computer and a tactile relief. The sensor was mounted over the relief and transmitted finger gesture data to the computer. The test users received the IAG concept very well.[RFMP16] However, the hardware solution was not suitable in a museum context, because it can be easily knocked over or moved by visitors. A more stable kiosk installation was found in the HP Sprout, so-called *Sprout* (Figure 3.4b).

The Sprout not only combines a computer with the depth sensor, but also has a projector, camera and scanner. With the integrated projector, the sprout has dual interactive screens: a 23-inch touch monitor (1920 x 1080 pixels) and the 20-inch projection screen (1024 x 768 pixel). The 23-inch touch monitor acts as an interactive TMG Graphical User Interface (GUI). The functions and interaction options of the TMG are described in more detail in Chapter 4. Under the 20-inch projection and the depth sensor lies the tactile relief. Various representations of the original painting can be projected onto the tactile relief.

3.1.2 Tactile Relief

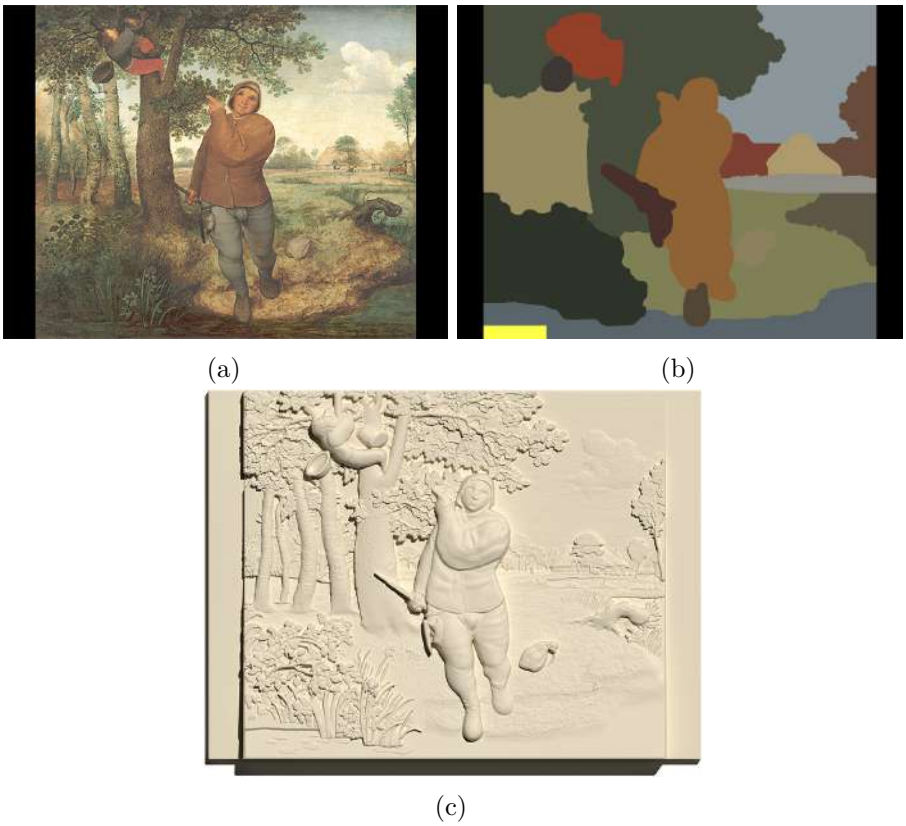


Figure 3.3: (a) Original artwork (*Vogeldieb* ©KHM-Museumsverband), (b) separated areas, so-called *sections* and (c) the 2.D tactile relief. (a) and (b) if the original is not the same proportions as the relief, the difference is filled in black.

Based on the research of Andreas Reichinger, outlined in Chapter 2 (Related Work), a development process has been established. Additionally he researched about different materials for better tactile sensitivity and durability of the tactile reliefs.[RSL+16] All six Museum received a relief, milled from Corian, of their selected painting. Figure 3.3c is showing the tactile relief of *The Peasant and the Nest Robber*. The other museums each received a copy in plaster. Thus, all participants were able to evaluate, improve and research the resulting reliefs. During the various test sessions in mid-2017, we observed that the participants keep shifting the relief, so that the reliefs have to be fixed to the table via tape. This observation and the TMG as a kiosk installation in a museum led to the development of a wooden frame, see 4.4. The frame stabilises the reliefs and encloses the sprout, so it can be mounted as one installation. In the course of the frame development, we have decided to design all reliefs in the same size: 40 cm width and 30 cm height and a depth of 10 mm base with an additional 25 mm dynamic depth to mill the relief. The uniform size, physically within the wooden frame and digitally, of the

tactile reliefs improves the calibration and the gesture recognition, which among other things prevents the moving of the tactile reliefs during use.

(a) Interactive Audio Guide (IAG)

(b) Tactile Multi-media Guide (TMG)

Figure 3.4: Hardware setup with IAG (left) and TMG (right) design. IAG with the projected sections of the Original sculpture Table fountain. TMG with the original artwork (*Vogeldieb* © KHM-Museumsverband) projection on the tactile relief. Settings has been selected.

3.1.3 Interactive Audio Guide (Software)

The Interactive Audio Guide, short IAG, is a gestured-based audio guide.[RCW+18] In combination with information provided by the camera of the HP Sprout the IAG calculates the touch interactions with the relief. It gives interaction audio feedback and information about the touched part of the relief in text form and plays a specific audio file.[RCW+18] Changing the hardware to the HP Sprout with its big touch monitor user liked the debug screen, see Figure 3.4a, on the monitor they saw during the various test sessions in 2017. Since our participants consist of 150 people with different access needs, we (participants, museums partner and our team) decided to improve the user interface of the IAG to the TMG, see Figure 3.4b.

3.1.4 Tactile Multi-Media Guide (Software)

The Tactile Multi-Media Guide, short TMG, is a combination of a *design for all* approach and a *user-centered design* approach. The TMG encourages exploring reliefs and learning more about the displayed painting. Its improved user interface allows people with different access requirements to provide information for a specific user need. The TMG is developed with our participatory research groups, which consist of people with differences and difficulties related to perception, memory, cognition and communication. Due to the various access preferences and the data extension like audio, video, 3D models and animations we decided to change framework. Our technology partner Coprix used the game engine Unity to develop their game. Since they had a good experience during their prototyping process, we changed framework from the graphical subsystem Windows Presentation Foundation (WPF) to Unity at the beginning of 2018. The resulting design concept and its function are described in Chapter 4.

3.2 Multi-media data

In cooperation with the museum partners, each artwork is divided into areas, so-called *sections*. The area delimitation depends on the points of interest of the painting, e.g. figure in a landscape or hairs of a head. A section should be at least as large as a fingertip to ensure correct touch calculation on the relief. Each section has a distinct colour, see Figure 3.3b. Each colour should be clearly distinguishable from the others and is derived from the original, if possible. Five extra sections have been created to provide additional information about the painting, the artist and other interesting information. They can be accessed via the touch screen.

A description was written for each section, under the following conditions:

- The average time of spoken text should be between 10 and 45 seconds to ensure easier access for the audience. The five additional information sections are longer, approximately between 60 to 110 seconds.
- It is very figuratively formulated to create a better imagination and helps uncover details that are not visible at first glance. An example is: *"Bird thief: A young lad is climbing the oak tree. He wears red pants and a gray-blue jacket. With both legs he clings to the trunk, so as not to fall down. Concentrated, he looks at a bird's nest in a branch fork. With a sure grip he already holds one of the three young birds in his fist."*

The content of each artwork is available in the main language of the country of the museum, where it is exhibited, as well as its *easy read* language for people with learning difficulties and disabilities. The *easy read* language differs among other things by the use of a simpler vocabulary and sentence length and structure. The Sub-chapter 4.2.5 (Language) shows an example. The Tactile Muli-Media Guide (TMG) also supports sign

language for each painting. As part of this thesis, sign language content for the easy read version has not been implemented.

3.2.1 Data types, data generating and management

A multitude of data is generated and integrated by the TMG:

- Text
- Audio (section and gestures-sounds and pluggy)
- Subtitles
- Video (animations and sign language)
- Animation (2D image animation, camera movements)
- 3D models (relief models)

Text, audio, subtitles, video are loaded into the application at runtime. Short 2D image animations, like flying birds in the background or a hat falling down to the ground, are generated for each painting. As we have a high quality image of the "Bird thief" painting, the camera zooms into the farmhouse to show detailed information that is explained in the audio and text. As we have modelled the painting in a 2.5D relief, we have included the 3D model of the relief in the second view (on relief projection). A pointing finger hovering over the relief acts now as a light source (torch), which casts shadows over the 3d model and so over the actual relief, see Figure 4.2b.

As the TMG incorporates a variety of data: text, audio, subtitles, video, images, animation, 3D models, we developed a content description file format, so-called *Painting metadata model*, to access and store the section content, e.g. texts and subtitle information in each language.

The *Painting metadata model* describes how the data of each painting is formatted. Each Painting consists of at least two *SectionGroups*, *Intro* and *Others*. Every *SectionGroup* must have at least one *Section*. The *Intro* must have at least seven *Sections*. The *Intro* stores the basic information (e.g. title and artist) as well as the additional information of the exhibited artwork. The *Others* must have at least one *Sections*, depending on the partitions of the painting. The example painting "Bird Thief" has 18 sections in *Others*.

Each *section* must have one *Language* assigned. A *Language* must have one *Multilanguage*. The amount of *Multilanguage* is determined in the *LanguageDict* in the *Painting*, see Figure 3.5. The *LanguageDict* of the painting *BirdThief* offers two languages *Deutsch* (German) and *Deutsch (einfache Sprache)* (German (easy read)). In the case of the painting *Bird Thief* every section must have two *MultiLanguage* (Figure 3.6). The section *Signature* can be identified by the attributes *Name* and *Color* (r,g,b). *Languages* includes the two-mentioned *MultiLanguage*: *GO* (German) and *G1* (German (easy read)). Each

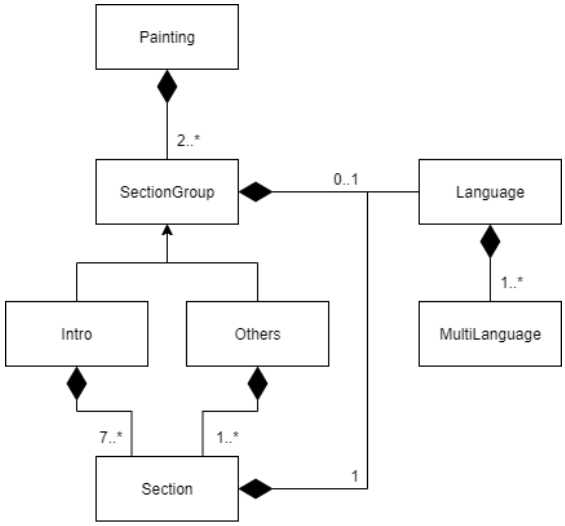


Figure 3.5: The domain model of the *Painting metadata model*.

Language contains the *Title*, *Body* and *SubtitleSentenceStarts* for this section. *Title* holds the name in each language and *Body* the description of the section. For the subtitles for the specific section audio file *SubtitleSentenceStarts* holds the beginning of an sentence or a line break for long sentence in the format "mm:ss.SSS" (minutes:seconds.miliseconds) and are separated with a comma.


```
"Signature": {
    "Name": "Signature",
    "Color": "253,255,72",
    "Languages": {
        "G0": {
            "Title": "Signatur",
            "Body": " In der Ecke links hat Bruegel das Gemälde in Goldfarbe signiert und datie
            ist in römischen Ziffern geschrieben: MDLXVIII.",
            "SubtitleSentenceStarts": "00:00.000,00:07.468,00:10.721,00:14.863,00:18.240"
        },
        "G1": {
            "Title": "Signatur",
            "Body": " In der Ecke links unten stehen der Name des Künstlers und eine Jahreszahl
            alt.",
            "SubtitleSentenceStarts": "00:00.000,00:12.068,00:15.634,00:21.293,00:25.628"
        },
    }
},
```


Figure 3.6: An extract from the JSON-file of the painting "Bird thief", the section "Signature".

Each painting has its own JSON-File ".json" (JavaScript Object Notation [Cro18]), which is parsed with the *Painting metadata model* (Figure 3.5). Figure 3.7 shows an extract from the JSON-file of the painting "Bird Thief", with collapsed section content.

In addition to the section information, the JSON-File also includes the following attributes:

- *Name*: Specific name to identify painting. The JSON-File must have the same name as declared.
- *CopyRight*: Textual copyright information for the painting image displayed on the monitor user interface.
- *AudioSequence*: Corresponds to the audio sequence when a section is selected. "OK", "Noise" and "Stop" are general audios for audio feedback. You can hear one beep by "OK" and a double beep by "Stop". "TitleAudiofile" plays the title audio file, same name as section, and "BodyAudiofile" the description audio file, same name as section and "_Text". If the title and the description is only one file it has the name of the description and is played in the "TitleAudiofile" spot, the "Noise" and "BodyAudiofile" will be skipped, Sub-chapter 4.1.
- *AudioSequenceGeneral*: This general audios being loaded at the start of the TMG.
- *LanguageDict*: The languages a user can choose from.
- *ButtonAreaSections*: Which additional information can be accessed, Sub-chapter 4.2.6.
- *SectionGroups*: As already mentioned a painting consists of two *SectionGroups*, *Intro* and *Others*.

Data generating
The museum partners collected information about their paintings, as they would do for a normal audio guide. Together we have divided the painting into sections and prepared texts for each section. The content and the size of the sections were taken into account, as the sections must be at least a little bit bigger as a fingertip. Sections with no relevant information available were combined with other parts of the painting or split up into more sections, if there is interesting information. This process went through several iterations and was evaluated several times with our participants. Participants pointed on parts of the paper printed paintings or on the relief then someone read the corresponding text to them, as well as the additional five information about the painting. The testing feedback, the experience of our museums partners and our own created a illustrative textual description. The resulting text was recorded as audio and sign language videos. For each available language offered, each section content consists information in text, audio and sign language. Figure 3.3b shows the final sections of the painting "Bird Thief".

```
{
        'Name': 'BirdThief',
        'CopyRight': 'KHM-Museumsverband',
        'AudioSequence': ["OK", 'TitleAudiofile', 'Noise', 'BodyAudiofile',
            "STOP"],
        'AudioSequenceGeneral': ["OK", "Noise", "STOP", "hoverBorder", "
            hoverTouch", 'hoverUp"],
        'LanguageDict': {
                "G0": 'Deutsch',
                "G1": 'Deutsch (einfache Sprache)'
        },
        'ButtonAreaSections': ['AboutTheArtwork', 'AboutTheArtist', '
            TheArtistAndHisPainting', 'InterpretationOfThePainting', "
            XRayPhotograph'],
        'SectionGroups': {
                'Intro': {
                        "Name": 'Intro',
                        "Sections": {
                                'Tutorial': {
                                'PaintingName': {
                                'Artist': {
                                'AboutTheArtwork': {
                                'AboutTheArtist': {
                                'TheArtistAndHisPainting': {
                                'InterpretationOfThePainting': {
                                'XRayPhotograph': {
                        }
                },
                'Others': {
                        "Sections": {
                                'Signature': {
                                'Brook': {
                                'PlantsByTheBrook': {
                                'FourBirches': {
                                'TheOak': {
                                'BirdThief': {
                                'HatOfTheBirdThief': {
                                'Poacher': {
                                'EquipmentOfThePoacher': {
                                'WetShoeTipOfThePoacher': {
                                'BurlapSack': {
                                'Landscape': {
                                'Pond': {
                                'BrookAndPasture': {
                                'Farmhouse': {
                                'FarmersWifeWithPitcher': {
                                'Barn': {
                                'Sky': {
                        }
                }
        }
}
```

Figure 3.7: Extract from the JSON-file of the painting "Bird Thief", with collapsed section content.

Data management
The first prototype implementation in the previous project AMBAVis was only targeted at a single relief "Gustav Klimt's - The Kiss", for demonstration purpose.[RCW+18] In ARCHES we built on this prototype and opened it up for more paintings. Therefore, we changed the content management from hard-coded to load on demand.

We developed a content description file format (JSON and Painting metadata model) and a folder structure for the content, and started implementing a first version of an authoring tool, that allows creating the description file and folder structure for the reliefs.[RTS+19] The authoring tool is explained in detail in the Appendix, Authoring Tool 6.2. The Table 3.1 shows a content overview of the six supported artworks.

Artwork	**Sections**	**Language** with easy read version	**Animations**
The Peasant and the Nest Robber	18	German	12
Triumph of Amphitrite (Meissen Table Fountain)	21	English	21
The Laughing Cavalier	15	English	9
Hotel Room	22	Spanish	4
The Adolescent Savior	7	Spanish	5
Noche de Frio Espeso	10	Spanish	6

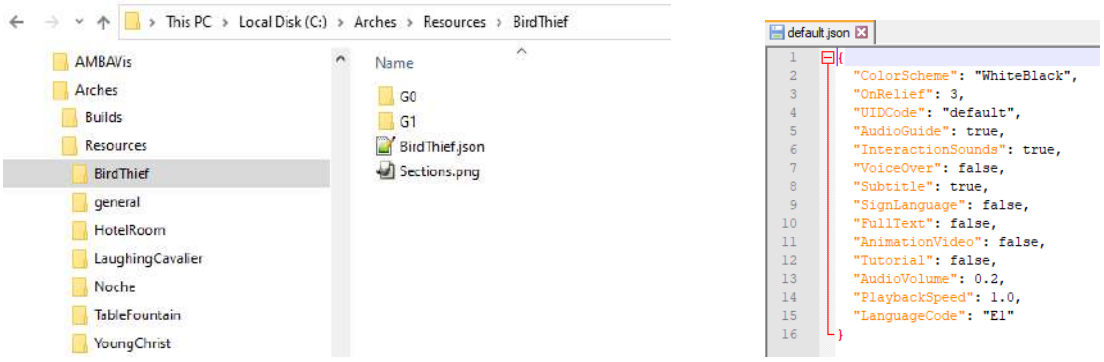
Table 3.1: Overview of the six supported artworks. Every artwork has five additional artwork information (e.g. artwork, artist...). Sign Language videos are provided for every main language for each artwork.

Another change happened at the early second quarter of 2018, as the currently called Tactile Audio Guide (TAG) extended from blind and visually impaired users to people with various access needs. For this reason, importance was placed on the implementation and polishing of the new named Tactile Multi-Media Guide (TMG), as well as the integration of the (multi-media) data. The further development of the authoring tool was on hold, instead Excel spreadsheets were used, which were converted into JSONs. We have chosen Excel spreadsheets for the following reasons:

- Usage of many people with different technological background
- Facilitated data transfer to external companies by museums partners
- Fast adjustments and additions for multi-media data expansions

The combination of the *Painting metadata model*, *JSON*, *Excel spreadsheets* supports loading a lot of data at run-time, as well as making quick adjustments without creating a new build. Figure 3.8a shows how the resources are stored in the folder hierarchy.

Each painting has its own folder. The JSON-File and the folder must have the Painting mentioned in the JSON-File. Also each painting folder as an image "Sections.png" of the coloured sections. For each provided language there is a folder with its abbreviation, "G0" (German) and "G1" (German (easy read)). The language folders contains the audio and video files loaded at run-time.



(a) (b)

Figure 3.8: (a) Resources folder hierarchy with selected example painting "Bird Thief". (b) Default user settings JSON-File.

The "general" folder stores the general audio sounds ("OK", "Stop", etc.) and the user settings as JSON-Files, Figure 3.8b. The default user settings are loaded at the software start or after three minutes with no user interaction. After starting the software a first selection window appears, where each museum partner can choose between all six paintings and their provided languages. Each museum can choose their default user settings, among others paintings and language. User Accessibility Settings (Sub-chapter 4.2.5) are stored in the user settings. Via QR Codes different user settings can be loaded, Sub-chapter 4.2.5 and Figure 4.21. At the moment there are a few example user settings for different access needs. Furthermore, we have created six more QR Codes that support the exchange of paintings at run-time. QR Codes can be activated by holding them under the projector and over the relief.

The next Chapter describes how the hardware and software components process the multi-media data in order to experience the paintings through interaction with special manufactured reliefs. The old numerical audio guide was updated with an explorative design of the Tactile Multi-Media Guide.

CHAPTER 4

Tactile Multi-Media Guide

Interaction design on tactile reliefs

This Chapter explains the design and functions of and the interactions with the developed Graphical User Interface (GUI) and the existing advanced interaction system, Interactive Audio Guide (IAG). In the last years, we developed the following user interface over several design cycles with the ARCHES participatory research groups. The initial goal of the project was to make art accessible for blind and visually impaired people. Since the participatory research groups consist of users with many different visual, hearing and cognitive access preferences, the existing design has been adapted to cover them all. The TMG design follows the exploratory approach.[Bra06] More details about the design process and the user evaluation can be found in Chapter 5.

The participant group had specific wishes for the Tactile Multi-Media Guide (TMG), as each participant has a special access needs to the information, acoustic, visual and haptic. Our focus was on a simple design that could easily be adapted to the various needs of the users. Information about the currently displayed artwork can be retrieved as audio file, text box or sign language video. Further information on the different access modes is provided under 4.2.

Every user should be inspired to explore the exhibited artwork by touching the tactile relief. To ensure the access for all users, several interaction possibilities were developed and optimised through the design process.

4.1 Interaction

After selecting the exhibited artwork and the language for the provided content, the user can start exploring the relief.

Gesture-based Audio Guide for BVI users

The TMG is a further development of the IAG.[RCW+18] Detailed Information about the software and hardware setup, see Figure 3.4, and the multi-media content is provided in the Chapter 3. The IAG gave an acoustic feedback about the interaction and the distribution of the information on the tactile relief in real time. However, during tests, participants could get visual feedback on their interactions on the debug screen. This leads to, based on the wishes of the users and the museums, the visual part was further explored and an advanced GUI design concept was developed, the TMG.

The participants liked the existing interaction system from the IAG. The IAG software calculates the relief interactions and provides the TMG with the corresponding results.[RCW+18] In general, we distinguish between following interaction options:

- On- and Off-Relief Gestures
- Screen Interaction

On- and Off-Relief Gestures

(a) On-Relief Gesture: Pointing finger

(b) Off-Relief Gesture: Fist

Figure 4.1: On- and Off-Relief Gestures with the HP Sprout setup and the 2.D tactile relief.

User interactions with at least one hand on the tactile relief are called *On-Relief Gestures*, see Figure 4.1a. In order to play and view information on individual regions, the so-called *sections* of the artwork, the user touches the desired section on the tactile relief with a pointing gesture, see Figure 4.2b. Hands should not touch each other.

We wanted to give a visual interaction feedback for the user on the relief. If the index finger lies on one section, the other sections are blacked out, see Figure 4.2a. The highlighted poacher in the middle of the painting is now selected.

A hoovering index finger also acts as a torch, which casts a shadow on the relief, see Figure 4.2b. The casting of shadows makes the relief livelier and supports the 2.5D depth design of the tactile relief.

(a) TMG system output.

(b) On tactile relief with pointing finger.

Figure 4.2: Relief projection of the selected section *Wilderer* (poacher) and other sections are blacked out.

Acoustic feedback for on-relief gestures is provided in these situations:

- no section touched,
- pointing finger is between two or more sections,
- a section is touched,
- hands are outside the relief.

When a section is selected the audio information with audible feedback is played in the following format: at the beginning the user hears a start sound "beep", the title of the section, then the detailed information, and finally a stop sound "double beep".

Off-Relief Gestures take place between the tactile relief and the projector, see Figure 4.1b. The so-called *Off-Relief Gestures* are gestures that are not executed directly on the relief. The user holds his hand between the tactile relief and the projector, see Figure 4.1b. With these gestures the user can e.g. interrupt the audio playback at any time by holding a fist above the re lief (an off-relief gesture) and under the projector, as seen in Figure 4.1b, or by directly starting another audio with a pointing finger gesture detected (on-relief gesture) on another section of the relief or interacting with the screen.

Screen Interaction

Since we use an HP Sprout with included touch screen, we are able to use the GUI as an interaction option, see Figure 4.3. The screen also functions as a temporary button bar. The entire user interface design has been developed in a way, which allows the button bars left and right, see Figure 4.3 and Figure 4.5, to also be included as physical button bars left and right of the relief in the future wooden frame. The Figure 4.4 depicts the first physical prototype of the future wooden frame setup. As every participatory research group had access to the Tactile Multi-Media Setup (hardware and tactile reliefs), each design iteration could be tested regularly. The following Chapters describe the structure and functions of the GUI of the TMG and its design process.

Figure 4.3: TMG with the original artwork (*Vogeldieb* ©KHM-Museumsverband) projection on the tactile relief. The Settings Menu has been selected via touching the button on the top right corner.

Figure 4.4: Tactile relief with original projection (*Vogeldieb* ©KHM-Museumsverband) with a wooden frame.

4.2 Graphical User Interface

The main goal of the new Graphical User Interface (GUI) was to create a design that is both visually and functionally appealing to all user groups. Special attention was paid to the needs of BVI people and people with learning disabilities and disorders, since they need a more considerate design. For people with learning disabilities is reading the primary area of difficulty.[KH11] As the need to focus harder on one thing, additional animation on the screen leads to a lack of concentration. For this reason, the TMG is designed without moving interaction elements (like sliding in button areas). Only in the Highlight of the Info Area simple animations of the original artwork are played. This setting can be deactivated via the Animaton toggle in the Accessibility Settings.

As mentioned earlier, one of our main user groups are people with visual impairments. The original project developed an interactive audio guide for tactile reliefs, the IAG (Chapter 2). In the design process, attention was paid to a high contrast design for better perception with impaired vision. High contrast can be achieved by simplification. This simplified design raises new challenges like visual hierarchical structures or colour schemes. Visual hierarchy is created by the visual contrast between forms in a field of perception.[Rod16] Here are some common tools to create hierarchy in design: *Size, Position, Negative space, Colour, Contrast, Repetition and Alignment.*[Rod16] This design guideline, as well as design guidelines for people with visual impairments, were considered, reviewed and questioned.

As seen in Figure 4.6 the user interface is split into six areas. Five of these six areas have a rectangular shaped background to visually distinguish form the others, Figure 4.5. The sixth area (Info Area) is the largest area and contains the more important information. Due to its size, it attracts the attention of the user. This area displays information about the audio guide at run-time, depending on the user's needs.

Figure 4.5: High contrast two colour (black and white) Tactile Multi-Media Guide GUI-Design with the selected painting *Vogeldieb* ©KHM-Museumsverband.

Figure 4.6: Overview of the Screen Layout

The TMG graphical user interface follows a two colour concept (e.g. black and white), except for the representation of the original artwork in the middle of the screen. This high contrast design supports a better visual perception for people with visual impairment.[BG17] With its simple design, it should be visually appealing to all users. Design guidelines from other research projects, as well as consultation with experts have led to this design concept.[BG17, PTGG18, OGGL15, BLG15]

As the TMG should in the future function as a standalone kiosk version in a museum, it was important to us that users could use the TMG with its new design as independently as possible. Thus, after several tests with the participatory research groups and in consultation with the museum partner, we agreed upon the finished GUI design, as can be seen in Figure 4.5.

The screen layout is divided into the (button) areas listed below, which can beseen in Figure 4.6:

- Tutorial (Orange)
- On Relief Projection (Red)
- Object Label Area (Black)
- Info Area (Blue)
- Settings (Violet)
- Additional Artwork Information (Green)

The HP Sprout has a 23-inch touchscreen monitor with a resolution of 1920 x 1080 pixels. The resulting touch area is 51 cm wide and 29 cm high. This sizeable touch area allows us to make the buttons large compared to buttons in similar apps on tablets. A round button covers an area of two by two centimetre on screen and is therefore large enough to be easily operated by people with thicker fingers. Larger buttons can also be seen well by people with impaired vision.

The interactive Tactile Multi-Media Guide (TMG) GUI consists of three different user interface elements - buttons, toggles, sliders.

Buttons indicate an action upon touch. They are typically labelled using texts, icons, images or a combination, as seen in Figure 4.7. There are three different shapes of buttons in the TMG GUI - round, rectangular and irregular. Round shaped buttons are the *Tutorial, On Relief Projections, Settings, Additional Artwork Content*, as well as the *Colour Scheme* buttons in the Settings Menu. The Object Label Area button, the OK-Button and the Credits-Button in the settings are rectangular shaped.

The *Highlight Subarea* within the *Info Area* contains irregular shaped buttons due to the boundaries of the diverse areas of an artwork. Contrary to the rectangular and irregular shaped buttons, the round buttons as well as the toggles are immediately recognisable as interface interaction options.

Figure 4.7: Example buttons used in the GUI. From left to right: Round button with text (Tutorial), selected round button with icon (Settings), image button (On Relief Projections), round button with text and icon (Additional Artwork Information), round button with an example letter "A" (Colour Scheme) and a rectangular button (OK-Button).

Toggles are a special type of buttons and belong to the input controls group. They allow a user to change a setting between two states - on and off. Due to the design concept, we only use the radio buttons with a description text next to it, see Figure 4.8. Toggles are only used in the Settings, as seen in Figure 4.20. In our case, toggles allow the user to select one or more needs as Voice Over, Audio Guide or Sign Language. It is not possible to activate Full Text, Subtitle or Sign Language at the same time, as they change the visual representation of the Info Area. The same applies to the language selection, since only one language can be selected.

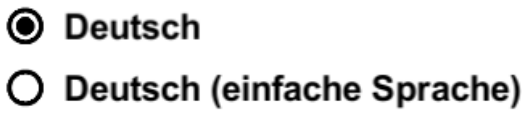


Figure 4.8: Example toggles used in the GUI. Language select options. The top toggle shows the selected Language *Deutsch* (German). The toggle are designed as radio buttons due to the round button GUI design concept.

Sliders belong to the navigational components group. Two different sliders - horizontal and vertical - are integrated in the GUI. The horizontal sliders are used in the settings for volume and playback speed to adjust their value. For visual feedback, the value above the respective slider is set with the slider adjustments, as seen in Figure 4.9. The vertical sliders are used for scrolling, in case the text information is too long for the text field in the *Full Text* Subarea, thus visually truncated.

The following pages explaining the graphical user interface and its interaction in detail.

Figure 4.9: Example slider used in the GUI. Slider with round handle due to the round button GUI design. Starts in the middle. On top there are two texts explains what can be changed - *Lautstärke* (Volume) - and the adjusted value - *0.5*.

4.2.1 Tutorial Area

The *Tutorial Button* is located in the upper left corner of the touchscreen, see Figure 4.6 in orange.

Figure 4.10: Tutorial Button

The tutorial can be activated by touching the *Tutorial Button*, see Figure 4.10, or plays every three min without any user interactions with the TMG. To make the Tutorial accessible for as many people as possible we decided to cooperate with our project partner Sign Time. Sign Time is an innovative company trying to enable communication between hearing and deaf people. During the ARCHES project, Sign Time has developed a Sign Language Avatar, as seen in Figure 4.11. To fit the requirements of the sign language video (1250 signs including blanks), we wrote the text for the tutorial first in German. During the formulation of each sentence, our main user groups - BVI people, people with learning disabilities and deaf people - were taken into account. We then discussed this text with trained museum staff from Vienna and Madrid and the research associate. Native speakers translated the text to English and Spanish.

The final English, German and Spanish tutorial text can be read below:

Hello and welcome - experience art in a new dimension! You can skip or repeat this tutorial at any time. Just click on the button in the upper left corner of the touchscreen. Explore the relief with your hands. Find general information about the artwork and its artist. Use the buttons 1-5 on the right hand side of the screen. For detailed information of individual parts point at them on the relief. Use only one finger while pointing. Make sure that your hands don't touch. You can get detailed or general information as audio, text or sign language video. To choose your preference, click on the button in the upper right corner of the touch screen. To stop the playback of a content, please make a fist. Lift the fist halfway between the relief and the projector. You can also select a new detail of the relief at any time without waiting for the end of the information. Change the projection on the relief by pressing one of the five buttons on the left side of the touchscreen. Have fun exploring the relief!

Herzlich willkommen - Erleben Sie Kunst in einer neuen Dimension! Sie können die Anleitung jederzeit überspringen und wiederholen. Klicken Sie einfach auf die Schaltfläche in der oberen linken Ecke des Bildschirms. Ertasten Sie das Relief nach Belieben mit Ihren Händen. Sie erhalten Informationen zum Kunstwerk und seinem Künstler. Dazu verwenden Sie die Schaltflächen 1-5 auf der rechten Seite des Bildschirms. Für detaillierte Informationen zeigen Sie auf einzelne Teile des Reliefs. Verwenden Sie zum Zeigen nur einen Finger. Dabei sollten sich Ihre Hände nicht berühren. Diese Informationen können Sie als Audiodatei, Textinformation oder als Video in Gebärdensprache abrufen. Um die gewünschte Einstellung zu wählen, klicken Sie auf die Schaltfläche in der oberen rechten Ecke des Bildschirms. Um die Wiedergabe eines Inhalts zu stoppen, machen Sie bitte eine Faust. Halten Sie die Faust in der Mitte zwischen dem Relief und dem Projektor. Sie können jederzeit ein neues Detail des Reliefs auswählen, ohne auf das Ende der Information zu warten. Auf der linken Seite des Bildschirms finden Sie fünf Schaltflächen. Mit diesen werden Bilder auf dem Relief sichtbar.

¡Bienvenidos! Descubre el arte desde un punto de vista diferente. Puedes saltar o repetir este tutorial en cualquier momento. Simplemente, pulsa en el botón de la esquina superior izquierda de la pantalla táctil. Puedes tocar el relieve con las dos manos. Para encontrar más información sobre la obra de arte, pulsa en los botones numerados del 1 al 5 en el lado derecho de la pantalla. Toca con un dedo cada una de las partes del relieve para obtener información detallada. Evita que tus dos manos se toquen. Puedes recibir esta información en audio, texto escrito o video en lengua de signos, según la configuración que elijas. Para cambiar la configuración, haz clic en el botón de la esquina superior derecha de la pantalla táctil. Si quieres parar el contenido, levanta tu puño entre el relieve y el proyector. Puedes seleccionar una nueva parte del relieve en cualquier momento. Para cambiar la proyección sobre el relieve pulsa los 5 botones en el lado izquierdo de la pantalla. ¡Disfruta del relieve táctil!

To introduce the currently displayed artwork to the BVI users the artwork title and the artist audio is played, after the tutorial has finished. To replay the artwork title and the artist audio users can click on the Object Label Area, Sub-chapter 4.2.3, located next to the tutorial button, at any time.

By clicking the tutorial button, the tutorial can be to stopped, skipped or activated. If the tutorial is activated, other playing content will be stopped and the tutorial button changes its colour to grey. As you can see in Figure 4.11, the Info Area, Sub-chapter 4.2.4, in the middle of the GUI, the blue coloured area in Figure 4.6, also has been replaced with the sign language avatar video and the Subtitle on the bottom. For BVI users and users with learning difficulties, the text is played as audio and displayed as audio synchronised subtitles. The signer avatar has been placed on the right side of the screen to show more information on the left side e.g. icons or example images or videos.

Figure 4.11: Tactile Multi-Media Guide Design with active tutorial. The *Tutorial Button* is coloured grey for visual feedback.

4.2.2 On-Relief Projections Area

The *On-Relief Projections Buttons* are located in the left hand-sight of the GUI, red area as shown in Figure 4.6. This area consists of five buttons that change the projection on the tactile relief, as can be seen in Figure 4.13.

The five On-Relief Projections GUI button bar listed from top to bottom:

1. Original artwork
2. Original artwork with semi-transparent sections
3. Original artwork with inverted colours
4. Depth image of the 2.5D tactile relief with depth black to white gradient
5. Combination of ultraviolet (UR) and infrared images (IR) of the original artwork to visualise preliminary drawings done by the artist

Figure 4.12: On-Relief Projections GUI buttons on the left side and the images to be projected on the right side. The displayed artwork is *Vogeldieb* (©KHM-Museumsverband) and its various projections.

Figure 4.12 shows from top to bottom and from left to right the top three images, the first three buttons are the same for each of the six artworks selected for this project. The second projection shows the original artwork with semi-transparent sections. Artworks are separated into various numbers of sections, e.g. *Vogeldieb* in 18 sections.

A section is a segment of an artwork, which contains information about these specific parts of the artwork. By touching a section on the relief with a pointing finger gesture, the related audio guide content will be played. Depending on the access needs e.g. subtitles for the selected section will be displayed on the monitor.

We incorporated several possibilities for on-relief projection to help users to interact with the relief. They can choose different projections suitable for their needs, like inverted colour, see in Figure 4.12 the middle button in the button bar on the left side.

The bottom two buttons - the two images on the bottom - are depending on the additional content provided for each artwork. For the selected artwork, the fourth option is a depth image of the 2.5D tactile relief with black (background) to white (foreground) colour gradient. The projected depth image allows a better visual perception of the depth of the original artwork as well as the resulting tactile relief. The fifth option is the resulting image from the UR and IR recordings. This enables to make preliminary drawings and non-executed areas visible.

(a) Image darkened to highlight the projections.

(b) Projection with semi-transparent section selected.

Figure 4.13: TMG with the original artwork (*Vogeldieb* ©KHM-Museumsverband) projection on the tactile relief.

4.2.3 Object Label Button Area

Figure 4.14: Object Label Button Area

The *Object Label Button Area* is located in the middle area of the GUI and is coloured black in the Figure 4.6. Like object labels or captions in museums, it shows the artwork title and the artist of the exhibited piece. After a few design versions and testing cycles, the following simplified was finalised. First, the title of the artwork is mentioned as usual, which is separated via a comma from the artist's name. Further information such as dates, which are usually given immediately afterwards, is not quoted to allow the title and the artist of the artwork to be as big as possible. This supports BVI users by immediately drawing their attention to the most important information – namely, which artwork can be explored there. The *Object Label Area* button provides as an audio feedback for BVI users. This information, artwork and artist, will also be played at the end of the tutorial.

The research revealed that there is a lot to decide about font characteristics for GUI design for visual impaired users.[BG17, PTGG18, OGGL15, BLG15, CCR+08] The following font characteristics were considered: weight, width, serifs and slope.

Weight defines the thickness of the font characters. Thin letters are more difficult to recognise than thick letters. Research has shown that semi-bold fonts are easier to recognise visually.[BG17, CCR+08] Due to the selected design, the text usually occupies the largest part of the screen, it supports the use of a bold font instead of a semi-bold, because otherwise it would appear too thin. Our participants preferred the bold font for this text field. As mentioned, the text has a big area to spread, so **width** of the text characters was no issue with the chosen font Arial. Block typesetting is not used due to their better readability.[BG17, CCR+08] This also applies to sans-serif fonts such as Arial. **Serifs** are small lines at the end of a letter. Here is an example of the Object Label Are with and without serifs.

Vogeldieb, Pieter Bruegel der Ältere Serif font

Vogeldieb, Pieter Bruegel der Ältere Sans-serif font

Visual depth is created by using different font sizes. This hierarchy separation is important for design for visually impaired people.[BG17] Furthermore, the larger font of the artwork title draws the eye to the highlighted, more important information. We decided on the bold, sans-serif font Arial in two different font sizes, artwork title 70 pt (unit of length: point (pt)) and artist 50 pt. The font size depends on the content. Whereby, the font size of the artist is always 20 pt smaller than that of the title. The **slope** style is usually used for highlighting important words. However, since thin letters inclined to the right are difficult to recognise for people with visual impairments, it was decided against the slope - so-called italic - style.

4.2.4 Information Area

The *Information Area*, short *Info Area*, is located in the middle of the screen. It is the blue coloured area in Figure 4.6.

In contrast to the static Object Label Area and the left and right button areas, the Info Area (the rest of the GUI) has a dynamic design to meet the various access needs of the users. This means, that depending on the Accessibility Settings, four different modes can be activated, see Figure 4.15 to Figure 4.18.

User needs				**Displays**	**Screen Modes**
Audio	**Subtitles**	**Full Text**	**Sign Language**		
✓ / ×				HL	1
✓ / ×	✓			HL | ST	2
✓ / ×		✓		HL | FT	3
✓ / ×			✓	HL | SL	4

Table 4.1: An overview of the use cases and the resulting screen modes. Each row represents one use case.

In the right column, *Screen Modes* shows the four different *Info Area* screens. It should be noted that the audio settings have no influence on the visual representations of the different modes. Since there are users, who like to read subtitles during listening to the audio guide to understand the spoken content more easily, subtitles are added. In the Accessibility Settings, users can activate and deactivate the following components individually, among others: Audio, Subtitle, Sign Language with Subtitles and Full Text. Note that only one use case, i.e. one screen mode, can be activated.

The column *Displays* reflects the visual presentation elements of the *Info Area* for the active user needs. The still cryptic abbreviations are now explained and their resulting GUI presented.

Highlight (HL) Subarea

Screen Mode No. 1 only **HL** Subarea is shown. As can be seen in Figure 4.15, an image of the original artwork spans over the whole Info Area. It represents the *Highlight*, where visual content is highlighted. The *Highlight* Subarea is part of the *Info Area* and present in every screen mode. Depending on the screen mode, the *Highlight* Subarea adapts to the remaining available space.

There is more behind the original picture than can be seen at first glance. At the beginning of the design process for the new GUI only an image of the touchable parts of the artwork was displayed. These so-called *sections* hold information about each individual part of the artwork. Every section is coloured differently, see Figure 3.3b. In total, there are 18 sections for the artwork *Vogeldieb*. The section colours were chosen following the colour scheme of the original artwork. If the contrast to adjacent sections

Figure 4.15: GUI with the Highlight Subarea spans over the whole Info Area. The Highlight Subarea displays the selected artwork *Vogeldieb* (©KHM-Museumsverband)

was too low, it has been adjusted accordingly. The background colour of the *Highlight* Subarea does not depend on the selected Colour Scheme. The black colour generates an excellent contrast to the colour choices of the sections. During the test, users instinctively clicked on the coloured section on the touch screen to get information about a particular section. To support this intuitive behaviour, the sections now act as interactive coloured buttons with irregular shapes. However, the main attraction is the original painting, so in the final design the sections overlay transparent. Thus, the user keeps being focused on the artwork. The coloured sections are projected semi-transparently with the original artwork onto the tactile relief. You can see the resulting image in Figure 4.12 (top middle image) and the projection on the relief in Figure 4.13b. Except for the invisible irregular shaped section buttons, all other GUI buttons are visually recognisable as interactive buttons through their round or angular design.

The *Highlight* Subarea acts as a kind of gallery space with an exhibited work of art. This area is also a dynamic space where additional information about the relief can be shown, especially content that cannot be projected on to the tactile relief in a meaningful way. This could be enlarged views of the painting or 3D rendering of a scan. For certain sections of artworks, images or animations can be (dis)played instead of the original artwork providing additional visual content to the played audio, e.g. image of the artist, for the text about the artist. The combination of audio, sounds and animations brings the painting to life and creates a new experience of exploring artworks. More information can be found in the Sub-chapter 4.2.5 (Accessibility Settings: Sounds and Animation).

Subtitle (ST) Subarea

In Screen Mode No. 2 an other visual element is added to the HL-Display. As seen in Figure 4.16, the *Info Area* is divided into the two areas *Highlight* Subarea and *Subtitles* Subarea (HL | **ST**). The *Subtitles* Subarea horizontally reduces the *Highlight* Subarea at the bottom.

Figure 4.16: GUI with active Subtitle Subarea. The default information text *Berühren Sie das taktile Relief.* (Touch the tactile relief.) is displayed. The selected artwork is *Vogeldieb* (©KHM-Museumsverband).

The ST Subarea is equivalent in size and design to the Object Label Area. The only distinction is the text format. In comparison to the Object Label Area text, the font size of the ST Subarea text corresponds to the standard font size of the design. The default font size is 50 pt. Due to the smaller font size and the amount of text displayed in the *Subtitles* Subarea, we have decided against a bold font. This and the centred text leads to a better readability as our participants mentioned.[CCR+08] Except for the default information text *Touch the tactile relief.*, the subtitles' text is displayed in two lines. Instead of Full Text (FT) and Sign Language (SL), the audio guide text is displayed at the playback speed of the audio file. At the end of an audio file, the subtitles are reset to the default information text.

Full Text (FT) Subarea

Screen Mode No. 3 adds yet another visual element to the HL-Display. As seen in Figure 4.17, the Info Area is divided into two parts, *Highlight* Subarea and *Full Text* Subarea (HL | **FT**).

Figure 4.17: GUI with active Full Text Subarea. FT Subarea displays the audio guide text for the selected section *Wilderer* (Poacher) in German. The displayed artwork is *Vogeldieb* (©KHM-Museumsverband)

Unlike the Subtitles Subarea, the Full Text Subarea vertically splits the Info Area into two columns of equal size. On the left side is the Highlight Subarea and on the right side appears the *Full Text* Subarea. If activated, the FT Subarea can display text content at once in a scrollable field. This allows reading of the whole text at one's own pace, and the use of the system without any audio. The font format corresponds to the standard thin font size of 50 pt. Our participants with hearing, sight and learning impairments have informed us that left-justified text format is preferred to block typesetting. As shown in Figure 4.17, the first line is bold to visually separate the title of the selected section from its description.[BG17, PTGG18, OGGL15]
[BLG15, CCR$^+$08, SGCR$^+$18, KH11] Generally, the full text contains the title (first line) and description of a selected section. If no section is selected, the default information text is displayed. Paragraph formatting is adjusted according to the language. Depending on the text length of a selected section, a slider on the right side of the text field is activated. If the text is too long, the text is truncated vertically at the bottom. This and the right lower black corner support the intuitive scroll behaviour of the user, see Figure 4.17. Interaction with the slider turns it grey, as visual feedback.

Sign Language (SL) Subarea

In Screen Mode No. 4 is added another visual element to the HL-Subarea-Display. As seen in Figure 4.18, the Info Area now is split into two areas, *Highlight* Subarea and *Sign Language* Subarea (HL | **SL**).

Figure 4.18: GUI with active *Sign Language* Subarea. The SL Subarea shows a female human signer with grey background and white subtitles are displayed within a dark grey rectangle, for better contrast. The displayed artwork is *Vogeldieb* (©KHM-Museumsverband)

As with Full Text, the Info Area is split vertically into parts of almost equal size. *Highlight* Subarea on the left and *Sign Language* Subarea on the right. However, the sign language videos contain their own subtitles. In order to display these the *Highlight* Subarea is also cropped below. Thus, the HL Subarea is located in the upper left area. The aspect ratio of the Highlight corresponds to the standard aspect ratio of a tactile relief. The same size, physically and digitally, of the tactile reliefs improves the calibration, as well as the support of the wooden frame, which among other things prevents the moving of the tactile reliefs during use. The Highlight displays the original artwork *Vogeldieb* with black background.

If sign language is activated in the accessibility settings, the *Sign Language* Subarea shows the sign language videos, i.e., the currently playing audio guide text translated into sign language with subtitles. In Figure 4.16, a human signer starts signing the selected *Wilderer* (poacher) section. The tutorial follows the identical display structure. The human translator is replaced with an avatar developed by our technology partners Signtime.

4.2.5 Accessibility Settings Button Area

Figure 4.19

The Accessibility Settings Button is located in the upper right corner of the touchscreen, Figure 4.6 in violet. The Settings Menu spans over the whole Info Area, Figure 4.6. By tabbing on the settings button, the Settings Menu is opened or closed, Figure 4.19, or closed with the OK-Button, Figure 4.20. The settings button is coloured grey, when the Settings Menu is open. Figure 4.20 is showing the opened Settings Menu in the TMG GUI.

Depending on the preferences of the user, different sections of the GUI can be enabled (set to visible) or disabled (hidden). During the design process, various accessibility settings were added to and removed from the Settings Menu. The On Relief Projections Buttons were extracted from the Settings Menu and placed on the left side of the screen for an easy access, as frequently used by our users. More about the GUI design process can be found in the Chapter 5, Design Process and Evaluation.

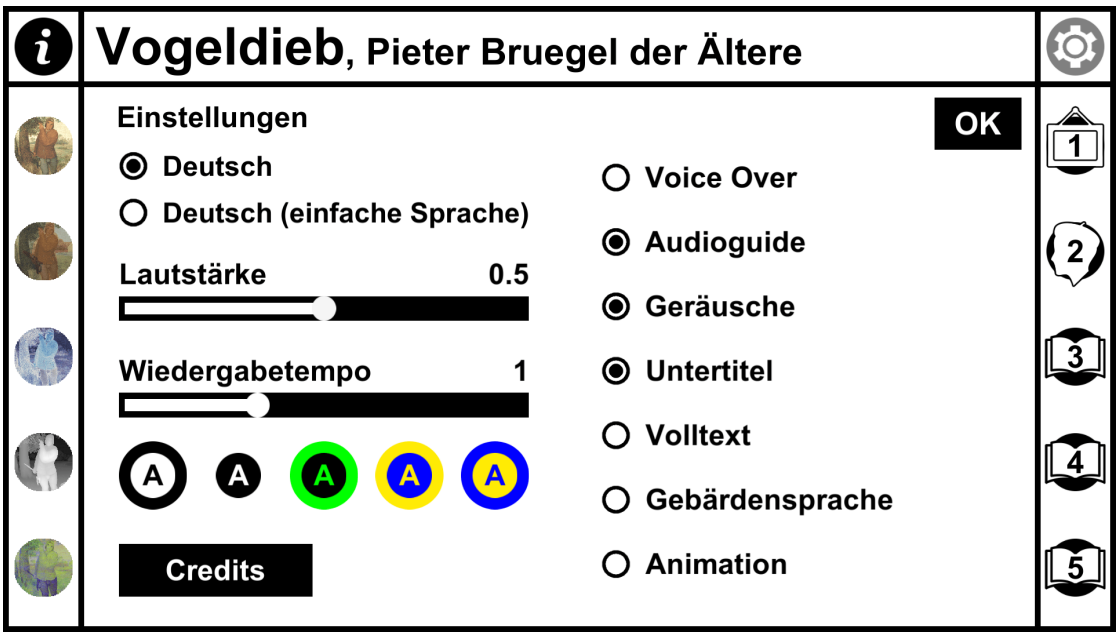


Figure 4.20: Tactile Multi-Media Guide Graphical User Interface with opened Settings Menu. The settings button is grey coloured.

The resulting accessibility Settings Menu consist of the following features:

- Language
- Volume
- Playback Speed
- Colour Scheme
- Voice Over
- Audio Guide
- Sounds
- Subtitle
- Full Text
- Sign Language
- Animation

The enumeration represents the positioning of the Settings Menu in the interface and represents the settings translated into English. The settings in Figure 4.20 are displayed in German, as the example artwork is the *Vogeldieb* (Bird thief). In 2019, the *Vogeldieb* by Pieter Bruegel the Elder was exhibited at the Kunsthistorischen Museum in Vienna, Austria.

Figure 4.20 shows also the **Title** *Einstellungen* (Settings) of the Settings, the **OK-Button** and the **Credits-Button**. The settings title is on the upper left corner. The OK-Button has been added additionally, as requested during a test session with our participants. It is placed on the upper right corner of the Settings. The Credits-Button, on the bottom right corner, opens a new area on top of the Settings. It contains information about the ARCHES Project, development company and copyright.

The **Voice Over**, **Audio Guide** and **Sounds** all handle audio related settings. **Subtitle**, **Full Text** and **Sign Language** have an influence on the presentation of the Info Area, Sub-chapter 4.2.4. **Animation** only changes the *Highlight* Subarea of the Info Area. Animations can be turned off via the Settings Menu to prevent visual over-stimulation for users with learning disabilities.[SGCR+18, KH11]

All of the above mentioned settings ca be changed either via Screen Interaction, Sub-chapter 4.1, or by Quick Response (QR) Code. For this purpose, a printed QR Code is held between the tactile relief and the projector in the same position as fist gesture, see Figure 4.1b. A QR Code is a two-dimensional matrix barcode. It allows the program to read the stored user settings information. Figure 4.21 shows example user profiles with the corresponding QR Code. The museum also can choose default user settings, which are activated at the beginning or after three minutes without any user interaction. More about user profiles and data management can be found in Sub-chapter 3.2.1.

The Settings Menu are separated in two columns as shown in Figure 4.20. The following description explains the settings from top to bottom, beginning with the left column following the right one.

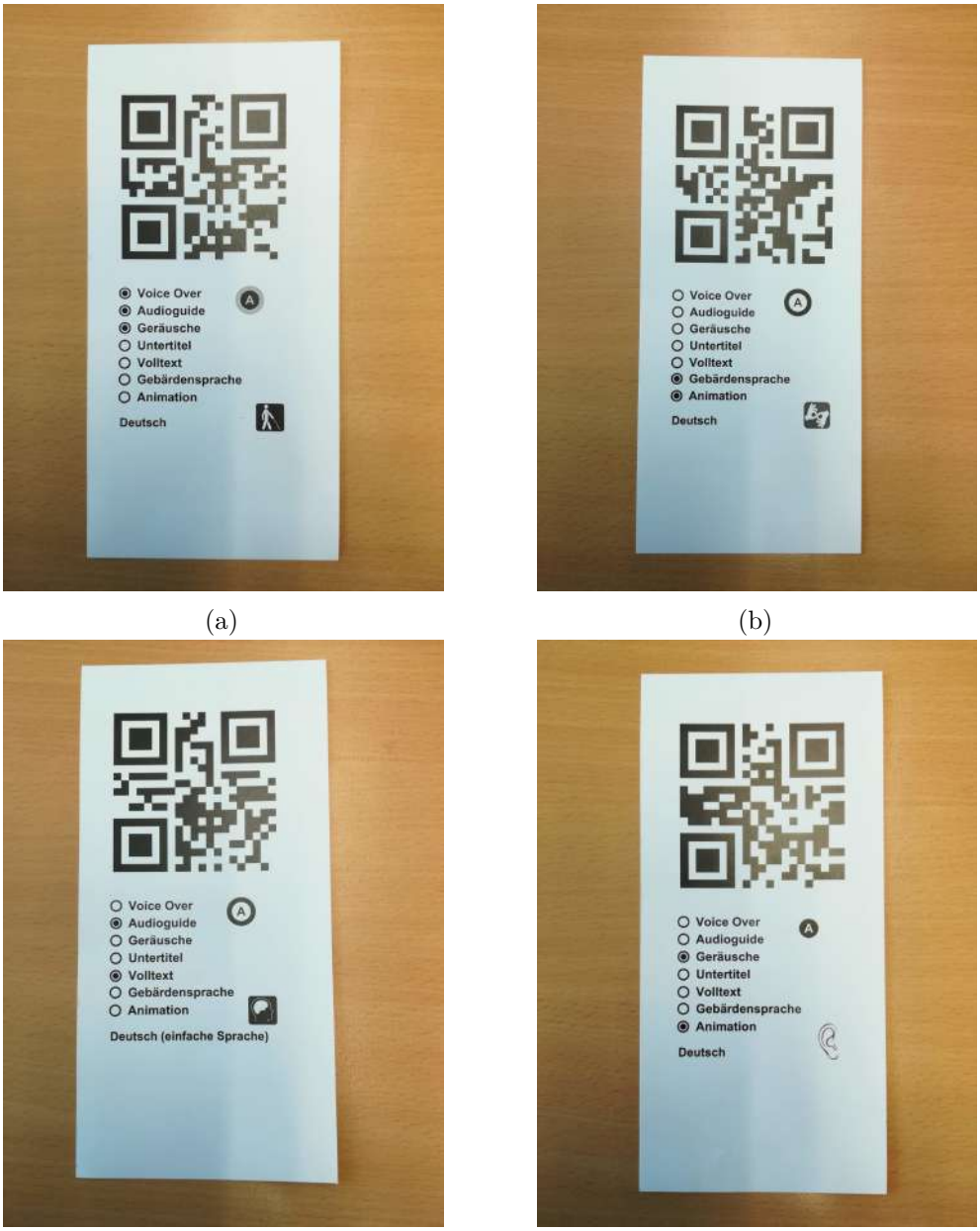


Figure 4.21: Example user profiles with corresponding QR Code for (a) BVI users: Voice Over, Audio Guide, Sounds and Yellow-Blue Colour Scheme. (b) Users with hearing disabilities (c) Users with learning difficulties (d) experience of the 3D soundscape with animations.

Language

Language is located in the left column underneath the settings title. Our museum partners provided us with the content for each artwork in the local language of each museum, as well with and *easy read* version for people with learning difficulties and disabilities. The *easy read* version among other things differs by the use of a simpler vocabulary and shorter sentences. Below, an example sentence of the artwork *Vogeldieb* of the section *hat*. One sentence in Standard German splits into two sentences in the easy read version:

Der Vogeldieb bemerkt gar nicht, dass er seinen Hut verliert.
The birdnester doesn't even notice that he is losing his hat.

Hier verliert der Vogeldieb seinen Hut. Er bemerkt es gar nicht.
Here the birdnester is losing his hat. But he doesn't even notice it.

The two language options *German* and *German (easy read)* can be listed below each other, see Figure 4.20 and Figure 4.8. If further content is added in another languages, it is possible to arrange three languages one below the other. If there are more than three languages, the toggles have to be converted into a dropdown list. However, dropdown lists lead to problems with the active Voice Over setting, thus to a more complicated usage for BVI people or people with fine motor difficulties, recording to the participant feedback and the WCAG.[CCR+08]

The language selection influences the settings: Audio Guide, Subtitle, Full Text, Sign Language. Due to the text differences between the languages, each language has its own collection of audio files for the audio guide. The Full Text justification changes depending on the language selection, as shown in Figure 4.30. Sign language videos are currently not offered in the easy read language. This is partly due to the cost of sign language videos with a human signer. Nevertheless, additional sign language videos for other languages can be easily added, due to the data management concept, Sub-chapter 3.2.1.

Volume and Playback Speed

During the test sessions, our BVI participants gave us the opportunity to gain an insight into the everyday life of a person with a visually impairment. During a conversation with a blind participant, he was so kind and showed me the speed and volume at which he normally plays the audio content on his phone. To my fascination, his standard playback speed was set to 1.7x. He explained to me that this is usually the case with many blind people. After some time BVI people get used to this fast playback speed. This allows them to listen to more information and therefore gain more knowledge in the same time span. After this encounter in June 2017 and similar feedback from other participants in other test sessions, adjustable volume and playback speed were included in the Setting Menu. Since these are two changing values, the best implementation was a slider, see Figure 4.22.

Both Volume and Playback Speed have a slider step size of 0.1. The Volume value range is from 0 to 1. The default value is 0.5. Modification of the Volume slider alters the volume of the TMG: e.g. Audio Guide with Subtitles, Sounds and Voice over. When the volume value reaches zero, Voice over and Audio Guide with subtitles are muted. The Playback speed range is from 0.5 to 2. The default value is one. The playback speed value influences the Voice Over, Audio Guide, Subtitles and Sign Language.

Figure 4.22: The Volume and Playback Speed sliders with round handle. Above each slider there are two texts boxes, one explains what can be adjusted -*Lautstärke and Wiedergabegeschwindigkeit* (volume and playback speed), and one that displays the current value - *0.5 and 1.*

Colour Scheme

The high contrast design supports the visual perception of users with visual impairments. Visual impairments are not only sight restrictions caused by illness, e.g. cataract (vision through a veil), but can also be inherited, e.g. colour blindness. Colour blindness is not a form of blindness, it is rather a deficiency to perceive colours.

The best known colour blindness are red-green and yellow-blue. The red-green affected have problems with discriminating red and green hues.[Won11, NN11] The yellow-blue affected have difficulty discerning between blue and green hues, as well as yellow and red hues.[Won11, NN11] Monochromacy, total colour blindness, only allows seeing in black and white tones (grayscale).[Won11, NN11]

Further design research and conversations with our participants, museum partners and experts have drawn our attention to two austrian organisations. The *Austrian Federation of the Blind and Partially Sighted (BSVÖ)*[BSV] and the *Austrian Association for the Blind and Visually Impaired*[Hil] support the following colour concepts, see Figure 4.23. The project *Eye to Ear - Gallery of Audible Images* for BVI people, also use the high contrast two colour (black and white) concept.[BG17]

(a)

(b)

Figure 4.23: Colour concepts from websites of BVI Associations: (a) BSVÖ [BSV] and (b) Austrian Association for the Blind and Visually Impaired.[Hil]

Figure 4.24: Five buttons of Colour Scheme of the high contrast design concept.

Both colour concepts, Figure 4.23, support the changed colour perception of people with forms of colour blindness. Our participants preferred the design of the colour scheme buttons of Figure 4.23b. Figure 4.24 shows the resulting five colour variants of the TMG: black-white, white-black, green-black, yellow-blue and blue-yellow. The coloured outer circle of the Colour Scheme buttons corresponds to the colour of the separation between the different areas. The colour of the "A" letter reflects the colour of the text. Sliders and symbols were designed using the two-colour concept. The colour between the outer circle and the "A" defines the button area background colour.

The colour scheme was controlled with simulation glasses by us, as well as tested with our participants. All user groups found the two-colour design concept visually appealing. A third colour (grey) was added as additional visual feedback to specify the active state of e.g. the settings button, see Figure 4.20. The Figure 4.25 shows the GUI in the different colour scheme variations. The colour scheme changes the display of the entire GUI, except for the Highlight, Sub-chapter 4.2.4, the on-relief projections buttons, Sub-chapter 4.2.2, themselves and the colour scheme buttons.

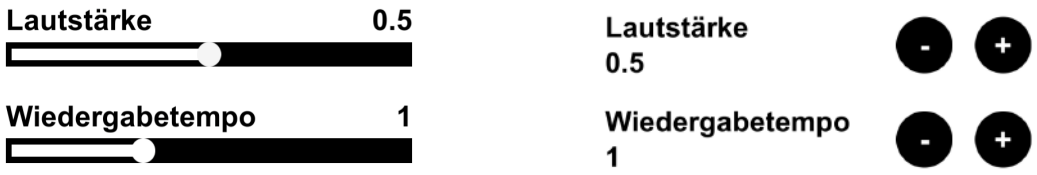
Figure 4.25: The colour scheme variations with open settings from left to right and top to bottom: black-white, white-black, green-black, blue-yellow, yellow-blue and blue-yellow with *Highlight* Subarea and *Subtitles* Subarea activated.

Voice Over

In addition to the audio feedback that when a section info is started a "beep"-sound and finished or stopped with a "double beep"-sound, a voice over function has been added. In cooperation with our ARCHES tech partner Coprix, we adapted their voice over feature, they developed for their App.

There are two common voice over interactions: single touch followed by another single touch or single touch followed by a double touch. After consulting with experts as Daniele Marano from the Austrian Association for the Blind and Visually Impaired[Hil] and the experience acquired by Coprix, the following void over interaction was selected. The first touch of a button selects it and the second touch activates this function. The audio output for the voice over activation would be as follows:

Voice Over	first touch
Voice Over activated	double touch afterwards



(a) (b)

Figure 4.26: Active Voice Over: (a) Volume and Playback Speed sliders change to (b) *minus* (-) and *plus* (+) buttons.

Every interactive GUI element has a voice over audio feedback attached. Testing with our participants showed that sliders are hard to use for blind people to use, because the beginning and end of the slider are difficult to make out on the screen.[BLG15, CCR+08] With active Voice Over each slider is converted into two buttons, see Figure 4.27. The textual information is placed on the left side one below the other, and on the right side there are two buttons *minus* (-) and *plus* (+) instead of one slider, see Figure 4.26.

The Voice Over can be activated via the toggle *Voice Over* in the Settings Menu, or via holding a special QR-Code under the projector, see Figure 4.21 in Sub-chapter 3.2.1. The museum also can choose to set the Voice Over active in the default user settings.

As additional physical support for BVI users, stickers can be placed on the screen. All areas except the Info Area are suitable, as they do not change during use. First tests with sample stickers have been made. The exact sticker design has not yet been determined.

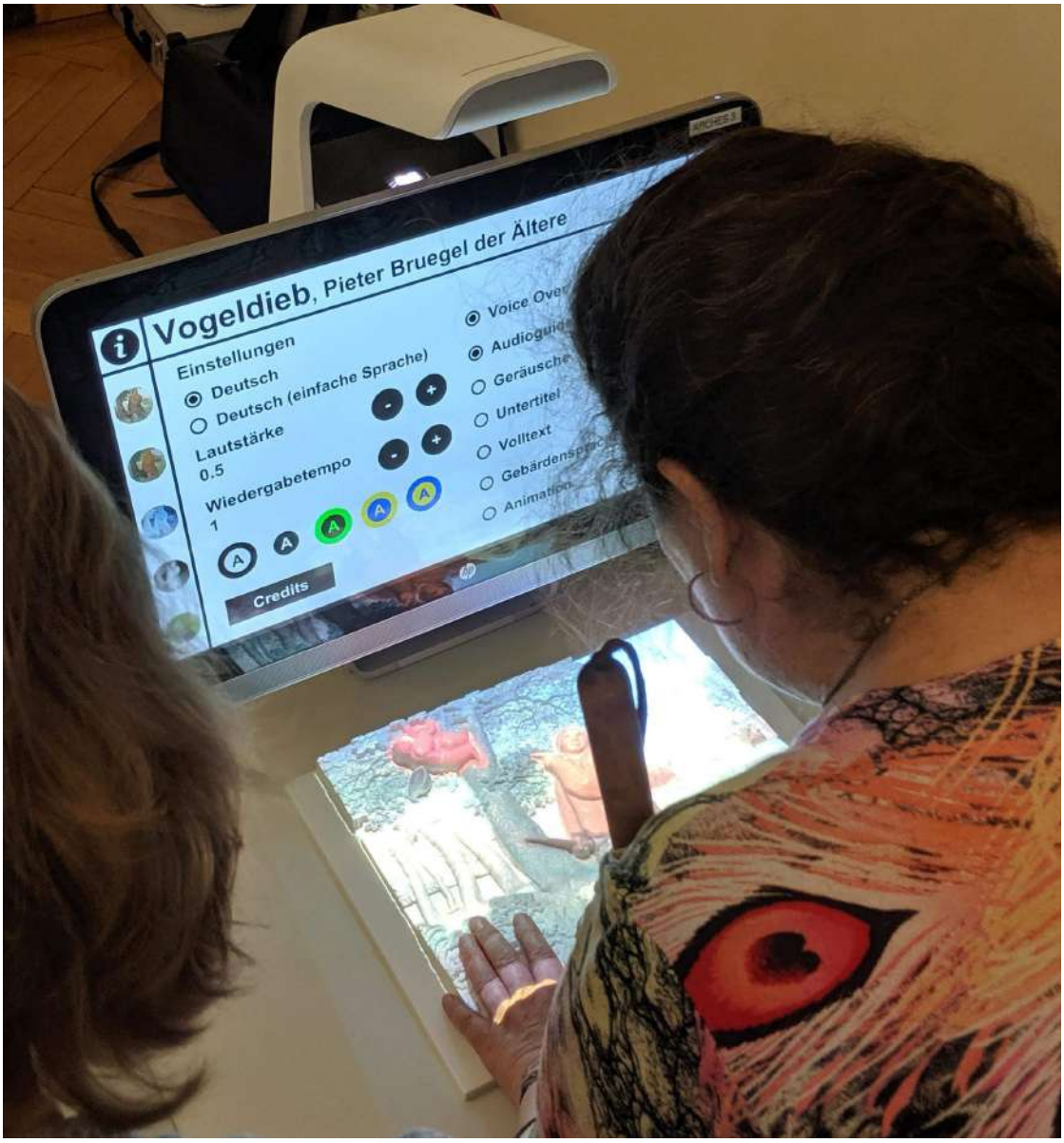


Figure 4.27: BVI user is testing the Tactile Multi-Media Guide. Screen is showing the GUI with opened Settings and active Voice Over. The original artwork with semi-transparent sections is projected on the tactile relief.

Audio Guide

A traditional audio guide plays a special audio file via number input. The Tactile Multi-Media Guide follows the interactive explorative approach. Instead of being stored numerically, information is stored on areas on the tactile relief or as a button on the GUI.

The tactile relief is separated in various regions, so-called *sections*, see Figure 3.3b. The section content can be accessed via screen interaction or on-relief interactions. If you touch a section on the relief with one finger (on-relief gesture Figure 4.1a), an audio file will be played. Section content consists of title and description, and can also be displayed textually in the GUI. In addition to the information about the touched area you hear a start "beep" and end sound "double beep" as audio feedback for BVI users. Every audio playback follows this format: start sound, information, end sound. The original artwork displayed on the screen holds the same content as the tactile relief. With a fist gesture (off-relief gesture Figure 4.1b), the currently played audio file can be stopped. As audio feedback for interactions the end sound "double beep" is played. Touching another section also stops the current playback. More about the interaction options, you can find in Sub-chapter 4.1. The selected language as well as the values for volume and playback speed adjust the played audio file.

The information stored on the five buttons of the *Additional Artwork Information* Subarea is played back in the same way as the section content. The Object Label Area Button stores audio files about the artwork and the artist. Touch the Tutorial button and the tutorial is played. The On-Relief Projections buttons and the (accessibility) settings button do not trigger an audio file.

Sounds

Depending on the artwork, different sounds are played during the interaction with the tactile relief, Sub-chapter 4.1. Three different sounds act as an acoustic feedback for on-relief gestures. The three audio files are fading into each other depending on the user interaction. When the user touches a section (part of the relief), he will hear a touch sound (like a chore is singing the letter "a"). If the pointing finger is placed between two or more sections, an audio file (a sound like water splashing) is played. If the user is not touching the relief or the finger hover over it, a "crumpled paper" sound is played.

In addition to the standard sound concept, a 3D soundscape for the artwork *Vogeldieb* was developed by the team of the EU project Pluggy (the Pluggable Social Platform for Heritage Awareness and Participation)[oCI18]. Among other things, Pluggy has developed the Plugsonic Suite with which interactive 3D soundscapes can be experienced. Using headphones, the user can hear the sounds surrounds him.

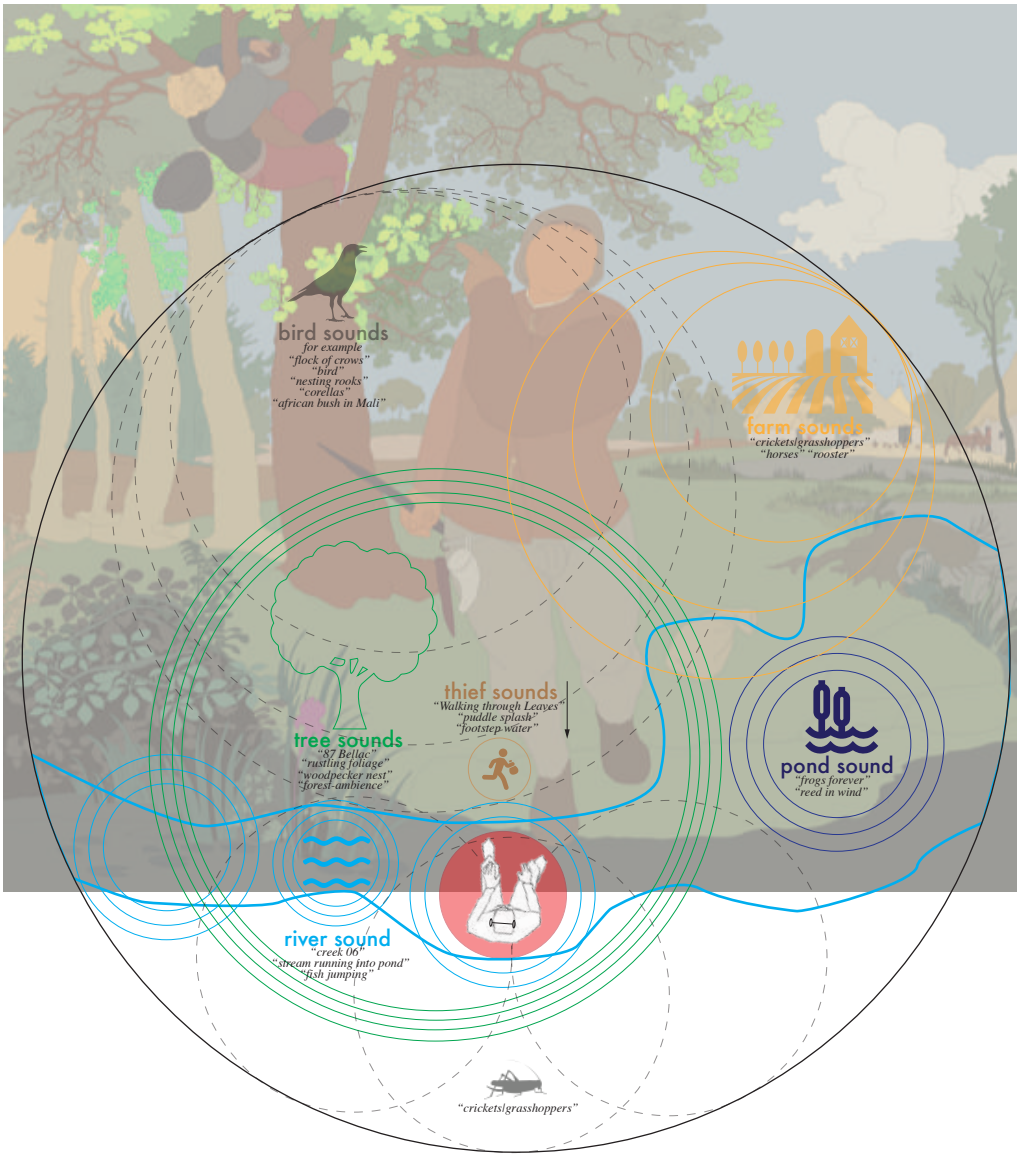


Figure 4.28: Pluggy 3D Soundscape as perceived by the person sitting in a red circle wearing headphones, view from above.

For this purpose, sounds were defined for all sections of the artwork, see Figure 4.28. A 3D effect was created corresponding the depth of the artwork, e.g. you can hear the chickens in the background, because the farm with the chickens was drawn in the background. Figure 4.28 shows the resulting 3D soundscape seen from above, the so-called bird's-eye view. Areas in the background are quieter and areas in the foreground sound louder.

The vertical and horizontal position of the sections in the artwork is also represented in the audio effects. The use of headphones intensifies the perception of the 3D soundscape, e.g. you can hear the bees in the left speaker or how the poacher slowly marches towards you. The use of the 3D soundscape helps to bring the work of art *Vogeldieb* to life. The combination of sounds and detailed picture description is supposed to make it possible to build up and perceive the artwork behind closed eyes.

In addition, a one-minute story-based 3D soundscape loop is added. This loop is played, when no single hand gesture is detected over and on the tactile relief. For an acoustic user interaction feedback, the area that is touched is acoustically moved into the foreground by playing the respective section sound louder. At the same time that the story-based soundscape loop becomes quieter. The audio guide and the sounds are balanced out, so the user still can listen to the information content of the selected section. When the finger is moving away from the selected section or the audio has stopped, the story-based soundscape volume will be restored.

Subtitle

As already described in the Sub-chapter Info Area, the Subtitle (ST) horizontally trims the Highlight (HT) with the original artwork representation below. The Subtitle corresponds to the size of the Object Label Area, see Figure 4.16. If no section is selected, the default information text *Berühren Sie das taktile Relief.* (Touch the tactile relief.) is displayed in the centre.

Figure 4.29: GUI with active *Subtitles* Subarea that displays in two lines the title of the selected section *Wilderer* (poacher) and the first sentence of its description over two lines. The displayed artwork is *Vogeldieb* (©KHM-Museumsverband).

During various tests, museum partners and participants have pointed out that the word-by-word display of the subtitle is very exhausting. Especially participants with learning disabilities and concentration problems rejected this display option.[SGCR+18, KH11] Subsequently, the subtitle display was changed to display one sentence at a time. Depending on the length of the sentence, the subtitle is displayed in one or two lines, see Figure 4.29. In the rare case of extremely long sentences, one sentence might be displayed in two parts. Line breaks are mostly made automatically according to different factors. For example, if a comma is contained in the sentence or the sentence length exceeds a certain letter length or number of words.

Native speakers checked the automatic line breaks. They also added manual line breaks, if sentences exceed the display capacity or their content requires it. So that, for example, words crucial for understanding are displayed together. Figure 4.29 displays the subtitle for the selected section *Wilderer* (poacher). The title *Wilderer* is bold and a colon is

separating it from the description. In this case the first line is longer to not split the adjective (älterer - elderly) from its subjective (Bursch - boy).

The subtitle are displayed coordinated with the audio being played. The mixture of automatic and manual line breaks made the creation of timestamps difficult, e.g. marking the beginning of a sentence. Existing libraries only support the word-by-word principle, so the timestamps were done manually while checking and setting the line breaks. Another reason for manual subtitle creation was that content is displayed in three languages: Spanish, English and German. Each language also has an additional easy read version. Our museum partners, as native speakers helped us to create all subtitles for each of the six artworks. Subtitle creation involved many people with different technical backgrounds. Therefore, a concept had to be developed first, which is understandable for all helpers. After creating the timestamps and manual breaks in Excel spreadsheets, it was converted to the data format JSON.[Cro18] With this subtitling concept, adjustments and additions can be made quickly. The Sub-chapter 3.2.1 explains the data management more.

Since the subtitles are synchronised to the audio, their speed also adapts to the playback speed. Subtitles can be activated and deactivated as desired via a toggle in the Settings Menu and remain synchronous. The subtitle is an accessibility feature desired and liked by our participants and museum partners.

Full Text

The Info Area is divided vertically in the middle into two equal parts. On the left side is the *Highlight* Subarea and on the right the *Full Text* Subarea, see Figure 4.17. As in the *Subtitle* text field, the default information text *Touch the tactile relief.* is displayed. When a user select a section, its content is displayed at once in the scrollable text field. People with learning disability and difficulties can experience the content independently from the audio playback, in their personal reading speed.

The slider on the right side is hidden by default. When the displayed text exceeds the text field size, the slider will be activated. The slider is trimmed according to the length of the text below, see Figure 4.30 (a) & (b). The text field and the slider are designed in the two colour concept. The displayed section content consists of title and description. For a better hierarchical representation, the title is formatted bold and then a line break is inserted. Depending on the selected language, an empty line as paragraph format is inserted after two sentences or one sentence for the easy read languages, see Figure 4.30. Choose either Subtitle, Full Text and Sign Language in the Accessibility Settings Menu. Only one can be active at a time as they visually change the Info Area.

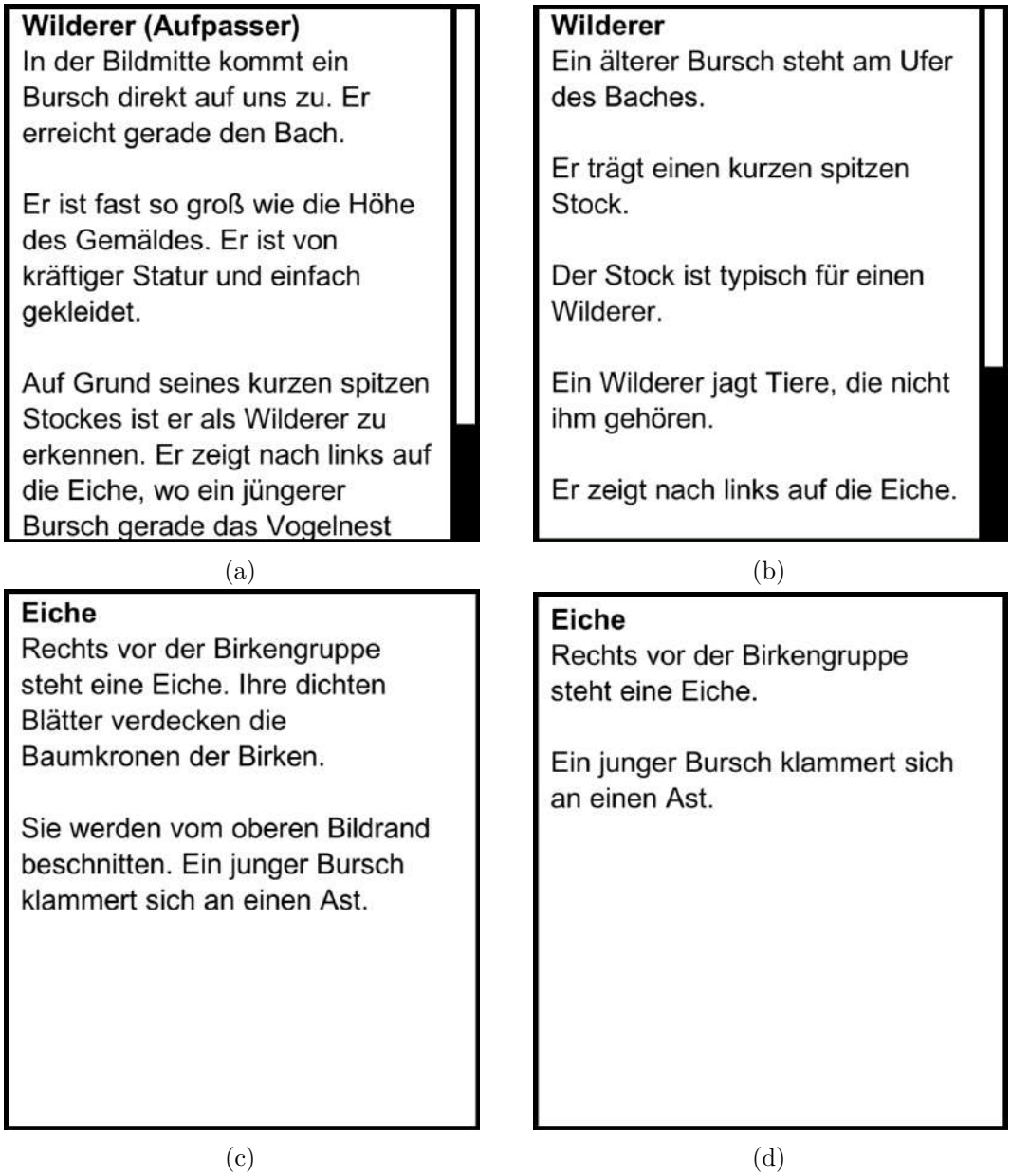


Figure 4.30: *Full Text* Subarea text field with title and description of selected sections. Paragraph formatting according to selected language: (a) & (c) line break after two sentences for Language *German* and (b) & (d) line break after one sentence for Language *German (easy read)*. (a) & (b) show the text content for the selected section *Wilderer* (poacher) with active slider. (c) & (d) show the text content for the selected section *Eiche* (oak) without slider.

Sign Language

The TMG supports users with hearing impairments by translating the audio guide content to sign language. Activating the Sign Language changes the layout of the Info Area. Figure 4.18 shows that the *Highlight* Subarea has been reduced in size and is located in the upper left corner. The *Sign language* Subarea spans over the right half of the Info Area. The signer is centred in the SL Subarea itself to avoid truncating arm movement. The six museum partners prefer human signers and commissioned the sign language videos from their own translation partners. Sign language content is available for all sections and the additional information of each artwork. For cost and time reasons only one language (not easy read version) was translated. The sign language video for the tutorial with an avatar is provided by Signtime, Sub-chapter 4.2.1. Playback speed also affects sign language videos.

As requested by the participants, the sign language videos contain their own subtitles. These are embedded in the videos, see Figure 4.18. The sign language subtitles are also centred and located on the bottom of the video. As the sign language subtitles are included in the videos, they are not created in our high contrast design. For better contrast the sign language subtitles font is white with dark grey rectangle, see Figure 4.18.

Animation

The original image of the selected artwork is displayed in the *Highlight* Subarea. Depending on the artwork, certain sections are animated or additional images fade in. For example, the eyes of a portrait blink or infrared images of the original are displayed. When a certain part of the painting is discussed, the camera zooms in.

The example artwork *Vogeldieb* can be brought to life by the combination of sounds, Sub-chapter 4.2.5, and animations. If no on-relief gesture or section selection is detected the 3D soundscape as well as an animation is playing in a one minute loop. The soundscape loop describes a short story, in which different section sounds are brought to the foreground and at the same time, the corresponding animation is played. For example, when the poacher hits the tree trunk, his arm moves to it, or the nest robber tries to steal birds in the tree, he moves and the oak he is sitting on it with him. These and similar animations for other artworks create a special experience. Section animations can be accessed via on relief interaction or by clicking on a specific part of the original image on the screen.

There are special cases like the artwork *Meissen Fountain*, is not only a sculpture, but also differs in its animations. For this purpose videos were produced especially for each content, e.g. about the creation of the table fountain and the fountain in original size.

Animations can be turned off via the Accessibility Settings Menu to prevent visual over-stimulation for users with learning disabilities.[SGCR+18, KH11]

4.2.6 Additional Artwork Information Subarea

Figure 4.31: Additional Artwork Information

As can be seen in Figure 4.6, the *Additional Artwork Information* Subarea is located on the right side of the GUI design. It is placed below the settings button and consists of five buttons. Via these buttons, users can access the general texts about the artwork.

The five buttons are numbered from top to bottom from one to five. The open book symbolises additional information, see Figure 4.31. The buttons one and two differ in their icons compare to the others, as they refer to the same content for all six artworks. The button one with the picture frame always provide general information about the exhibited artwork. For the second button, a silhouette with a beret was chosen, symbolising information about the artist. Depending on the work of art, the buttons three to five contain further information provided.

The additional artwork information is played in the same audio format as the sections. Every audio playback follows this sequence: a start sound "beep", title, description and an end sound "double beep". This additional information is only accessible via buttons on the touchscreen. An access via off-relief gesture was rejected by the users. More about the user evaluation and design process can be read in the following Chapter.

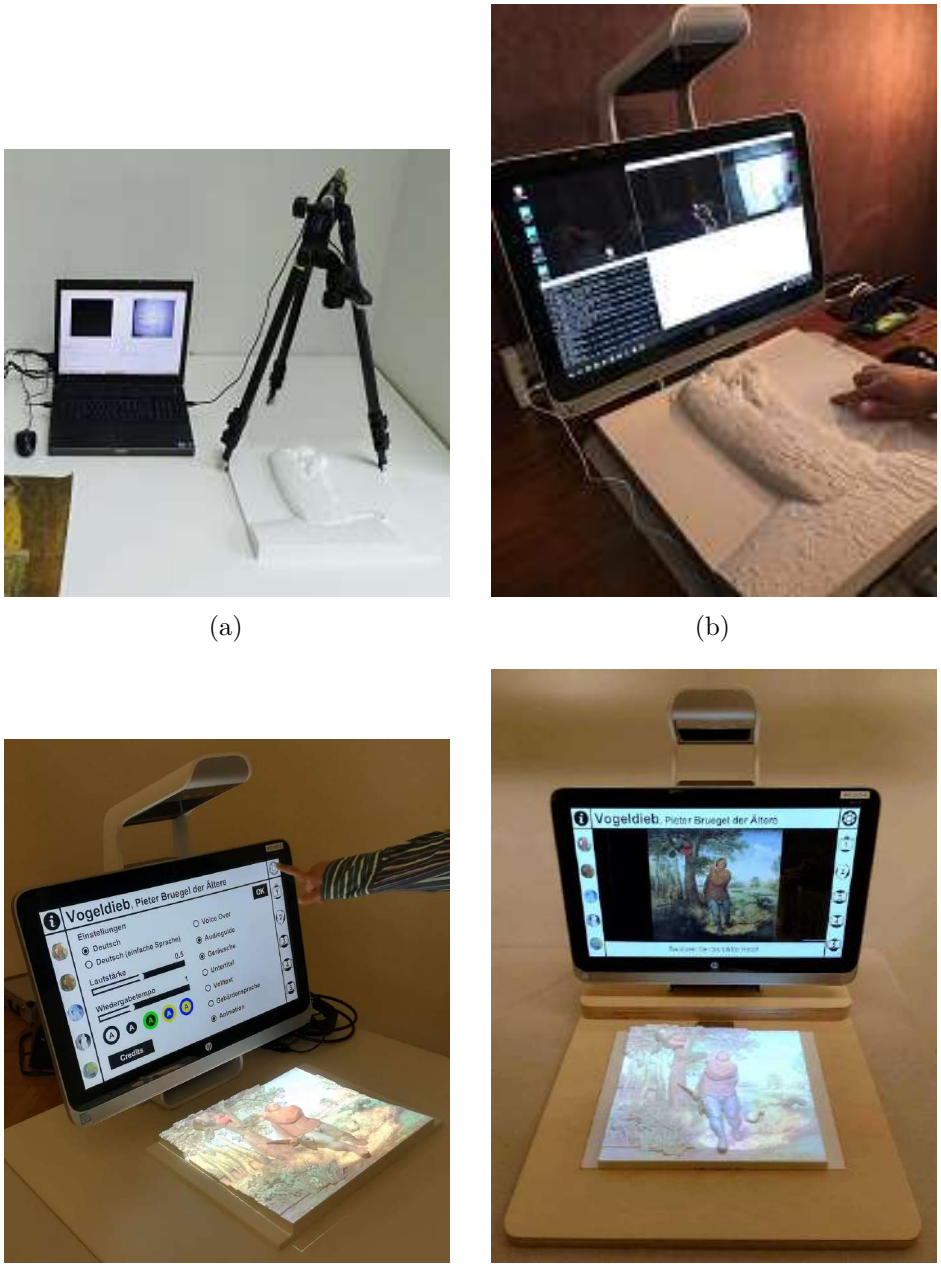
CHAPTER 5

Design Process and User Evaluation

Chapter 4 explains the design, functions and the interactions with the Tactile Multi-Media Guide (TMG) and the existing advanced interaction system, the Interactive Audio Guide (IAG). The TMG was developed with an iterative user-driven design approach. With the gathered expert feedback from the ARCHES participatory research groups and the cooperating museums the visual representations and interactions were enhanced. The participatory research methodology requires that all the newly developed parts be regularly evaluated with the user groups, so that their specific needs can be addressed, as well as well as new design ideas can be developed together. In addition to the feedback received within the ARCHES project, we used external expert feedback as well as the findings of other studies in this area.

Any visual feedback (in addition to the audio comments) was not planned, as the tactile audio guide was mainly targeted at blind and visually impaired (BVI) people. However, users from the participatory research group saw the debug screen when testing the audio guide gestures and liked it very much to have some visual feedback of their actions. Therefore, we started to investigate the possibilities to add visual features to the IAG. By choosing the HP Sprout as hardware, with its built-in touch screen and projector, we were able to make the IAG to the called Tactile Audio Guide (TAG) for a wider user group. Through various testing cycles the TAG transformed into a Tactile Multi-Media Guide (TMG), which offers additional information about the exhibit, as well as guidance for people with various kinds of needs.

Figure 5.1 shows the new Hardware Setup HP Sprout, (b) and (c). (c) and (d) are showing the resulting Graphical User Interface with open settings window.



(a) (b)

(c) (d)

Figure 5.1: Comparison of old and new hardware setup with one hard-coded painting *Gustav Klimt's - The Kiss*[RFMP16], (a) and (b), to (c) the Tactile Multi-Media Guide with currently six provided paintings for users with various access needs.

5.1 User evaluation

The ARCHES team consisted of six museum, four technology companies and two university aimed to make art accessible for people with various access preferences. The project was designed around the participatory approach. Over two hundred people with diverse disabilities met regularly in the museums in London, Madrid, Oviedo and Vienna. They developed ideas, tested prototypes and helped shape the outcome of the project.

5.1.1 Participatory research groups

The museum and university partner held in total 31 session for testing the VRVis prototypes. Approximately ten to twenty people with various disabilities attended a session. Among other things, the participants tested our prototypes, gave us insights and helped us developing improvements.

The following papers published from our partners explain e.g. in detail how they developed a unique evaluation approach for participatory research session.

- ARCHES Project: Validation of Technological Outcomes of Gaming Software based on a Participative Research Methodology. (2019) [CH19]
- Cultural Differences in ARCHES: A European Participatory Research Project-Working with Mixed Access Preferences in Different Cultural Heritage Sites. (2019) [GCDKSG19]
- Towards a participatory museum – A how-to-guide on inclusive activities. (2019) [CDS]
- Blind Visitor Experiences at Art Museums (2017) [Hay17a]
- An auto-ethnography of a hearing-impaired researcher in museum-based participatory research. (2018) [Hay18a]
- Flipping Descriptions: A new phase of democratising audio description. (2018) [Hay18c]
- Inclusive Capital & Human Value. In S. Hayhoe, Cultural Heritage, Ageing, Disability and Identity: Practice, and the development of inclusive capital. (2018)[Hay18d]
- Classical Philosophies on Blindness and Cross-Modal Transfer, 1688-2003. (2018) [Hay18b]
- Interactive demonstration on the use of existing apps on mobile technologies to teach basic photographic techniques to participants who are blind, visually impaired and sighted together: A demonstration of an exercise using apps and cameras on iOS and Android platforms to image ‘the body’ and handwriting. (2017) [HPS17]

- Locke and Hume's theory of color is interrogated through a case study of Esref Armagan, an artist born blind. (2019) [HCC19]
- Accessible Resources for Cultural Heritage Eco Systems (ARCHES): Initial Observations from the Fieldwork. (2018) [HCR+18]
- A Model of Inclusive Capital for Analysis of Non-Economic Human Capital. (2017) [Hay17b]
- The while of participation: A systematic review of participatory research involving people with sensory impairments and/or intellectual impairments. (2019) [RCS+19]
- Emergent analysis and dissemination in participatory research. (2020) [RGCH+20]
- A proposal for a unified framework for the design of technologies for people with learning difficulties. (2018) [SGCR+18]
- Inclusive museums and augmented reality. Affordances, participation, ethics and fun. (2019) [SGCR+19b]
- A participatory approach to the evaluation of participatory museum research projects. (2019) [SGCR+19a]

The ARCHES team have described the issues and achievements of user evaluation very well. However, we would like to share with you the extract from Key performance indicators (KPI) for designing for Agency by Simon Hayhoe: "Technologies should - allow feedback for design evolution, be designed for reflection, be designed to promote needs confidently."[HGCR+19] Through the whole design process we considered the following KPI for Designing for Accessibility by Simon Hayhoe:[HGCR+19]

"Technologies should:

- be designed for different language groups
- allow for evolving access preferences and needs
- be designed to allow for Easy Read texts
- provide for broadest possible choice of access preferences
- use simple, familiar icons and navigational conventions
- be multi-modal, and use elements of multi-modal augmentation
- allow for changes of colour, brightness, contrast, etc.
- allow for zooming to text or images
- include practical information"

To summarise the user evaluation process done as a participatory research group showed how to establish and perform tests and evaluations. We demonstrated the advantages of the participatory research group in comparison to a regular user evaluation for this use case.[RCS+19, SGCR+19a] This processes uncovered various challenges like the usage of audio feedback in certain situations and the influence of labels and sizes of descriptions.

In addition, the feedback of the participants showed a positive influence on people with various access preferences, as they feel included. Furthermore, the feedback comes to the conclusion that not all barriers can be solved with TMG, as other restrictions such as ensuring a barrier-free museum, e.g. the way to and in the museum, must be taken into account.[CDS]

5.2 Design Process

Figure 5.2 is showing a selection of changes in user group, data volume, types and management, as well as the graphical user interface. The user interface design process began with the participants' need for more visual feedback in 2017. After some research and collecting existing knowledge from our ARCHES partners, a new design concept of the new graphical user interface (GUI) was created. During the design process, the user group of blind and visually impaired (BVI) user was extended to users with different access preferences. From January 2018 to June 2019, design iteration with user evaluation was performed every three to six weeks. A design iteration consisted of feedback input, data preparation and prototyping. In March 2019, the design adaptions were completed.

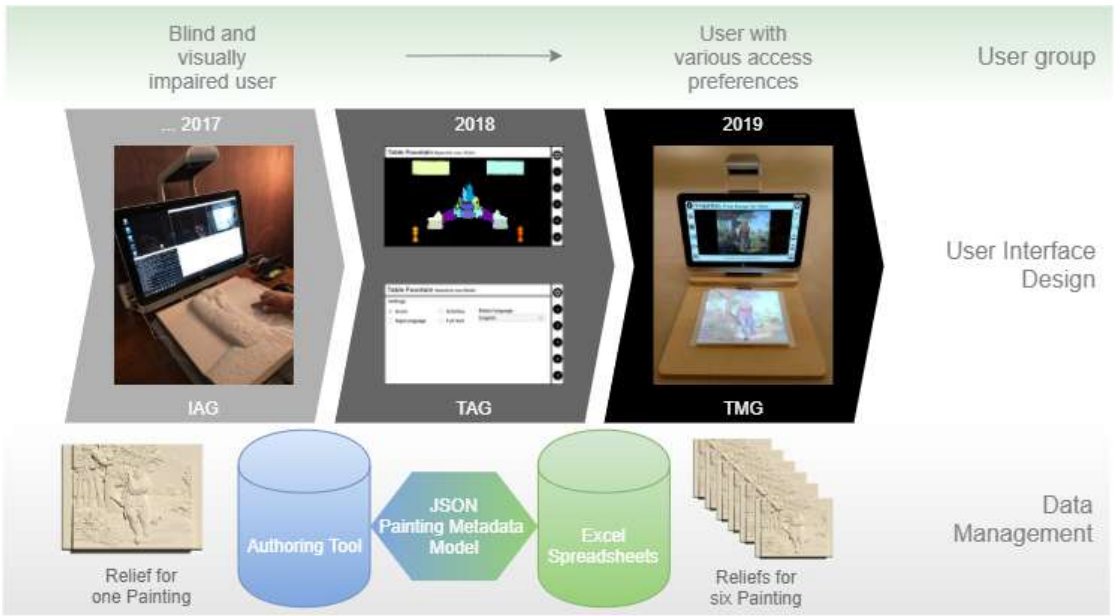


Figure 5.2: Overview of the design process

The user evaluation was performed by trained staff of the museums and universities of the ARCHES team. In these sessions, the participants developed ideas, tested prototypes and helped shape the outcome of the final Tactile Multi-Media Guide (TMG). An average of 14 people with different access preferences take part in a session. During the user evaluation, the participants receive one to one support from the trained staff. Not only software prototypes are tested, but also design concepts are discussed. With paper prototypes of the graphical user interface design the usability is evaluated. Usability Testing Technique helps to specify the different requirements and detect design weaknesses. Using paper printouts of the works of art, audio texts were also tested in advance. A large printout was placed in front of the participants. By pointing at an specific area, the a trained staff member reads the corresponding text to the participant. With design changes came also the change of name from Interactive Audio Guide (IAG) to Tactile Audio Guide (TAG).

5.2.1 Tactile Audio Guide (TAG)

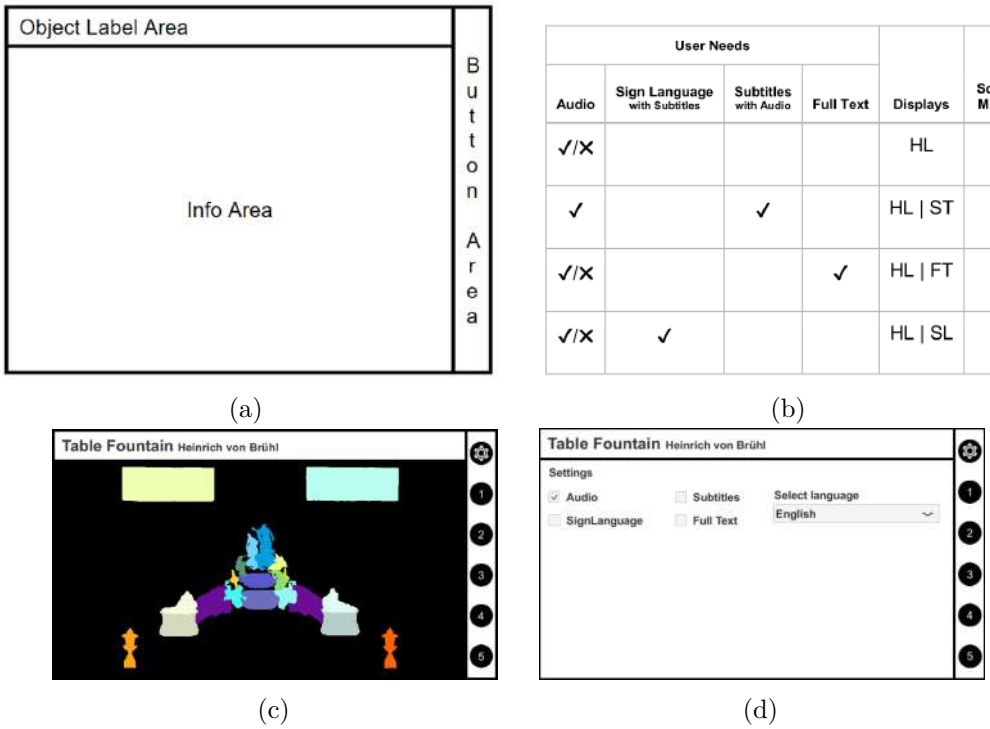
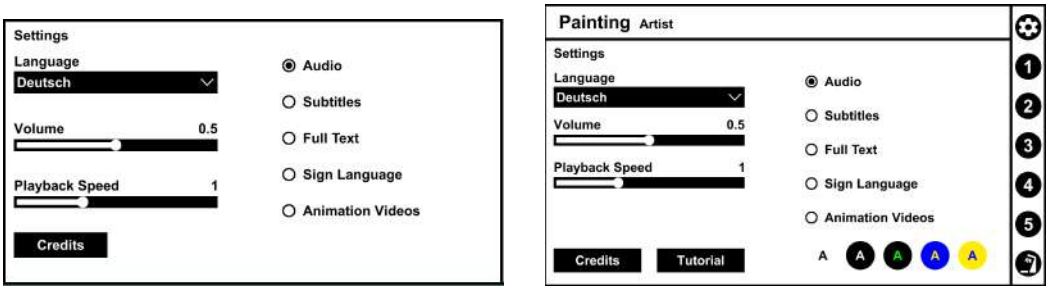


Figure 5.3: First user interface mock up from the TAG. (a) Screen Layout (b) Table of user needs (c) User interface with example painting with coloured sections and (d) user interface with opened Settings Menu.

First, we collected gained information from our ARCHES partners, as well as related research projects. A use cases table and a division of the screen into three parts (Object Label Area, Info Area and Button Area) was created, Figure 5.3 (a and (b). The two coloured design concept was introduced in this early design stage. The user interface

is designed simple. Important information, which is often used, is placed in the first screen, Figure 5.3 (c). The Button Area consists of buttons 1 to 5 (Additional Artwork Information) and the Accessibility Settings button. The settings in the first mock up consisted of Audio, Subtitle, Sign Language, Full Text and a Language dropdown list.

As shown in Figure 5.4, the Settings Menu was redesigned for better readability, as well as volume and playback speed sliders were added. The five projections on the relief were planned as a dropdown list for in the Settings Menu. Participants used them a lot, so we planned different design versions. Figure 5.4 (b) shows a design version evaluated with paper prototypes. Participants did not like the *On Relief Projection* button below the button 5. Also the five two coloured designs were introduced.



(a) (b)

Figure 5.4: User interfaces after some design iterations. (a) Settings Menu (b) Mock up for paper prototype testing: Settings Menu redesign with additional playback speed and volume sliders, colour schemes and additional *On Relief Projection* button.

Figure 5.5 is showing the interaction flow chart from its *Inactive* state with first user interaction to the *Main Mode* state. If a hand is detected, the tutorial video is played. The tutorial is followed by the information about the artwork and its artist. The *Main Mode* represents the interaction with the relief by touching with a finger a section of it.

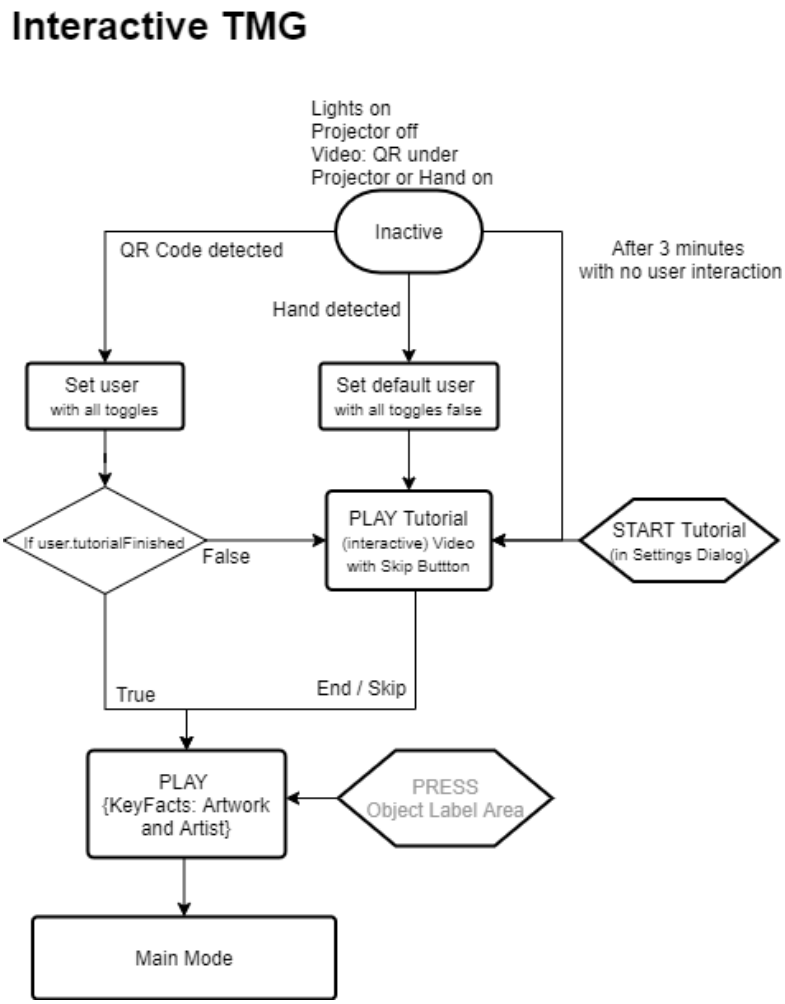


Figure 5.5: Interaction flow chart by first user interaction.

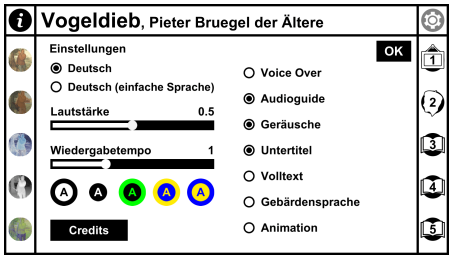
5.2.2 Tactile Multi-Media Guide (TMG)

(a)

User needs				Displays	Screen Modes
Audio	Subtitles	Full Text	Sign Language		
✓ / ×				HL	1
✓ / ×	✓			HL | ST	2
✓ / ×		✓		HL | FT	3
✓ / ×			✓	HL | SL	4

(b)

(c)



(d)

Figure 5.6: Final user interface design from the TMG. (a) Screen Layout (b) Table of user needs (c) User interface with artwork displayed (d) user interface with opened Settings Menu.

As shown in Figure 5.6 (c) and (d), the resulting user interface design of the TMG is more complex as the initial design, Figure 5.3. The user interface is now split into six areas, with additional *Tutorial* button and *On Relief Projection* buttons on the left side of the user interface. The icons of buttons 1 to 5 also have a new design. Instead of the coloured section, the original artwork is now displayed. In the Settings Menu, the language dropdown list has been replaced with toggle. In addition, Voice Over, Interaction Sounds and Animation can now be activated. Chapter 4 explains in detail the design and interaction of the Tactile Multi-Media Guide.

CHAPTER 6

Conclusion and Future Work

Designing for and with people with various access preferences has led me to seeing the world through their eyes and keeping them in my mind during future design processes.

6.1 Conclusion

This thesis was part of the *Accessible Resources for Cultural Heritage EcoSystems* (ARCHES) project, which was focused on creating more inclusive cultural environments, especially for visitors with various visual, hearing and cognitive access preferences. The ARCHES team consisted of six museum, four technology companies and two universities. The project was designed around the participatory approach. Over two hundred people with different disabilities met regularly in the museums in England, Spain and Austria. They developed ideas, tested prototypes and helped shape the outcome of the project.

This thesis introduced, developed and evaluated a new technology that showed how to make art accessible for all visitors. The solution demonstrated with a combination of hardware, software and tactile reliefs in a feasibility study on how to enable access to artworks. In multiple design iterations with regular testing with participatory research groups in three different countries, this thesis answered the question on how to design a user interface to be accessible for the audience and concluded on how to process multi-media data for selected artwork. The foundation of a this thesis was an existing gesture-based audio guide with one relief. The contribution of thesis helped evolving to the Tactile Multi-Media Guide with a user interface that can be configured to various access preferences. Further, the previous prototype was expanded to cover six artworks as well. The combination of the *Painting metadata model*, *JSON*, *Excel spreadsheets* helped with loading a lot of data during run-time, as well as making quick adjustments without having the need to create a new build. This enables faster deployment and adjustments for new artworks. The thesis concludes with a standalone mixed reality solution that can

be used in a museums context. The final prototype can be visited in small groups at the ARCHES museums partners.

The ARCHES project, as a bridge between art, technology and science, was honoured with three awards:

- IIID Award 2020 in the category *Social Affairs*.
- Zero Project Award 2020
- eAward 2020

6.2 Future Work

With the TMG we have created a solid basis for further developments for *accessible for all* designs. Among others, we would like to suggest the following improvements and ideas:

Tactile Stickers for the touch screen. As further support for blind and visually impaired (BVI) users, we have thought about tactile stickers on the touch screen of the HP Sprout. These will serve as guidelines for navigating the interface elements. In combination with braille stickers, you can identify desired elements.

User settings with QR Codes. We have tested QR Codes for quick and easy setting changes. A QR Code is held under the projector and the TMG is automatically switched to the desired access preferences. In the future, the desired settings could be set in a smartphone app, which automatically generates a QR Code.

Reducing user interface input on screen. To ensure independent use of TMG, we have placed the buttons at the edge of the interface. They encircle the artwork displayed on screen, Information Area. Therefore, the buttons could be embedded in the future in the wooden frame, which encloses the tactile relief, see Figure 5.1(d) setup with wooden frame.

From the museum to the educational institutions. Due to the compact setup of HP Sprout (hardware), a wooden frame and the reliefs, it can be used e.g. in schools. Shi et al. already shows the use of 3D models to close the educational gap.[SLZA19]

Relief printer To reduce costs as well as storage space for the tactile reliefs, a patent for a prototype for a so-called *relief printer* was already granted during the ARCHES project. This technology would allow a wider range of the application.

Appendix

Authoring Tool

This attachment describes the authoring tool developed in early stage of the ARCHES project, before it further developed into the Tactile Multi-Media Guide for people with various access needs. This is an extract from the Deliverable D5.2 (Chapter 3.2.4, Page 43 to 47)[RTS+19]:

"The Tactile Audio Guide evolved from a previous project.[RCW+18] This prototype implementation was only targeted at a single relief, for demonstration purpose, and all interaction and content was hard-coded in the program code. In ARCHES we build on this prototype, but intend to open it for many reliefs. Therefore, it is necessary to remove the hard-coded content for the one relief from the program, and let the program load it from multiple places on demand. We developed a content description file format and a folder structure for the content, and started implementing a first version of an authoring tool, that allows creating the description file and folder structure for the reliefs. Currently it is implemented as an internal tool, but our intention is, that by the end of the project, this authoring tool will allow museum staff to easily edit the textual and auditory data for their reliefs, as well as to change the default settings. As mentioned above the current implementation of the Tactile Audio Guide offers up to five general descriptions, and one description each of an arbitrary number of regions on the relief. Similarly, the current state of the Authoring Tool focuses on exactly this content, and already tries to create a hierarchy of regions, that will later allow to divide larger regions (e.g., a whole figure) into smaller regions (e.g., head, body, arms, legs,...). As the development started, before the reliefs for ARCHES were created, all examples are based on the relief for Gustav Klimt's "Der Kuss" created in the previous project AMBAVis.[RCW+18] There is a single resource folder for the application in which all relevant content is stored (cf. Figure 1).

Figure 1: Resources folder.

All general content that is required for each relief is located under the "general" folder. It currently consists of the audio files for the sound effects as well as some text that is used for each relief, e.g., the spoken numbers 0 to 5. There are different sub-folders for different languages. Each painting has

its own folder inside the resource folder, containing all content specific to the painting:

- Audio files (.wav), which are stored in the corresponding subfolder of each language (e.g. “Audio_de”, “Audio_en”, . . .),
- Painting label picture (.png), which specifies the interactive regions on the painting JSON file (e.g. “Der Kuss.json”), as the root specification of the content.

The JSON file (see snippet in Figure 2) is loaded first. It contains all textual information, and links to all the other information.


```
"Name": "Der Kuss",
"SectionGroups": [
  {
    "Name": "Intro",
    "TextualAudioDescriptions": [
      {
        "Language": "en",
        "title": "Welcome to the interactive touch relief of Gustav Klimt's \"The Kiss\".",
        "Body": "Please explore the relief with your hands, as you like. If you want to know
        "TitleAudiofile": "_Intro.wav",
        "BodyAudiofile": "",
        "CanBeInterrupted": true,
        "IsStoppable": true
      },
      {
        "Language": "de",
        "title": "Herzlich Willkommen zum Interaktiven Tast-Relief zu Gustav Klimts „Der Kuss
        "Body": "Bitte ertasten Sie das Relief nach belieben mit beiden Händen. Um mehr über
        "TitleAudiofile": "_Intro.wav",
        "BodyAudiofile": "",
        "CanBeInterrupted": true,
        "IsStoppable": true
      }
    ],
    "Sections": [
      {
        "Name": "Brief description of the painting",
        "Color": "#FFFFFFFF",
        "TextualAudioDescriptions": [
          {
            "Language": "de",
            "title": "1. Der Kuss - Kurzbeschreibung des Gemäldes",
            "Body": "Auf dem Gemälde ist ein eng umschlungenes, junges Liebespaar zu sehen. D
            "TitleAudiofile": "_brief description of the painting_.wav",
            "BodyAudiofile": "_brief description of the painting.wav",
            "CanBeInterrupted": true,
            "IsStoppable": true
          },
          {
            "Language": "en",
            "title": "1. Brief Description of the Painting",
            "Body": "The painting shows two young lovers locked in an embrace. The couple is
            "TitleAudiofile": "_brief description of the painting_.wav",
            "BodyAudiofile": "_brief description of the painting.wav",
            "CanBeInterrupted": true,
            "IsStoppable": true
          }
        ]
      },
      {
        "Name": "The artist Gustav Klimts",
```


Figure 2: Part of an example JSON-File describing the content for the interactive audio guide.

The structure of the painting is also described in the JSON file. As a preparation for the aforementioned hierarchical labels, a painting consists of sections that are assigned to section groups. Section groups and sections have textual and audio data per language,

as seen in the file “Der Kuss.json”. At the start the program loads all JSON files of the paintings from the resource folder. The painting of the kiss consists of the following sections, as can be seen in Figure 3: background, halo, signature, tendrils, meadow, male figure head, male figure cloak, etc.

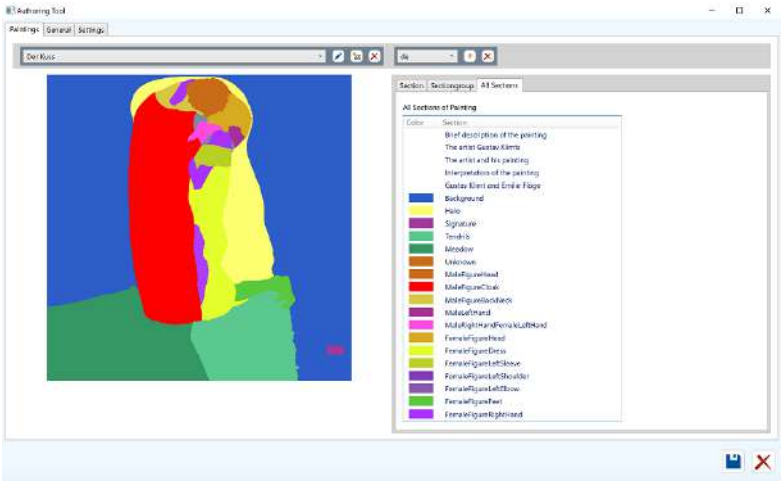


Figure 3: Sections of a picture.

In order to make it easier to handle, they are subordinate to section groups. As can be seen in the table in Figure 4, the section group “Malefigure” consists of the sections: head, coat, back and neck, left hand and the right hand of the man and the left hand of the woman. The Figure 4 shows that the painting “Der Kuss” with Language “de” (short for German) and the male figure is selected. Now it is possible to edit the title and detail description of this section group. The audio file of each textual description can be played or can be set again.If you click on a section (e.g., male figure cloak) on the label picture the tab automatically changed to “Section” and the correct section is selected (cf. Figure 5).

The selected section is highlighted with the same colour as the section in the label picture. Also the correct section group is displayed. The textual and audio description can be edited in the section tab.

Changing the general structure is facilitated by adding, moving or deleting section groups or sections. This structure change is edited for all languages at once. After the paintings have been edited, they will be saved by clicking on the storage icon on the right bottom.

Similarly, general texts and sounds across all reliefs can be set under the “General” tab, as well as other settings under the “Settings” tab (cf. Figure 6). The authoring tool already allows switching between the different paintings and will be expanded in the future in order to allow authoring the new interaction modes yet to be developed."

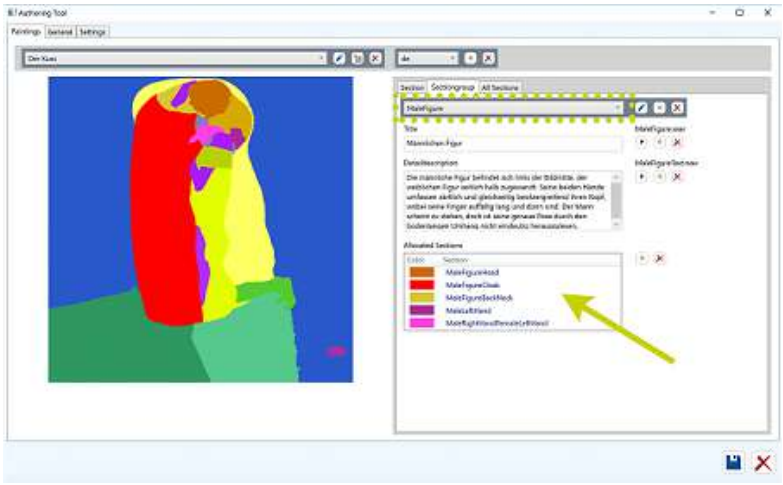


Figure 4: Subdivision of section group.

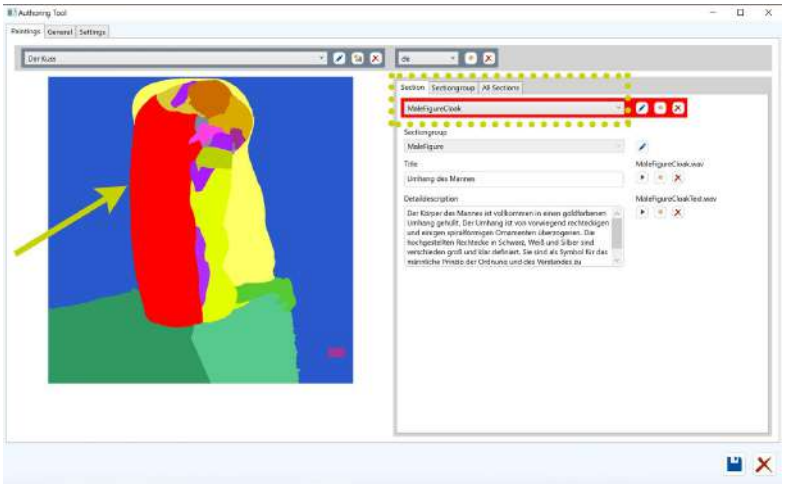


Figure 5: Section “cloak” selected.

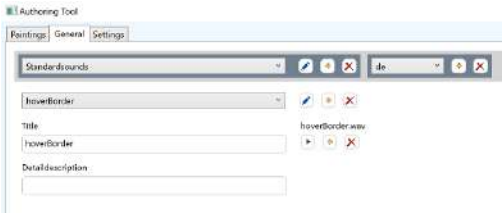


Figure 6: General sound settings.

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Acronyms

BVI Blind and visually impaired. 2, 3

GUI Graphical User Interface. 23, 29, 42

IAG Interactive Audio Guide. xiii, 2–4, 15, 23

TMG Tactile Multi-Media Guide. 4, 29, 31

Bibliography

[BG17] Verena Blöchl and Katharina Götzendorfer. *Eye to Ear - Gallery of Audible Images*, 2017. http://eyetoear.com/, Masterthesis at University of Applied Arts Vienna (accessed July 25, 2018) https://phaidra.bibliothek.uni-ak.ac.at/detail_object/o:7712.

[BLG15] Johan Borg, Ann Lantz, and Jan Gulliksen. Accessibility to electronic communication for people with cognitive disabilities: a systematic search and review of empirical evidence. *Universal Access in the Information Society*, 14(4):547–562, 2015.

[BQK+18] Jorge Iranzo Bartolomé, Luis Cavazos Quero, Sunhee Kim, Myung-Yong Um, and Jun-Dong Cho. Exploring art with a voice controlled multimodal guide for blind people. In *Tangible and Embedded Interaction*, 2018.

[Bra06] Eva Brandt. Designing exploratory design games: A framework for participation in participatory design? In *Proceedings of the Ninth Conference on Participatory Design: Expanding Boundaries in Design - Volume 1*, PDC '06, pages 57–66, New York, NY, USA, 2006. ACM. http://doi.acm.org/10.1145/1147261.1147271.

[BSV] BSVÖ. *Austrian Federation of the Blind and Partially Sighted (BSVÖ)*. (accessed May 26, 2020) https://www.blindenverband.at/.

[CCR+08] Ben Caldwell, Michael Cooper, Loretta Guarino Reid, Gregg Vanderheiden, Wendy Chisholm, John Slatin, and Jason White. Web content accessibility guidelines (wcag) 2.0. *WWW Consortium (W3C)*, 2008.

[CDS] Helena Garcia Carrizosa, Jara Diaz, and Felicitas Sisinni. Towards a participatory museum. (accessed January 24, 2019) https://www.arches-project.eu/wp-content/uploads/2019/07/EnglishGuide_Hyperlinks.pdf/.

[CH19] Helena Garcia Carrizosa and Simon Hayhoe. Arches project: validation of technological outcomes of gaming software based on a participative research methodology. *Technology and Disability*, 31(s1):16–17, 2019.

[Cro18] D. Crockford. *How JavaScript Works*. Virgule-Solidus LLC, 2018. https://books.google.at/books?id=csUwvQEACAAJ.

[GCDKSG19] Helena Garcia Carrizosa, Jara Diaz, Rotraut Krall, and Felicitas Sisinni Ganly. Cultural differences in arches: A european participatory research project—working with mixed access preferences in different cultural heritage sites. *The International Journal of the Inclusive Museum*, 12(3):33–50, 2019.

[Hay17a] Simon Hayhoe. *Blind visitor experiences at art museums*. Rowman & Littlefield, 2017.

[Hay17b] Simon Hayhoe. A model of inclusive capital for analysis of non-economic human capital. 2017.

[Hay18a] Simon Hayhoe. An autoethnography of a hearing-impaired researcher in museum-based participatory research. In *A PARTICIPATORY MUSEOLOGY: How can we research participation in art galleries, museum and heritage organisations?*, 2018.

[Hay18b] Simon Hayhoe. Classic philosophies on blindness and cross-modal transfer, 1688-2003. 2018.

[Hay18c] Simon Hayhoe. Flipping descriptions: a new phase of democratising audio description. *Vocal Eyes*, 2018.

[Hay18d] Simon Hayhoe. Inclusive capital, human value and cultural access. *The Routledge Handbook of Disability Arts, Culture, and Media*, 2018.

[HCC19] Simon Hayhoe, Ruby Cohen, and Helena Garcia Carrizosa. Locke and hume's philosophical theory of color is investigated through a case study of esref armagan, an artist born blind. *Journal of Blindness Innovation and Research*, 2019.

[HCR+18] Simon Hayhoe, Helena Garcia Carrizosa, Jonathan Rix, Kieron Sheehy, and Jane Seale. Accessible resources for cultural heritage ecosystems (arches): Initial observations from the fieldwork. In *Educational Research Association of Singapore (ERAS) Asia-Pacific Educational Research Association (APERA) International Conference 2018: Joy of Learning in a Complex World*, 2018.

[HGCR+19] Simon Hayhoe, Helena Garcia Carrisoza, Jonathan Rix, Sheehy Kieron, and Jane Seale. Deliverable d6.5 evaluation of pilot exercises arches-eu-project (grant agreement no. 693229). 2019.

[Hil] Hilfsgemeinschaft. *Austrian Association for the Blind and Visually Impaired*. (accessed May 26, 2020) https://www.hilfsgemeinschaft.at/.

[HPS17] Simon Hayhoe and Noemi Pena-Sanchez. Interactive demonstration on the use of existing apps on mobile technologies to teach basic photographic techniques to participants who are blind, visually impaired and sighted together: A demonstration of an exercise using apps and cameras on ios and android platforms to image" the body" and handwriting. In *2017 14th IEEE Annual Consumer Communications & Networking Conference (CCNC)*, pages 622–623. IEEE, 2017.

[KH11] James M Kauffman and Daniel P Hallahan. *Handbook of special education*. Routledge, 2011.

[Kha16] Zabrina Khan. *Visual Art for the Visually Impaired: Designer-User Interactions in Developing 3D-Printed Tactile Models to Facilitate Access to Museum Art*, 2016. Doctoral dissertation at University of Vienna, (accessed July 26, 2018) http://othes.univie.ac.at/41677/1/2016-04-06_1306023.pdf.

[Neu18] Moritz Neumüller. *The Routledge Companion to Photography and Visual Culture*. Routledge, 2018.

[NN11] Jay Neitz and Maureen Neitz. The genetics of normal and defective color vision. *Vision research*, 51(7):633–651, 2011.

[oCI18] Dr. Angelos Amditis – Institute of Communication and Computer Systems (ICCS). *EU Project: PLUGGY - Plug into Cultural Heritage.*, 2018. (accessed July 24, 2018) https://www.pluggy-project.eu/.

[OGGL15] Sile O'Modhrain, Nicholas A Giudice, John A Gardner, and Gordon E Legge. Designing media for visually-impaired users of refreshable touch displays: Possibilities and pitfalls. *IEEE transactions on haptics*, 8(3):248–257, 2015.

[Org18] World Health Organization. *Disabilities*, January 2018. (accessed May 26, 2020) https://www.who.int/topics/disabilities/en/.

[Org19] World Health Organization. *Blindness and vision impairment*, October 2019. (accessed May 26, 2020) https://www.who.int/en/news-room/fact-sheets/detail/blindness-and-visual-impairment.

[PTGG18] Hari Prasath Palani, Jennifer L Tennison, G Bernard Giudice, and Nicholas A Giudice. Touchscreen-based haptic information access for assisting blind and visually-impaired users: Perceptual parameters and design guidelines. In *International Conference on Applied Human Factors and Ergonomics*, pages 837–847. Springer, 2018.

[RCS+19] Jonathan Rix, Helena Garcia Carrizosa, Jane Seale, Kieron Sheehy, and Simon Hayhoe. The while of participation: A systematic review of participatory research involving people with sensory impairments and/or intellectual impairments. *Disability & Society*, pages 1–27, 2019.

[RCT18] Andreas Reichinger, Helena Garcia Carrizosa, and Cornelia Travnicek. Designing an interactive tactile relief of the meissen table fountain. In *International Conference on Computers Helping People with Special Needs*, pages 209–216. Springer, 2018.

[RCW+18] Andreas Reichinger, Helena Garcia Carrizosa, Joanna Wood, Svenja Schröder, Christian Löw, Laura Rosalia Luidolt, Maria Schimkowitsch, Anton Fuhrmann, Stefan Maierhofer, and Werner Purgathofer. Pictures in your mind: Using interactive gesture-controlled reliefs to explore art. *ACM Transactions on Accessible Computing (TACCESS)*, 11(1):2, 2018.

[RFMP16] Andreas Reichinger, Anton Fuhrmann, Stefan Maierhofer, and Werner Purgathofer. Gesture-based interactive audio guide on tactile reliefs. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility*, pages 91–100. ACM, 2016.

[RGCH+20] Jonathan Rix, Helena Garcia-Carrizosa, Simon Hayhoe, Jane Seale, and Kieron Sheehy. Emergent analysis and dissemination within participatory research. *International Journal of Research & Method in Education*, pages 1–16, 2020.

[RMP11] Andreas Reichinger, Stefan Maierhofer, and Werner Purgathofer. High-quality tactile paintings. *Journal on Computing and Cultural Heritage (JOCCH)*, 4(2):1–13, 2011.

[RNR+12] Andreas Reichinger, Moritz Neumüller, Florian Rist, Stefan Maierhofer, and Werner Purgathofer. Computer-aided design of tactile models. In *International Conference on Computers for Handicapped Persons*, pages 497–504. Springer, 2012.

[Rod16] Rikard Rodin. A graphic designer's guide to visual hierarchy. *Blog, Design, Designer's Guide, Tutorials, Typography*, sep 2016. (accessed Sept 9, 2019) https://zevendesign.com/designers-guide-to-visual-hierarchy/.

[RSL+16] Andreas Reichinger, Svenja Schröder, Christian Löw, Sam Sportun, Peter Reichl, and Werner Purgathofer. Spaghetti, sink and sarcophagus: design explorations of tactile artworks for visually impaired people. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction*, pages 1–6, 2016.

[RTS+19] Andreas Reichinger, Cornelia Travnicek, Maria Schimkowitsch, Moritz Neumüller, Helena Garcia-Carrzosa, John Wood, Laura Luidolt, and Daniela Stoll. Deliverable d5.2 arches-eu-project (grant agreement no. 693229). 2019.

[SGCR+18] Jane Seale, Helena Garcia-Carrisoza, Jonty Rix, Kieron Sheehy, and Simon Hayhoe. A proposal for a unified framework for the design of technologies

for people with learning difficulties. *Technology and Disability*, 30(1-2):25–40, 2018.

[SGCR+19a] Jane Seale, Helena Garcia Carrizosa, Jonathan Rix, Kieron Sheehy, and Simon Hayhoe. A participatory approach to the evaluation of participatory museum research projects. *International Journal of Research & Method in Education*, pages 1–21, 2019.

[SGCR+19b] Kieron Sheehy, Helena Garcia Carrizosa, Jonathan Rix, Jane Seale, and Simon Hayhoe. Inclusive museums and augmented reality. affordances, participation, ethics and fun. *The International Journal of the Inclusive Museum*, pages In–Press, 2019.

[SLZA19] Lei Shi, Holly Lawson, Zhuohao Zhang, and Shiri Azenkot. Designing interactive 3d printed models with teachers of the visually impaired. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, CHI '19, page 1–14, New York, NY, USA, 2019. Association for Computing Machinery.

[Won11] Bang Wong. Points of view: Color blindness, 2011.

[Wor19] Disabled World. *Disabilities: Definition, Types and Models of Disability*, December 2019. (accessed May 26, 2020) https://www.disabled-world.com/disability/types/.