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Can't touch this - A Prototype for Public Pointing Interaction

Master Thesis

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Affidavit

Affidavit

I hereby declare that this master thesis has been written only by the undersigned and without any assistance from third parties. Furthermore, I confirm that no sources have been used in the preparation of this thesis other than those indicated in the thesis itself, as well as that the thesis has not yet been handled in neither in this nor in equal form at any other official commission.

Michael Pannier

Abbrevations

MS	Microsoft
RFID	Radio-Frequency Identification
FSD	Functional Specification Document
MIT	Massachusetts Institute of Technology
SDMS	Spacial Data-Management System
WYSIWYG	”What you see is what you get”
GUI	Graphical User Interface
SUI	Single-User Interface
MUI	Multi-User Interface
HCI	Human Computer-Interaction
TUI	Tangible User Interface
VR	Virtual Reality
3D	three-dimensional
HMD	head-mounted display
DOF	degrees of freedom
AR	Augmented Reality
SDK	Software Development Kit
2D	two-dimensional
BCI	Brain-Computer Interface

MVT Museumsverband Thüringen

HDD Hard Disk Drive

PDLC Polymer Dispersed Liquid Crystal

IR infra-red

FUBI Full Body Interaction Framework

1 Abstract

Museums tend to be perceived as old fashioned. At least, that is what some people assume and therefore not even consider having a look for themselves. Nevertheless, there are many modern and open minded ones, which are willing to experiment with new possibilities, to get rid of their dusted reputation and to evolve.
So, I was called to do exactly that. – Implement a novel informatory interaction system for a museum of pre- and protohistoric history, where precious artifacts are locked up behind thick glass. The challenge was not only to develop a working prototype, but also make it intuitive, low maintenance and robust enough for everyday use. The system I developed employs the natural behavior of visitors. It detects potential users and enables them to interact with the system via pointing-gestures. Moreover, it can easily been set up and altered by museum personnel.

2 Introduction

In the beginning, there only was a raw concept of collaboration with a local museum to develop an innovative museum installation. The installation would be interactive and based on in- and output modalities that actually make sense in a museum. Therefore, visitors and staff should be observed and interviewed. Further, it was planned to use Microsoft (MS) Gadgeteer-hardware[1] as embedded components of tangible devices. I looked out for suitable museums in Weimar and found some interested ones. Later, I narrowed them down to a single one, which had the most fitting properties and attitude. Together, we conceived some ideas for possible installations. Not all of them were applicable or to far off my expertise. Nevertheless, there were two concepts, we were very interested in and excited about.

The first concept, *"Interaction with Tangibles"*, was directly addressing the visitors' haptic perception. A number of reproductions could be placed outside the showcase. Each somehow interactive tangible could then be manipulated or placed on a pedestal to gain information about its corresponding exhibit. Here, certain exhibits could have been photogrammetically scanned in three dimensions. After that, the digital model could be scaled to a handy size and otherwisely modified. Ultimately, the tangible could be printed or casted. Such an object could then be enhanced by using Radio-Frequency Identification (RFID)-technology[2]. In order to make it interactive, it would be fitted with such a RFID-tag. There is a RFID-module for Gadgeteer, which would have allowed identification of each tangible. The corresponding information could then be provided by any medium compatible with Gadgeteer.

A completely opposing approach was based on an assumption of natural behavior of

1 MS Gadgeteer is a modular system of various hardware-components distrubuted by GHI Electronics. It resembles Arduino- and other microcontrollers.

2 RFID-transponders or -tags do not require any batteries, are cheap and robust. In addition, their range is very limited, which allows several tags on one tangible.

visitors. After a meeting at the museum, a second concept of *"Interaction by Pointing"* emerged. Later the underlying assumption was confirmed by the observation of visitors' behavior around showcases. Whereupon, visitors do not only talk about exhibits, but they also point at certain exhibits during interaction with each other. Therefore, a device should be build or utilized to point into the showcase and select a certain exhibit. Additional information of it would then be displayed in an appropriate manner.
These concepts were fairly comprehensible, but their exact technical realizations were not this clear, yet. Throughout further investigations, the work turned from testing various modes of input to a more technical approach. Both ways of input are fairly special and revealed different challenges along the way.

Throughout the following chapters I documented my proceedings during the development of the aforementioned system. Chapter 3 gives basic information about the fields of study, which are included in my work. Thus, there is a brief outline about the progression of technologies employed by museums, users behavior around public interfaces and with tangibles. In addition, a brief overview of virtual reality-techniques is given.
Afterwards, I describe my goals for the development of this system. Before I come to explain the schematics and evaluation of my implementations, I give a short review of my partnering process. Thus, chapter 4 deals with finding the fitting museum for a collaboration.
Conception explains the whole development-process of the system's schematics and functionality. It begins with possible system designs and explains their possibilities and constraints. In the end of chapter 5, the final concept is shown along with necessary obligations such as an Functional Specification Document (FSD) and the contract between me, the university and the museum.
Chapter 6 addresses the implementation of the system's functionality. Therefore, all libraries and softwares are explained in more detail.
Experimental lab-installations and the final museum-installation are described in chapter 7. Therefore, measurements, hardware specifications, and other influential criteria are presented in detail.
The final installation is evaluated in chapter 8, where visitors were observed and interviewed before and after alterations by the system. Chapter 9 then deals with the discussion of the evaluation's findings.
In the end, I thought about future work, which could improve, extend, and follow my sys-

tem. In chapter 10, I would also like to mention reactions and suggestions I encountered along my work.

3 Background and Motivation

Over time public places became more and more enriched with all kinds of technology. Nowadays, on nearly every corner something is beeping or blinking and buttons, leavers and knobs make us - their potential users - interact with our environment. This trend does not spare anyone or anything. Even traditionally calm and sophisticated places open up to the possibilities of contemporary technologies.

3.1 Museums

Museums, much like libraries, are foremost seen as a place of knowledge and its preservation. Hence, visitors behave in a very reserved manner. Whilst applying for libraries, museums are willing to involve people instead of merely providing information. Many Museums therefor employ guides, who give tours and tell visitors about the exhibits. In addition to their factual knowledge, they also provide interesting anecdotes and other exciting information needed to bond with a certain topic. Apart of instructive and teaching staff, museums have tried many other ways to involve their visitors. One of those is employing technology. With time technology evolved, and so did technological augmentations in museums.
The name "museum" comes from the ancient greek's "Museion". It describes an, in honor of a muse, sanctified place [Mus14a]. Basically, museums are collections of arts and science or at least parts of them on display. In modern history, those collections were of an artistic nature and mostly private. Later, scientific and otherwise cultural museums were established for the general public.
One of the first high-tech installation of the modern age was the *Diorama*. In 1821,

Louis Jacque Mandé Daguerre[3] and the painter Charles Marie Bouton partnered up to develop this spectacle. It is an elaborate combination of painting and lighting [Woo93]. Through ingenious lighting, the paintings became vivid. This way, a diorama could simulate the moods of a whole day within minutes. Thus, it might be seen as an early predecessor of the cinema. Even today, although in much smaller size, dioramas are still thematised [Sch14].
The first interactive displays appeared at the *Urania* in Berlin around 1889, when they introduces visitor-activated models and a scientific theater. In 1907 the *Deutsches Museum* in Munich also began experimenting with film and mechanical models, which were operated by visitors [McL93]. Later, other museums all over the world followed. Since then the

> [...] wider museological community's understanding of nature and purpose of interactiveness

has taken shape.

> This understanding almost invariably involves:
>
> 1. The presence of some technological medium.
> 2. A physical exhibit which is added to the main display.
> 3. A device which the visitor can operate, involving physical activity. [Wit08]

As electronics and microchips evolved, computers became popular and affordable. The technological equipment of museums grew with what was available and new kinds of devices and installations appeared. Today, nearly every museum has a certain guide system such as an audio guide. It either leads visitors through the museum on a predefined course or a visitor can choose the track according to a given code for each included exhibit. In 2004, Chou et al. compared different museum guide systems in various categories, which were considered necessary to provide a user-friendly and informative experience. Expositors, tape machines, CD-players and a PDA were judged. The PDA was most versatile and easy to use system [CWH+04] (*see Figure*). The described system had the portability of an audio guide, but due to position recognition the PDA would

3 Daguerre is a scene painter and stage designer by trade. He also is the inventor of the first photographic process called daguerreotypy

always present the current exhibit. The system could replace common audio guides and immobile information terminals all together. In addition, it still was able to give predefined tours depending on the user's interests.
Yet another chapter was opened, when the internet and wireless communication were introduced. Museums began to also maintain websites. Burgard et al. went a step further, included robotics and build an autonomous tour-guide robot called *RHINO*. It was able to navigate through the museum freely and without bumping into visitors. On demand, RHINO worked as an information terminal for present visitors and it could be used as a tour-guide as well, because it had a simple build-in web interface. Thus, the museum's contents where simultaneously used by the website and the robotic tour-guide. RHINO was deployed at the *Deutsches Museum Bonn* in 1998.

In 2002, a group from the *University of Limmerick* made a survey in *Hunt Museum*. The museum is owned and run by the Hunt-family. Its tradition is to involve the visitors since its early days. Therefor, they had so-called *cabinets of curiosity* [Cio02], special compartments within the exhibition, where additional exhibits were hidden. For example, a curious visitor had to open drawers in order to find a collection of plates. Via this exploration, the visitors became involved. Inspired by their observations, Ciolfi et al. implemented a completely new and interactive part of the exhibition in 2005 [Cio05]. Two new rooms were introduced. First, there was the *study room* with three interactive devices for getting further information about certain exhibits. They were disguised as a chest, a painting and a desk. The second room, the *room of opinion*, was plain white with plinths, on which visitors could record their interpretations of the intended function of certain exhibits. In order to manage all the data, a third and hidden room was used to host all the data-servers.
The *medien.welten*-exhibition at *Technisches Museum Wien* was not only showcasing technical devices from all eras and genres of modern media, it also invited visitors to make use of some. As Hornecker et al. described, throughout the exhibition users were given opportunities to produce their own medial content. The interfaces ranged from an abacus over a telegraph to a whole rebuild of a news-studio from an Austrian TV-channel. Visitors could not only use the devices, but store some of their produced contents in a *digital backpack* [Hor06]. This way, visitors did not only have an exciting experience, but also something to remember it by later.

3.2 Interfaces and Interaction

The only connecting link between user and system is the interface. It dictates the way of interaction and, therefore, whether the whole systems works or not. A ground breaking system is worth nothing without proper interaction between its operator and it. This presents the need for suitable kinds of input and feedback. Thus, Ben Shneiderman once introduced his *eight golden rules of interface design*:

1. Strive for consistency.
2. Enable frequent users to use shortcuts.
3. Offer informative feedback.
4. Design dialogs to yield closure.
5. Offer error prevention and simple error handling.
6. Permit easy reversal of actions.
7. Support internal locus of control.
8. Reduce short-term memory load. [Shn98]

Following this guideline should yield a well operable interface. However, there still might be particular difficulties for specialized or novel systems. Especially public user-interfaces bring new factors, which are not explicitly included in Shneiderman's rules. How should an interface behave,

- in order to invite users?
- on a user's first encounter?
- if there are multiple users?

The ideal interface should be as intuitive and naturally to use as possible. This requirement was already addressed in 1980 by Richard A. Bolt. He described the *Media Room* at Massachusetts Institute of Technology (MIT) as an office with a chair, a wall-sized screen and other analogue or electronic installations. The room's equipment allowed the user to navigate through the *Spacial Data-Management System (SDMS)* called *Dataland*. The user would sit down and had several input-devices at its disposal. One of them was

a small device that could measure its position and orientation in space. The device was used to calculate where on the big screen the user was pointing. In combination with simple voice-commands the user was able to create and manipulate geometrical primitives [Bol80].
Since then, this seemingly futuristic furnishing could not be established as a common way of interaction. Keyboard and Mouse are still the most widely used input-devices. Meanwhile, touchscreens and voice-recognition are closing the gap though. The principle of "What you see is what you get" (WYSIWYG)[4] became of ever greater importance. Many interfaces are designed with Shneiderman's rules and usability in mind. Developments in Human Computer-Interaction (HCI) seem promising. More intuitive devices and interfaces are developed and tested thoroughly.

There are basically two types of interfaces. A Single-User Interface (SUI) is designed to be operated by only one user, whereas a Multi-User Interface (MUI) can be operated by a group of users at once. However, there is no strict distinction between the two. People might look over a SUI's user's shoulder and give instructions, or a lone person could operate a MUI on its own. Another factor that influences how people use an interface is the occasion. Public interfaces, such as a kiosk system at a cinema or for photo-developing provide a GUI on a touchscreen. Those systems are intended to be used by a single user, but might also be confronted with groups. Azad et al. investigated how groups behave around such kiosks. Most groups approached the interface asynchronously. Meaning, one member is interacting with the system, while the others watch. As time passes, the rest of the group might get more active due to *intra-group communication*. They further observed, that

> there is a semantic, profound difference between pointing and touching. Users who point are communicating ideas within a social group and may not want the technology to treat it as input. [ARHL11]

Moreover, inter-group communication is also of great importance. Shyness or frustration may inhibit an individual or group from interacting with a system. Other, strange people

4 WYSIWYG first came up in the 1970s, when the first office-programs appeared. Due to different resolution-densities of displays and printers, it was necessary to show correct relations of letters and page. Later on, the term was synonymously used for Graphical User Interface (GUI)-elements.

can ease the use, when the act as an example or explain their actions to those shy or frustrated [HF14].

Interfaces can not only be categorized by their intended demographics. Input- and output-devices dictate the kind of interaction. As mentioned earlier, keyboard and mouse are being replaced with novel technologies. Touchscreens and voice recognition have become established means of input as well. Moreover, novel approaches towards interaction are made and influenced by novel possibilities in technology. Museums in particular strive for innovative interfaces to involve visitors and, therefore, tend to explore many fields of interactive possibilities.

> Interactive exhibitions are thriving, encouraged by a new approach to museology developed in response to current social demand and a much more participatory philosophy involving a redefinition of the concept of the museum in general and of the science museum in particular. [...] The classic concept of observation has been replaced by that of participation. [FB00]

A Tangible User Interface (TUI) are a very natural approach. Here, a tangible object represents a digital entity. This could be a virtual object or something more abstract like an operation or property. Those tangibles can be used to interact with a system or even each other. Ullmer et al. described the principle of *token and contraint*. Two name-giving types of tangibles are involved, tokens and constraints. They have two phases of interaction. At first, tangibles can be associated, which means that their physical shape dictates, whether tokens will or will not work with a particular constraint. After that, the constraints' properties dictate the further way of interaction as shown in *Figure ?4a,b,c* [UIJ05]. In comparison to ordinary interfaces, this kind of interaction offers way more haptic perception. This could increases the users' attention to the interface and as a consequence their involvement with a possibly related exhibit. Apperceptive and playful interfaces might raise visitors' involvement. So, groups of visitors tend to spend more time with an interactive exhibit, because the majority wants to make the experience for itself [FB00].

Virtual Reality (VR) provides a less tangible approach. Contemporary VR-systems offer a way to display and manipulate three-dimensional (3D) data in real-time. Users can be immersed into vast, 3D environments, which are projected on huge stereoscopic

displays or shown by a head-mounted display (HMD)[5]. Those systems require a special kind of interaction to either navigate through or select objects in the virtual environment. Therefore, special interaction metaphors were developed. Proper navigation can be realized via any input-device capable of six degrees of freedom (DOF)[6] and is rather familiar. But, since navigating to each object in order to select and manipulate it is inconvenient, a separate metaphor for interacting with objects had to be developed as well. Thus, a pointing device was introduced. In order to calculate its correct position and direction it has reflective markers in a unique pattern, which are then tracked by a system of infrared cameras (*see Figure 1c*) [AKKF10]. A virtual ray into the scene is calculated accordingly. Basically, objects can be selected by pointing at them and triggering selection in some way. *A survey of 3D object selection techniques for virtual environments* showed that 29 of 31 reviewed techniques were based on ray-interaction. The remaining two used a hand avatar like in *Figure 1a*. Both of them track a user's hand and one also applies ray-based leverage to extend reach [AA13].
In late 2010, Microsoft began selling the *Kinect for Xbox 360*. Independent drivers and software for it were developed almost immediately, which enabled developers and researchers to utilize the system's capabilities on regular computers. The official Software Development Kit (SDK) and *Kinect for Windows* followed about half a year later. Other devices like *ASUS' Xtion PRO* followed working with the identical internal hardware. The more detailed hardware specifications will be explained in chapter 5. This development introduced a low cost solution for user-tracking, whilst the aforementioned tracking systems for VR are very expensive. Several interfaces were developed making use of the hardware's potential. Thus, its performance and suitability for VR-tasks was examined. Ren and O'Neill stated that

> More and more information and other content is visualized and manipulated in 3D, bringing a corresponding increase in the importance of effective and usable 2D user interfaces. [RO13]

5 Recent, distinct examples are *Occulus Rift* and *Google Glasses*. While Occulus Rift provides a completely closed solution for 3D VR-environments, the Google Glasses are an Augmented Reality (AR)-approach. Here, additional information is displayed on top of perceived reality.

6 One DOF is either translation along or rotation around one spacial axis. Hence, there are six possible movements in 3D space.

Hence, they conducted two kinds of test. First, they looked into two-dimensional (2D) interaction techniques such as touchscreens and *freehand 3D* interaction and described similarities and differences. Accordingly, both techniques' WYSIWYG-approach makes them spontaneous and direct. This natural *walk-up-and-use* interaction style decreases the interaction cost for any possible user. Further, users are able to move freely, because there are no extra devices to pick up and operate [RO13]. In the second test, the low cost solution was evaluated for common 3D interaction techniques for VR-environments and came up with a *design guideline for 3D freehand interaction* [RO13].

- Avoid single actions with either high accuracy or keeping the hand up for long.
- Use goal crossing [AZ02] as a trigger.
- Map complex 3D-movements on 2D interaction.
- Use the extra dimension as a trigger.
- Avoid uncomfortable hand or arm positions.

In the end, Ren and O'Neill concluded:

> Freehand gestural selection enabled by a single low cost camera is a potentially valuable technique enabling flexible, low configuration interaction in 3D environments, without any requirement for dedicated devices to be worn on or carried by the user. With appropriate designs, freehand 3D interaction can share the appealing fluidity and immediacy of currently popular multi-touch surfaces, [...] enabling walk-up-and-use access to services, holding the promise of wide applications for ordinary users in everyday life. [RO13]

This was only a short overview of some existing interfaces and forms of input. There are more specialized interactions like tracking eye-movements or Brain-Computer Interface (BCI). The examples given above represent a general insight of how to interact with a system, as well as the breadth and versatility of possibilities.

3.3 Goal

After having gathered experiences with several of the aforementioned interaction techniques, I intended to combine those experiences into a unique interface. Especially the intuitive motivation behind tangibles, touch-based interfaces and the immersive nature of VR-environments are interesting fields.

> Unfortunately, current user interfaces often lack adequate support for 3D interactions: 2D desktop systems are limited in cases where natural interaction with 3D content is required, and 3D user interfaces consisting of stereoscopic projections and tracked input devices are rarely adopted by ordinary users. The success, both in research and commercial applications, of recent touch-based interfaces raise an interesting possibility. Can the immediacy, control, and expressiveness of recent touch-based natural interfaces be applied to 3D problems? [SKK$^+$13]

I wanted to answer this question. But before that, several issues had to be dealt with. First, a suitable cooperation partner would have to be found. As described earlier, a museum in Weimar was ideal. I merely needed access to an unbiased audience and topical expertise. Second, we would have to agree on a feasible concept and clarify responsibilities. Subsequently, the system would have to be developed and implemented before the final installation could be evaluated in its real-world environment. Finally, some small adjustments could be made and larger improvements or augmentations should be discussed.

A museum was found, concepts were made and a touch-based or TUI for 3D interaction was needed. The *SMSlingshot* combines all this. It is a tangible device, which enables a user to splat short massages onto a facade [FHZ13]. The device's affordance is clear, since most people are aware of the functionality of both a phone-sized keypad and a slingshot. Nevertheless, the device can only be used by one user at a time. This is where *Shared Encounters* come into play. There are different types of interrelated spaces, which offer different grades of interaction between a user and either the interface or others [FH12]. In course of my work, those two key concepts will reappear in more detail.

In the end, my 'answer' was using the most intuitive device there is – the user's body itself.

4 Partnering process

The very first step after having the idea of introducing a new way for information to be retrieved in public places, was to find a partner to realize it with. In order to find the most promising and possible cooperation, decision properties would have to be defined and considered for each institution before partnering with any of them. Afterward, a suitable exhibit, and an agreement on a design for the installation would be found.

4.1 Requirement analysis

To determine the ideal partner for a cooperation, a mutual beneficial system of needs and demand had to be established. Therefor, each party's needs and offerings were identified. As Table 4.1 shows, three major criteria were determined. Possible cooperations would be composed on those criteria. In addition, special characteristics would be considered as well.

	Museum	**Me**
Needs	Improvement / Innovation	Access to a public space with exhibits and visitors
	New group of visitors	Authentic content
	Publicity / Awareness	Potential test subjects
Offerings	A public space	Technological expertise
	Factual expertise	Development and testing
	Resources	Motivation

Table 4.1: Needs and Demand.

Museums want to get people interested in their respective topics. Thus, reaching more people and raising awareness is one of their main interests. A good way to attract new groups of visitors is to offer something unique and innovative. Although there are

companies offering services like guide- or information-systems, they are either cosmetic, expensive or high-maintenance. On the other hand, a museum has valuable offerings. Usually, they have a budget for renovation and improvements. The staff is highly skilled and experienced concerning the exhibits and visitors' behavior around them. Finally, a museum offers a public space, where a system can be tested under natural conditions.
The Bauhaus-Universität or rather its chair of HCI and I wanted the final system to work in a real-life environment, but not as a lab-study alone. Hence, we needed access to a public place in order to reach a broad variety of people. Those would be unbiased toward the nature of interaction and content as well. Meanwhile, we could provide our knowledge of interaction design and the suitability of contemplable technologies. And lastly, I was highly motivated to develop a working system.
After finding a cooperation partner, a FSD would be made, which includes the system's properties ordered by necessity. In addition, a contract between all parties would be drawn up to register each party's contributions and obligations.

4.2 Potential partner museums

According to Museumsverband Thüringen (MVT) [Mus14b], there are a lot of museums in and around Weimar. More than 50 are listed within a distance of a few kilometers. Table 4.2 only shows museums registered at the MVT and the three towns with the most of them. Other towns have between one and six registered museums. Further, it is most likely that there are more museums than those in this list. It provides a good point to start from, though.

Town	Museums
Weimar	26
Erfurt	12
Jena	12

Table 4.2: Museums in and around Weimar.

Regarding the high amount of museums in Weimar alone, it seemed logical to start looking for a suitable cooperation partner right here. Since 26 museums are too many to investigate thoroughly, a preselection had to be made. In the first step, the focus was on flexibility. This meant, only a small administrative apparatus could guarantee fast decisions and less organizational meetings with boards and other decision makers. Hence, all the *Klassikstiftung*'s museums were crossed of the list, narrowing it down to only 10 remaining candidates. Next, and after some further research, museums with less interesting topics or inconvenient concepts were withdrawn. This included the tiny *umbrella museum* and *Weimar Haus*, a place glutted with animatronics. Afterward, the list of candidates was down to five (see Table 4.3). A personal visit to each of these museums was indispensable now.

Museum
Deutsches Bienenmuseum
Kirms-Krakow-Haus
Museum für Ur- und Frühgeschichte Thüringens
Palais Schradt
Pavillon Presse

Table 4.3: Remaining cooperation candidates.

Gathering impressions in person was a process of three stages. In the first stage, I would visit a museum and note its technical and pedagogical equipment, directly followed by the next stage. The first, informal introduction to some of the staff was more or less a chat about my ambitions and the respective persons' attitude towards them. The final stage was a formal introduction-meeting between my professor, me and the administrative staff of each museum, that had expressed serious interest. This serious interest wasn't shown by the Kirms-Krakow-Haus and the Pavillon Presse. Hence, the aforementioned meeting only took place at the Deutsche Bienenmuseum, Museum für Ur- und Frühgeschichte Thüringens and Palais Schardt. We introduced ourselves at each venue, because a discussion about what might be done was more efficient directly on site.

4.3 Decision for a partner museum

A formal introduction-meeting went as follows. First, I explained some of my previous projects, related installations in other museums and the general intent of the professor's chair. Next, the staff explained their museum's concept and which subject area they would like to emphasize. After that, we discussed potential concepts. Those ranged from augmentations of existing exhibits to completely new installations.

Deutsches Bienenmuseum The museum is run by the beekeepers association of Thuringia. The staff we encountered were very skilled with the craft of beekeeping, but less professional concerning museum education and design. They listened to my remarks and we had an inspiring discussion about potential topics and their feasibility. Unfortunately, the assosiation's chairman and us could not agree on a project. Also, because bees hibernate, attendances are seasonal and also fluctuant. Hence, the Deuschte Bienenmuseum was out of the picture.

Palais Schardt This venue is owned by a family, which exhibits multiple collections of art and crafts as well as the building itself. In addition, they operate a cafe and use the adjacent hall for events. The husband is a restorer by trade and gives talks about the building and its historic significance, while his wife handles planning and the cafe. Events are regular and the cafe supplies casual customers and visitors. Both were very interested in a cooperation and had some ideas for installations. But the monument protection of the building and minor financial issues complicated feasibility. Therefor, Palais Schardt also had to go.

Museum für Ur- und Frühgeschichte Thüringens Since the state office for preservation of historical monuments and archaeoligy of Thuringia is the bearer of the museum, all personnel is very competent at their field of work. In addition, the museum employs special staff, that maintains the exhibition, gives tours and is present for arising topical questions during opening hours. Classes of 5th and 6th grade visit regularly for field trips as well as visitors from all age groups. The exhibition was already altered by several media installations. Moreover, the director was very ambitious from the first meeting and had several ideas, of which exhibits to emphasize.

Summarizing, the Deutsche Bienenmuseum and Palais Schardt were deemed less interesting and lacking feasability. The Museum für Ur- und Frühgeschichte was chosen to be the cooperation partner, because it checked the most boxes of the previous Requirement Analysis (see Chapter 4.1), while the others lagged at least once in the *Needs*- or

Offerings-category. It was the most professional and ambitious candidate with promising resources and conditions.

5 Conception

After the *Museum für Ur- und Frühgeschichte Thürigens* was chosen as a partner, all previous ideas had to be analyzed more thoroughly with feasibility in mind. Thus, impractical and too complex or too simple ideas were eliminated in two rounds of review. At first, vague ideas were either improved or discarded. Hence, a screen displaying only information about a fossilized fireplace was eliminated. The idea of a system for digitizing stone carvings was considered too complex to realize and therefor discarded as well. Afterward, some of the museum's staff and I looked at the contents, that could be provided for the remaining candidates. This left us with two remaining possibilities, that were promising enough from an educational and a technical standpoint. The first one was the reproduction of the *Fürstengrab von Haßleben*, which contains replicas and original findings from a 1700 year old grave of a teutonic princess. A close second was a workshop, which should have shown how archeologists and preparateurs work behind the scenes of a museum. Here, the latter consisted of too many single parts and a lot of questions remained unanswered.

According to the aforementioned review, the Fürstengrab von Haßleben was most promising and therefore chosen in the end. It contains many special relics from ordinary, teutonic pottery to rare, roman coins and jewelry as shown in Figure **??**a,b and c. This apparent eclecticism is, what makes the grave so special though. It is a sublime showcase for thriving trade and cultural exchange between Teutons and Romans as far east as Thuringia. Further, it proves how Teutons began adapting roman traditions, such as burials. In order to emphasize this insight, an interactive system was to be developed.

5.1 System presets

The system was to be developed and tested by me, and the museum-staff will be responsible for future its maintenance. Some visitors might not have the proper technical experiences to operate contemporary interfaces. Consequently, it was crucial to design the system with that in mind. It had to be operable by absolute lay persons, who have no prior experience concerning information technologies. Hence, the interface had to be as intuitive as possible. Four major points had to be considered.
First, established and common input devices, such as keyboard and mouse, had to be replaced by something different. In order to be intuitive, the interaction was designed to capture and use the natural behavior of visitors. Outputs, on the other hand, had to be as discreet and as conservative as possible to not disturb or interfere with the exhibition. Thus, invasive technologies such as speakers and animatronics were excluded from the beginning. This consideration only left visual and haptic channels for output. The third point was, that daily operations at the museum were not to be compromised. So, it was not possible to develop the prototype inside the Haßleben-showcase itself and a full-size mockup had to be build somewhere else. Therefore, I measured the showcase and acquired a room in which a mockup could be placed for the prototype's implementation and testing[7]. Finally, the system's components, in- and output devices, had to be robust enough to cope with daily use. Moreover, they should also stay in their intended place. This meant attaching them to the showcase in some way of form.
In summary, the requirements for the final system were narrowing down the possibilities right from the beginning. Hence, we came up with more than on idea and followed up on them, until one promised to be the most feasible.

5.2 Constraints and capabilities

Demo The early idea behind this work was to work with MS Gadgeteer to develop a tangible interface for and with a museum. Thus, we first thought about how to include those Gadgeteer-modules. Therefore, I build the demo device shown in Figure **??**, which

7 For a further description of the lab-setup see chapter 7.1

was based on a *FEZ Spider Starter Kit* [GHI14b]. In addition, it utilized an RFID-reader [GHI14d] and a potentiometer [GHI14c]. The RFID-transponders were attached to an old 2,5" Hard Disk Drive (HDD) and a wireless mouse. When the RFID-tags were recognized, an image of the object was displayed on the screen. By turning the potentiometer's knob the angle of view changed accordingly. This gave an impression of the possibilities of the hardware. Unfortunately, we only had two RFID-tags that had the size of a credit card. After some research though, I found some tags for the correct frequency band and in sizes from a grain of rice over credit cards to key chains [IK14]. Hence, including RFID-tags in tangibles was feasible. Only the shape and size of the tangibles were still up for debate.

Tangibles The main point was, whether the hardware would be placed inside or outside the tangibles. This decision dictates the shape and size of the tangibles and therefore the interaction.
If it would be placed inside, the tangibles would have to be big. They would have turned out at approximately the size of a box of milk. Such an *active tangible* would be handy and a whole system could be concentrated in one device. On the other hand, they would be prone to damage and maybe even theft. Hence, the tangibles would have to be tough and in some way attached to the showcase. In addition, batteries would have to be either charged or changed. This would take a certain amount of maintenance.
With the Hardware outside the tangibles and hidden in a pedestal in front of the showcase, the tangibles could be smaller. Moreover, *passive tangibles* grant more flexibility concerning the shape as well. Several RFID-tags could be placed in each tangible. According to their *constrained* position on the RFID-reader could trigger different reactions of the system [UIJ05]. The tangibles would have to be attached to the pedestal as well, although they would be less expensive to replace.

Both approaches had their advantages and disadvantages and none of them was concrete enough to make a decision. Thus, we continued to specify the concepts depending on their strengths and weaknesses. We did this, by anticipating probable relations between the exhibits inside and the behavior of visitors outside the showcase. There are several things visitors tend to do, if they are interested in an exhibit. They would like to inspect it up close. First, this means they would like to touch an exhibit and feel it. Second, they want to see it in more detail and from different angles. Next and induced by restrictions,

visitors talk about an exhibit or request further information. This could be anything from its age to where and how it was found.
An active tangible could provide nearly all of those qualities in one package. It could - like the demo device - be fitted with a display and an RFID-reader. The corresponding RFID-tags could then be placed close to the device in order to trigger a particular output. Those outputs could be saved either on the device itself or provided by a server. The question of how to trigger different reactions was to be answered next. The device could either be placed on a pedestal equipped with RFID-tags or the tags had to be brought to the reader in any other way. As mentioned earlier, an active tangible would be sizable and it would have to be related to the showcase's topic as well. Hence, it would be reasonable to combine those two criteria and produce enlarged reproductions of exhibits from the showcase. In order to fit the whole hardware, an active tangible would have to have a simple shape. This unfortunately excluded several of the more interesting exhibits, such as coins, a golden ring and other jewelry. Some templates remained though. There was a skull, pottery and the metal remains of two jewelry boxes.
The passive tangibles did not appear to cause this much consideration. Any exhibit could have been 3D scanned[8], turned into a digital model, appropriately altered to fit an RFID-tag and then printed or milled out. The printed or milled reproduction could be used as a positive to produce casting molds, afterwards. Thus, replacing damaged or otherwise lost tangibles would be more cost-efficient. In addition, it could be done by the museum-staff themselves. One or more RFID-readers could be placed in a pedestal in front of the showcase. Depending on the RFID-reader and a tangible's tag, the system would display the corresponding output.
During those considerations, a third possibility came up. A hybrid approach that combined both principles was possible as well. The reproduction of a jewelry box could be turned into an active tangible and passive tangibles could be put inside to trigger an output. The RFID-reader would be placed underneath the box's floor and the display in the lid. In order to provide different types of content, we thought about also producing two different types boxes. A more or less *authentic reconstruction* made of wood and metal fittings could provide authentic information about a passive tangible's cultural background. Meanwhile, the other box could be constructed of transparent material,

8 The scans could have been done in the labs of the chair of Computer Vision and Engineering at Bauhaus-Universität Weimar.

which would allow the user to see the hardware. This *futuristic reconstruction* could provide statistical content for the same passive tangible.

However, the main problem remained with all approaches. Some kind of pedestal would have to be build and placed outside the showcase to hold the active and/or passive tangibles. Although passive tangibles would have been more cost-efficient to replace than active ones, maintenance was rated too high. Furthermore, if the pedestal was not to obscure the showcase, it would have been too low[9] to grant satisfactory access for any visitor.

Tangible pointing As a result of the earlier drawbacks, we tried to minimize the objects outside the showcase. Hence, the display should be put inside. Since the display should not interfere with the exhibits or occlude them, we had to make decisions about the position, size and type of the display. In order to not occlude exhibits the display should not be placed among the exhibits or directly behind the glass panel. It could be placed along the visitors peripheral view though. This way, it would still imply coherence through visual proximity. A monitor on the one hand, and a projector on the other were two possible technologies to choose from. Both came with their own challenges. While a projector would have been easier to conceal than a monitor, a monitor would produce less heat an noise. Because most of the visitors approach the showcase from the long side an tend to stay there for most of the time, the display should be visible from this direction. This meant placing the projection plane or display on the opposing wall. Another solution for a projector came up during this consideration. A Polymer Dispersed Liquid Crystal (PDLC) switchable film [IRI14] could have been placed on the glass panel. Whenever the system was activated, the film and projector could have been activated as well[10]. Unfortunately, this solution was to expensive and difficult to install. A projection in the other direction was also disregarded, because the cost and heat issues caused by a projector were considered to high. Therefore, we decided to install an LED-screen. It should be placed inside the showcase close to the exhibits but not among them.

9 The height of the showcase floor is about 65cm. For more details see chapter 7.

10 A PDLC switchable film can be switched between a transparent and an opaque state. In its opaque state, it can be very well be used as a projection surface [IRI14].

Like *object selection in VR-environments* [AA13] and the *SMSlingshot* [FHZ13], a *pointing device* seemed to meet this requirement. This way, a potential user could directly point at the original exhibits to gain additional information about it. As described in detail in chapter 8, this also made use of the natural behavior of visitors. I observed interactions between visitors and the showcase as well as between each other. It turned out that they often pointed at the particular exhibits they were talking about. The interface could be designed to emulate this natural interaction between visitors.
The first intention was to rebuild the SMSlingshot with Gadgeteer-hardware. The tangible was equipped with a microcontroller, a small display, a keyboard, a green laser, a wireless transmitter and of course batteries. A PC was used to put all the information together and render the output. Therefore, it had a camera to track the point a user was aiming at and a corresponding transmitter to receive the fired messages [FHZ13]. All those modules could be provided by Gadgeteer except the laser. A laser could have been controlled with a *Breakout module* [GHI14a] and a relay. However, shooting a laser into the showcase was a delicate issue. Hence, this solution had to be revisited, because for safety reasons it was not feasible. There could have been injuries of visitors' eyes or some of the precious exhibits might have reacted to the laser's energy in a corrosive way. We did not want to take those risks, but we were very keen on the idea of pointing interaction. Thus, I looked for other tracking methods. We could have used a tracking system similar to the aforementioned ones used in VR. Those systems are expensive to install and maintain though. Moreover, a proper compatibility with Gadgeteer was doubtful. So, I started looking for alternatives to Gadgeteer, too. Two established systems immediately came to mind. First, the *Nintento Wii*, which uses a wireless device with pointing capabilities and additional inputs. Second, the *MS Kinect*, which is able to recognize gestures and might not require any device. Both are comparably inexpensive to acquire, have experienced support and communities and use less dangerous infra-red (IR) light.
The decision between the two was made according to the same criteria as mentioned above. Pointing with no device should be a more intuitive way to interact with the exhibition and other visitors than any handheld device. Furthermore, the restraint to use the system should be reduced. No tangible or pedestal would have to be created and attached to the showcase, which decreased cost for maintenance. Hence, the MS Kinect was chosen.

Pointing There is a Kinect for MS Windows along with a special SDK for MS Visual Studio. As it turned out, the hardware inside the MS Kinect was developed by *PrimeSense* and is also used by the *ASUS Xtion PRO*. This 3D-sensor is less expensive and smaller, which allows to be less intrusive inside the showcase. Besides, we already had some of them at the faculty, which meant that I could start developing right away. Another change was the decision for an open source SDK called *OpenNI*[11], which in combination with its add-on *NiTE* would enable me to use *skeleton tracking*. This was critical for my approach, because I needed to have a 3D vector in order to be able to calculate where a user was pointing. Skeleton tracking would deliver the joints of a tracked person. Hence, I should get the directions a limb is oriented in. If this vector was extended, I could calculate its possible intersection with an exhibit. More about used software and the exact calculations can be found in the next chapter.

The last topic that needed addressing was *feedback*. Since there would be no haptic or acoustic feedback, and no *glowing dot* produced by a laser either, future users would need another visual feedback in order to be able to see where they were pointing and determine how to correct that. Once more, Gadgeteer could have provided a solution. Our first idea was to simulate the glowing dot by a spotlight. The system would calculate the position a user was pointing at and transmit it to a Gadgeteer-system. It would then move a special highlight to this position within the showcase. Only two actuators would be sufficient. The maintenance of this kind of installation could become very complicated though, because the system would have to be installed on the ceiling of the showcase. Actuators need to be calibrated regularly and gearing will wear out. Hence, this implementation was declined. Nevertheless, the principle should remain the same. Thus, the aforementioned position would now be shown on an overview of the showcase on the display.

11 OpenNI was co-founded by PrimeSense, a hardware developer that produces 3D sensing hardware. In November 2013 PrimeSense was bought by Apple, whereupon OpenNI was shut down.

5.3 Final concept

The final system would consist of a *depth sensor*, *PC* and *display*. This hardware would be placed inside the showcase. In addition, an active tangible to remotely activate and deactivate the system should be developed as well. It is only intended to be a feasibility study, which determines if and how active tangibles might be incorporated into the system. Suitable components would be recommended by me and provided by the museum according to a mutual agreement.
The system would have to work as follows. When one or more visitors enter the area in front of the showcase the system would recognize them and react in an inviting fashion. An interaction zone would be declared from where one user would be able to interact with the interface by pointing at an exhibit. The exhibition could be defined by museum-staff themselves. Therefore, an exhibition plane would have to be defined and validated as well as the exhibits' positions on it. This would be executable by the staff and pointing at the required positions as well. Furthermore, the staff would provide the corresponding contents such as images and explanatory texts.

The final concept all parties agreed on was written down by me in a Functional Specification Document (FSD) and responsibilities were covered by a contract. The document states, which features of the final system must, should and must not be implemented and working.

Necessary features - "Musts"

- The system has separate modes for administration and presentation of an exhibition.
- Visual feedback of the interaction will be provided on the display.
- The system recognizes visitors and only one user can interact with it at a time.
- The system will be maintainable by the museum's staff and will start and shut down automatically.

Preferable features - "Shoulds"

- There should be a system's manual.
- It should be possible to switch the system into a 'blind' mode for guided tours.
- Extensive exhibits should have a slide show.
- The system is operable with either the left or right hand.
- Statistics about the system's use should be logged.

Necessary features - "Must nots"

- The will be no recognition of gestures.
- The system will not controll the lighting inside the showcase.
- There will be no auditive feedback.
- There will not be any tangibles.

Furthermore, the FSD describes system requirements, data formats and other organizational parameters.

The contract was drawn up by the university's layer's office and later signed by the museum's director, my professor and me. Both documents can be found in the appendix.

5.4 Testing

Before anything could be installed or evaluated, a reliable system had to be developed. Therefore, I researched suitable environments for an extensible system. Because most SDKs for PrimeSense's hardware are implemented in C++ or C# and Gadgeteer uses Microsoft's .NET framework and C#, the final system should be implemented in C#. Thus, an SDK written in C# was to be found. After having tried several open source frameworks, the Full Body Interaction Framework (FUBI) developed at Universität Augsburg proved to fit our needs best. FUBI came with a C#-wrapper, which incorporated all functionality of OpenNI and NiTE that was necessary to achieve our goals. Moreover, its leading developer, *Dipl.-Inf. Felix Kistler*, kindly explained how to incorporate the new approach to FUBI.

Annotations

- Test of pointing accuracy
  1. One centered Point I
     - Only Pointing
     - *Images and sketches*
     - *Data and Statistics*
     - results and conclusion
     - See appendix
  2. One centered Point II
     - Pointing, Aiming and Combined
     - *Images and sketches*
     - *Data and Statistics*
     - results and conlusion
     - See appendix
  3. Four Points on each corner of the plane
     - Classification of combined values
     - *Images and sketches*
     - *Data and Statistics*
     - results and conlusion
     - See appendix
- Development of algorithms for eye-hand mismatch (elbow/hand + head/hand)

  - Description of Eye-Hand Mismatch [ref]
  - *Sketches of classification*
- Test of algorithm's accuracy
  - Target = '90 percent of all values within a 10cm radius of mean value'
  - Differentiation between real and virtual point
  - Necessity of 1:1-mapping of real and virtual point

6 Implementation

The IMI-system consists of two main parts. First, the hardware part involves the physical tracking and computing of its data in the background. Second, the software part, which includes the IMI-libraries and IMI-softwares utilizing them, provides the **UI!** (**UI!**)s.

6.1 Interactive Museum Installation - Libraries

Annotations

- 'What are the libraries?'
  - Overview
  - Structure of Exhibition and Exhibits
- 'What does each one do?'
  - Modularity
  - Config-files (XML)
  - Particular methods (Lotfußpunkte, Ebenenschnittpunkt, DataLogger etc.)

6.2 Interactive Museum Installation - Administration-software

Annotations

- 'What is the administration-software?'
  - Define and edit exhibitions
    - ExhibitionPlane

    * Define, load and remove Exhibits
    * Define and change UserPosition
    * Edit dwelltimes
    * Load Background(s)
  - Define and edit exhibits
    * Define and change Position
    * Load and remove Images
    * Write and load Description (up to 310 charcters)
- 'What does it do?'
  - *Sequences*
  - Paper-mockup
  - Create (re-)loadable Config-files

6.3 Interactive Museum Installation - Presentation-software

Annotations

- 'What is the presentation-software?'
  - Display information of previously defined interactive exhibits
  - Overview-map of ExhibitionPlane
  - Feedback of exhibits' positions and pointing position
  - Description (Readability, Sehwinkel) and Images as slide show
- 'What does it do?'
  - Check for Exhibition
  - Pre-calculate Lookup for exhibit-selection (saves processing power)

- Recognize visitors
- Identify user by predefined UserPosition

6.4 Interactive Museum Installation - Presentation-remote

Annotations

- 'What is the presentation-remote?'
  - Microsoft Gadgeteer-Device
  - Bluetooth / WiFi-connection to PC
  - For lecturers in order to explain exhibits themselves
- 'What does it do?'
  - Automatically connect to Presentation-software
  - Toggle Presentation-software's blindness

6.5 Interactive Museum Installation - Statistics-tool

Annotations

- 'What is the statistics-tool and what does it do?'
  - Small tool to evaluate logged user-data
  - Statistics, such as average length of stay/session, exhibits chosen and how many transitions

7 Setups and Hardware

Three installations were build. One lab-setup for development, one makeshift setup was placed in the faculties lobby, and the final one was installed inside the showcase in Museum für Ur- und Frühgeschichte Thüringens. The various setups differed more or less in dimensions and were run with different hardwares. Early tests were conducted with the lab-setup. The lobby-setup was used for a stress-test during an open door-event at the faculty, whereas the final evaluation took place in the museum. Then, only the presentation-software was tested.

7.1 Lab-setup

A special lab had to be found and equipped with all necessary Hardware. The Hardware was lend to me by multiple sources of the faculty, while the museum's carpenter made a pedestal consisting of a surface and feet. The surface is made out of four 9mm-press boards. The feet seemed to unstable and thus were replaced with one desk rack for each board.

7.2 Lobby-setup

After some technical difficulties with the museum-setup, the first test under aggravated conditions was conducted during *Summæry*[12]. Therefore, I build a makeshift setup in the facultie's lobby. It consisted of three tables forming the exhibition plane and a bar table, on which the computer and a tripod with the sensor on top were positioned. There

12 Summæry is an open door-event at the faculty of media, where all chairs present their work throughout the faculty-buildings.

were three targets - a candy bar, a stack of coins, and a stack of fliers - lying on the plane (*see Figure*).

7.3 Final museum-setup

- Automatic boot at 8:30am [Bios]
- Runnging
- Logfiles for each *Session-Event*
  - Start Session: User in interaction zone (Exhibition.UserPosition +/- Threshold from SessionHandler := 250mm)
  - New Target: User pointing at a target
  - Target Selected: Dwelltime (Exhibition.SelectionTime := 700ms) starts slide show for selected target
  - End Session: User leaves interaction zone
- Automatic shutdown at 4:45pm [Software]

8 Evaluation

Annotations

- Pre- and postcondition of exhibition
- Survey of visitors' behavior prior to system's installation and afterwards
  - Interaction between visitors
  - Interaction with display
  - **LOS!** (**LOS!**)
  - Interviews
  - Evaluation-Forms

9 Discussuion

Annotations

- Conclusions
  - Comparison to Conception
  - Comparison to 'Pflichtenheft' see *Ref: Appendix*
- Anecdotes
  - Very short short-time memory → Instruction-sticker
  - Misconception of screen an a simple video and no interaction
  - Inhibitional factors (shyness, frustration, being watched)

10 Future Work

Annotations

- My work in relation to situation described in chapters 2 and **??**
- Outlook of possible further developments or optimizations of the system
  - Multi-user
  - Mobile devices
  - Audio
  - 3-dimensional positioning of objects and users
  - different possibilities of feedback

Bibliography

[AA13] Ferran Argelaguet and Carlos Andujar. A survey of 3D object selection techniques for virtual environments. *Computers & Graphics*, 37:121–136, May 2013.

[AKKF10] Ferran Argelaguet, André Kunert, Alexander Kulik, and Bernd Fröhlich. Improving co-located collaboration with show-through techniques. In *2010 IEEE Symposium on 3D User Interfaces*, pages 55–62. IEEE, March 2010.

[ARHL11] Alec Azad, Jaime Ruiz, Mark Hancock, and Edward Lank. Group Behaviours around Public Displays, 2011.

[AZ02] Johnny Accot and Shumin Zhai. More than dotting the i's - foundations for crossing-based interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '02)*, volume 4, pages 73–80. ACM, April 2002.

[Bol80] Richard A. Bolt. Requirement Analysis and Implementation of Palm-Based Multimedia Museum Guide Systems. In *SIGGRAPH '80 Proceedings of the 7th annual conference on Computer graphics and interactive techniques*, pages 262–270. ACM, 1980.

[CWH+04] Li-Der Chou, Chia-Hsieh Wu, Shih-Pang Ho, Chen-Chow Lee, and Jui-Ming Chen. Requirement Analysis and Implementation of Palm-Based Multimedia Museum Guide Systems. In *Proceedings of the 18th International Conference on Advanced Information Networking and Application (AINA'04)*, 2004.

[FB00] Guillermo Fernández and Montserrat Benlloch. Interactive exhibits: how visitors respond. In *Museum International (UNESCO, Paris)*, volume 52, pages 440–444. Blackwell Publishers, October 2000.

[FH12] Patrick Tobias Fischer and Eva Hornecker. Urban HCI: Spatial Aspects in the Design of Shared Encounters for Media Facades. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*, pages 307–316. ACM, May 2012.

[FHZ13] Patrick Tobias Fischer, Eva Hornecker, and Christian Zoellner. SMSlingshot: An Expert Amateur DIY Case Study. In *Proceedings of the 7th International Conference on Tangible, Embedded and Bembodied Interaction (TEI '13)*, pages 9–16. ACM, Februar 2013.

[GHI14a] electronics GHI. 5x Breakout Module Set. `https://www.ghielectronics.com/catalog/product/405`, November 2014.

[GHI14b] electronics GHI. FEZ Spider Starter Kit. `https://www.ghielectronics.com/catalog/product/297`, November 2014.

[GHI14c] electronics GHI. Potentiometer Module. `https://www.ghielectronics.com/catalog/product/275`, November 2014.

[GHI14d] electronics GHI. RFID Reader Module. `https://www.ghielectronics.com/catalog/product/366`, November 2014.

[HF14] Eva Hornecker and Patrick Tobias Fischer. Interaktion in öffentlichen Räumen. In *Informatik Spektrum*, volume 5, pages 440–444. Springer-Verlag, October 2014.

[IK14] I-KEYS. RFID-Transponder 125kHz. `http://www.i-keys.de/de/Transponder/125-khz.html`, November 2014.

[IRI14] IRISFILM. The Introduction of Polymer Dispersed Liquid Crystal Switchable Film, Specification, and Optical Testing Data. `http://www.irisfilm.com.tw/upload/newsfile/wkc0mynr20120922011639.pdf`, November 2014.

[McL93] Kathleen McLean. *Planning for people in museum exhibitions.* Association of Science-Technology Centers, 4th edition, 1993. `http://books.google.de/books?id=mpHuAAAAMAAJ`.

[Mus14a] Deutscher Museumsbund. Geschichte & Definition. http://www.museumsbund.de/de/das_museum/geschichte_definition/ursprung_des_museums, October 2014.

[Mus14b] Thüringer Museumsverband. Liste der Museen in Thüringen. http://www.museumsverband-thueringen.de/museumsverband/museen/orte.html, August 2014.

[RO13] Gang Ren and Eamonn O'Neill. 3D selection with freehand gesture. *Computers & Graphics*, 37:101–120, May 2013.

[Sch14] Helga Schneider. Das Herbarium als Illusionsspiel - Eine zeitgenössische Untersuchung zum Einsatz der historischen Dioramen, July 2014.

[Shn98] Ben Shneiderman. *Designing the user interface: strategies for effective human-computer interaction.* Addison-Wesley, 3rd edition, 1998.

[SKK+13] Frank Steinicke, Daniel Keefe, Antonio Krüger, Jean-Baptiste de la Rivière, and Hrvoje Benko. Foreword to the special section on touching the 3rd dimension. *Computers & Graphics*, 37:A1–A2, May 2013.

[UIJ05] Brygg Ullmer, Hiroshi Ishii, and Robert J. K. Jacob. Token+constraint systems for tangible interaction with digital information. In *ACM Transactions on Computer-Human Interaction (TOCHI)*, volume 12, pages 81–118. ACM, March 2005.

[Wit08] Andrea Witcomb. Interactivity: Thinking Beyond. http://www.blackwellreference.com/subscriber/tocnode?id=g9781405108393_chunk_g9781405108398327, September 2008.

[Woo93] Derek R. Wood. The Diorama in Great Britain in the 1820s. *History of Photography*, 17(3):284–295, 1993.