Using Projective Augmented Reality in an Interactive Museum Application

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In this paper we present a projective AR application developed in cooperation with the "Museum für Abgüsse klassischer Bilderwerke" in Munich. It allows visitors to interact with the Tombstone of Xanthippos by painting it on a tablet and casts this coloring onto the actual exhibit via a projector. The application additionally includes historical background information. Our goal is to examine whether the usage of projective AR in this way is improving the visitors experience during an exhibition. Furthermore, the application should be intuitive to use in order to be appealing to users of all ages. To evaluate these goals we used the INTUI [16] and MMGS [10] questionnaires. The results of the user study suggest that our application has been regarded as an informative, experience enriching and mostly intuitive addition to an exhibition.

1. INTRODUCTION

Augmented reality offers new and exciting ways to interact with our surroundings. This phenomenon is being adopted by museums world wide, and for good reason. Visitors of these venues have reported positive experiences when the exhibitions are enhanced with augmented reality technology [9, 7, 4]. In this paper we explore one possible usage of AR in a museum: Introducing color to a colorless grecian artwork. For modern research has shown that some grecian sculptures have indeed been colored once and were not always the purely white artworks we know them to be today [3, 13]. This phenomenon is called polychromy.

For this project we collaborated with the "Museum für Abgüsse klassischer Bilderwerke" in Munich [8]. The concrete artwork we use is the Tombstone of Xanthippos (see figure 1). It depicts himself sitting in a chair and his two daughters reaching out to him. Xanthippos is holding a last, suggesting he was a shoemaker. Currently there is no known scientific reconstruction of the paint on this object, nor is it known if it even had any.

In the following we discuss the implementation and evaluation of an AR application, which enables visitors of the museum to paint the designated tombstone using a tablet. The painting process is then projected onto the actual exhibit in real-time to be shared with the other attendants. This offers a save way to interact with the artwork without physically touching or altering it, while still giving the impression of retrieved color. Furthermore it allows for artistic freedom and dynamic modification of the paint.

To further enhance the utility of our application we added the possibility to gather historical background information on the tombstone and the pigments used for painting in ancient Greece. Moreover the current user is able to view the saved paintings of the visitors before him or her as inspiration.

All testing during production and the user study were performed using a scaled 3D printed replica of the original tombstone generated through Autodesks ReCap Photo. For the implementation we used the Unity3D game engine.

Our main research question is whether this interactive use of projective AR is a suitable way to improve the visitors experience during the exhibition. Another major focus were easy and intuitive controls for the application. Firstly, to reach visitors of all ages and technological backgrounds. Secondly, since many of the visitors will only spend a short time with this feature during an exhibition and have no time to learn a more complicated interface.

2. RELATED WORK

One famous worldwide exhibition bringing the topic of ancient polychromy to the broad public is "Gods in Colors" [3]. Showcased are brightly colored statues and pieces of architecture, as they are believed to have appeared originally. These reconstructions are based on the findings of modern analysis and discoveries.

Figure 1: *A cast of the Tombstone of Xanthippos*

Whereas their goal is to demonstrate correctness based on research, our application allows for true creative freedom, as it invites the users to bring their own visions to life.

The CHESS Project [11] is an EU funded project and a prime example of an interactive museum experience. Thanks to it, visitors of a museum can tailor the visit to their liking, enhancing it with small games and awaking the characters on display to life. For this the CHESS Project is also using AR, though only by tracking an object and displaying it on a mobile device for example in its original, scientifically reconstructed color. This colorization is however prefabricated and static, whereas our applications allows for individual and dynamic coloring. Moreover we project the color live onto the object so it is visible for all other visitors as well. Kurth et al. [6] likewise use projections to colorize an antique grecian sculpture, yet this colorization is again static and prefabricated.

Regarding the technical aspect of the projection onto the tombstone, there has been a lot of research done in this area. Bandyopadhyay et al. [1] denote how making use of projectors alongside trackable objects can result in an immersive experience, using a tracked stylus to directly paint on tracked surfaces. Bimber et al. [2] and Kurth et al. [6] provide tracking algorithms for automated calibration, assuming that a three dimensional projection receiving surface is tracked, and ensuring optimal visual quality.
Although this has been helpful as a reference, our object of focus is rather two dimensional and statically remains in place during the exhibition, thus needing to be calibrated to only once. Therefore we decided not to make use of the described methods. Seeking our own methods allowed us to accomplish our goals with fewer resources used. We are aware that this research is technically more advanced. However, we sought to unlock the creative potential within the visitors of the exhibition by offering highly individualized interaction through allowing the user to freely paint, create and share their visions, thus presenting a new perspective onto the original exhibit.

3. METHODOLOGY

3.1. Setup

Since the object provided by the museum, the Tombstone of Xanthippos, is a rather flat stele, with all important features on one site, it is perfect for a single projector setup. This allows for a focus on other aspects of this project. The users point of interaction is an app running on a tablet, as a touchscreen allows for the most intuitive drawing experience. Since most tablets can not be directly connected to the projector a intermediary computer is needed. How the connection between tablet and computer is handled is described in section 3.6.

3.2. Features

The app allows for three main ways to interact with the exhibition object as can be seen in figure 2.
The first and arguably most important of these is the drawing screen. Here the user can draw on the surface of a 3D model of the stele. This can be done with one of two provided tools. A brush tool that draws lines of variable sizes, similar to any normal paint program, and a fill tool, with which users can color predefined areas with a single click. The drawing process is projected live onto the object. How the color selection works is further described under section 3.7.

Another way of interaction is the gallery. This is also the default state of the app when no visitor is using it. It displays all the previously created drawings and switches between them every 30 seconds. The drawing currently displayed is also projected onto the stele.

Lastly there is the info menu, which gives visitors additional historic background information about different parts of the tombstone. The user can select a part and read an informational text about it. Meanwhile, the corresponding part is highlighted on the real object. This is particularly of use when the part on the original object

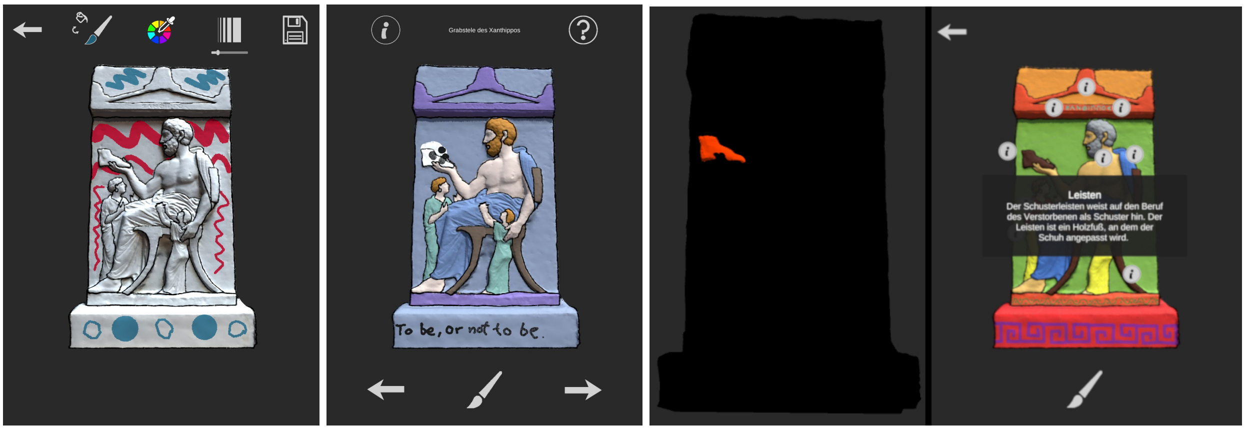

Figure 2: *These are the three main interaction screens of the application from left to right: The drawing screen, the gallery and the info screen. The next to the info screen is a view of the projected, highlighted part.*

is damaged - as for example the name "Xanthippos" engraved on top of the stele - and can thus be reconstructed. All historic information was provided by the museum.

3.3. Tools

The main tool that was used in this is Unity3D, a game engine which has many build-in functions that are useful for this project. It handles the rendering process, offers simple creation tools for graphical user interfaces and has support for many different platforms, such as Android and Windows.
Additionally, Autodesks ReCap Photo was used. This program takes a number of photos from different angles of an object as input, and generates a 3D model of it. This was then both used in the application and 3D-printed as a test object.
Lastly, Ubi-Interact [15] was used to handle network connectivity. This is described in section 3.6.

3.4. Drawing

The drawing process present its own challenges. The object might be mostly flat, but it is still three-dimensional, so we have to draw on its surface. It has to be done that way for two major reasons. First of all, the viewing angle on the draw screen is not the same as on the projection. This means the object has to be rendered twice from two different perspectives. And second, to allow for more complex objects, that might be added in the future. So we cannot just draw in the two-dimensional space of the screen. Instead, the drawings on the screen have to be translated into texture space, the coordinate system of the objects surface, which is also two-dimensional, but wraps around the object [5]. To do that the scene is rendered in the background with the objects texture coordinates visible. The result of this can be seen in figure 4. The application then reads out the texture coordinates of the parts that are supposed to be drawn on and changes the corresponding pixel of the texture to the chosen drawing color. The object is then rendered again, with the changed texture wrapped around it. A visualization of this process is show in figure 3.

Figure 4: *This image shows the stele with its texture coordinates visible. The coordinates are encoded in the red and green values of this image. Each of them corresponds with a pixel on the objects texture*

3.5. Projection and Calibration

For a visually appealing result, the projection has to be calibrated to match the original object as close as possible. Since calibrating projectors for three-dimensional surfaces has already been researched by the previously mentioned papers, we decided to focus more on the interactive aspects of this project. Hence we have decided, in agreement with the museum, to choose an object with a comparatively flat surface. This allowed us to do the calibration without the need for additional cam-

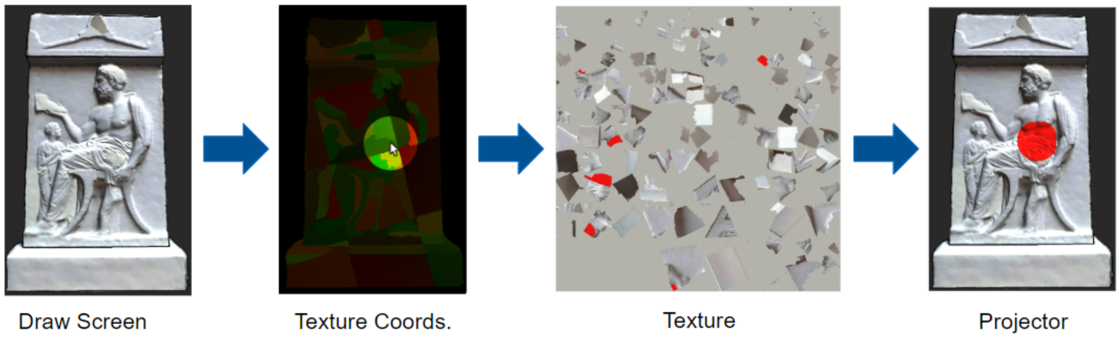

Figure 3: *This shows the internal process that makes the drawing possible.*

eras, since only simple manipulations of the projection are necessary. The application only allows for translation, for adjusting the position, scaling, for matching the dimensions, and some rudimentary perspective manipulations that would not produce great results on real 3D objects but are sufficient enough for our purposes. All of this has to be done manually once when the exhibition is set up. The result are shown in figure 5.

Figure 5: *This shows the projection onto the original casting at the museum.*

3.6. Wireless connection setup

To send data from the tablet via the intermediate computer to the projector we tried two communication approaches: Bluetooth and Ubi-Interact [15], a framework for building reactive and distributed applications developed at the Technical University Munich. The advantage of Bluetooth is that it allows connections between any two Bluetooth enabled devices, while Ubi-Interact requires a local network connection. Nevertheless, in the end we decided to use Ubi-Interact as it allows for faster transfer rates and integrates more smoothly with Unity.

We use three strategies for the actual transmission of the paintings: In the gallery we send entire texture files, which is time consuming due to the huge amount of data, but allows for higher independence and variety, as it is possible to send any texture.

For the info menu we store the already known and thus static texture files on both devices and simply send a command containing the filename. This is very efficient, but also introduces redundancy, as the same file is stored twice, which has to be considered when changing any of those textures.

To display the drawing process in real-time on both the tablet application and the original exhibit the transferred data has to be kept to a minimum to ensure maximal time efficiency. Therefore only the position of the user input via touch are send. Using these coordinates the drawing update on the current texture is computed on both devices separately. As both applications update at different frame rates a small error is introduced during rapidly changing drawing movements due to lost position updates. However, both programs run stable at frame rates between 20-30 fps.

3.7. Color Selection

There are two options for selecting the drawing color as can be seen in figure 6. One possible way is to choose from a preselected range of pigments which were likely to have been used at this time period according to [12], [13] and [3]. Upon selection of a pigment historic background information for example on the production of the pigment is displayed.
However it is difficult to accurately represent the color of those pigments due to lost knowledge about the used binding agents. Thus the used color values are only a semi-historic approximation. For this reason they were replaced by a general selection of useful colors for the official museum exhibition.

Ultimately the focus of our application is not historic authenticity, but the creative interaction with the exhibited object. Therefore the user may also use a HSV color picker to choose any possible color to allow for artistic freedom. We chose the HSV color model as it seems to be more intuitive than RGB colors [14]. The recently used colors are additionally saved for convenience.

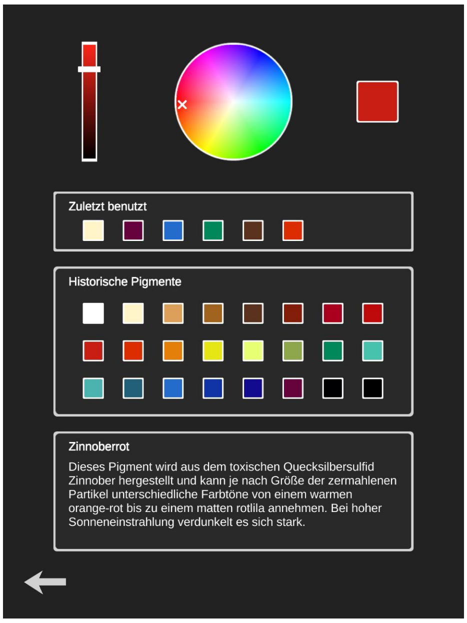

Figure 6: *This shows the color selection screen.*

4. EVALUATION

We used two standardized questionnaires to evaluate our application.
The first is INTUI, a questionnaire measuring the intuitiveness of an application by looking at 4 core components: Verbalizability, Magical Experience, Gut Feeling and Effortlessness.
A high value in Verbalizability means that the user is not able to articulate the single decisions and operation steps which should be the case within interactive intuition. A high value in Magical Experience indicates that the user felt that using the application was an extraordinary and magical event. A high value in Gut Feeling corresponds to a highly unconscious, non-analytical process, guided by feelings and not reasoning. A high value in Effortlessness means that the interaction with the application appears to be quick, effortless and intuitive [16].
The other used questionnaire is MMGS, which measures how well a multimedia guide fits into a museums exhibition. Consequently, it measures the general usability, the learning ability and control, as well as the quality of interaction with the guide [10].

In order to evaluate the application, 20 persons between the age of 21 and 34 were asked to test the application and to fill out the questionnaires mentioned above. 17 of the participants identify themselves as males, one as females and two as diverse. 85 % of the participants have a technical background, one has a scientific background, one has a background in humanities and one indicated that his background is something other.
For the test of the application we used a small 3D print of the stele, on which a projector projected the results of the users. This setup was placed at the Technical University of Munich during the demo day, which is a special event, where different games and computer applications are presented. See figure 7 for the setup of the user study.

For the evaluation of the results the likert scale of every question was aligned so that the "correct" answer to the question corresponds to 7, and the other to 1. Then the average of the questions corresponding to a particular core component of the questionnaires.
The results of the INTUI show that the application performs very well with regard to Effortlessness, it also performs well in view of Magical Experience and Gut Feeling, but it does not perform as well considering Verbalizability. These results can be seen in Figure 8.
Moreover, it also shows that the application works well in terms of usability. This is shown by the question that the participants (1) felt lost or (7) knew easily what to do while using the application and the result of the evaluation is 6,5, which shows that the participants knew what to do while using the application.
On the other side, the worst results of the INTUI questionnaire were 1.4 for the questions: in retrospect (7) it is hard for me to describe the individual operating steps or (1) I have no problem describing the individual steps, as well as in retrospect (1) I can easily recall the operating steps or (7) it is difficult for me to remember how the product is operated. This shows that the participants felt able to recall the single operation steps of the application, which does not correspond with intuitive interaction.

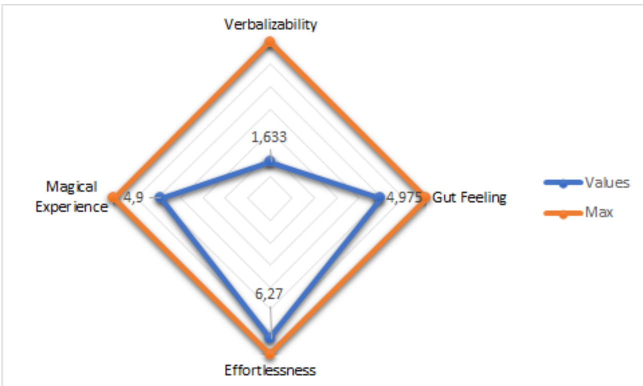

Figure 8: *These are the results of the INTUI questionnaire.*

The results of the MMGS indicate that the application functions well in regard to the general usability, the learning ability and control, as well as the quality of in-

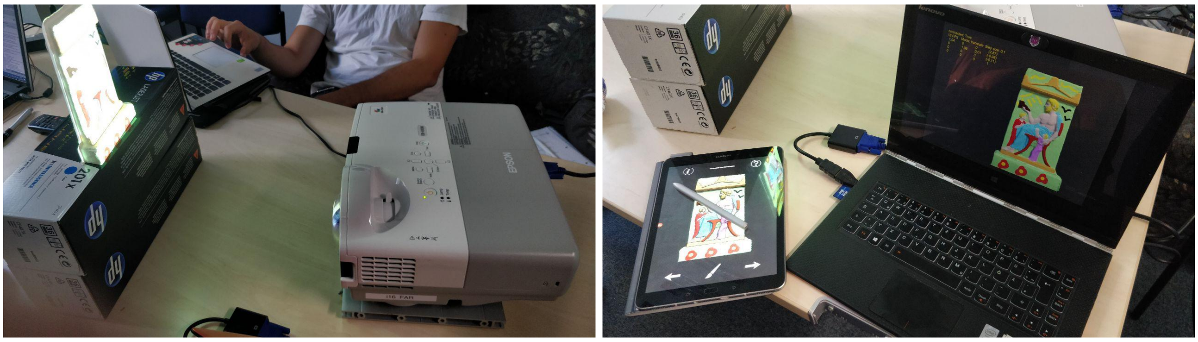

Figure 7: *This is the setup of the user study.*

teraction with the multimedia guide. Moreover it shows that it performs slightly better in view of the quality of interaction than it does considering the general usability, which can be seen in Figure 9.
Furthermore, the application performs especially well in regards of usability and learnability. This is shown by the questions that the operation of the audio/ multimedia guide was difficult to understand, where the score was 6.6 from the participant strongly agrees (1) to he strongly disagrees (7), as well as the question that the Audio/Multimedia Guide presented the information in an easy to understand way, where the score was 1.85 from the participants strongly agrees (1) to he strongly disagrees (7). The learnability aspect is hereby addressed in two ways, on the one side it is easy to learn the controls of the application and on the other side it is easy to get access to the information shown by the application, which therefore enables the user to learn the provided information about the exhibition.

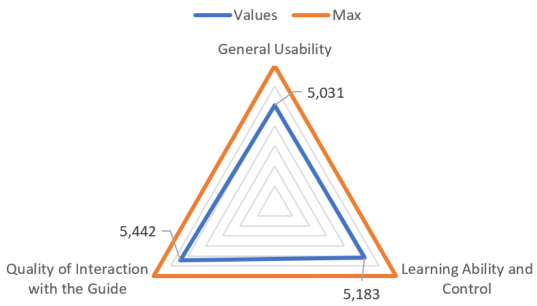

Figure 9: *These are the results of the MMGS questionnaire.*

Overall, the results of the user study show that the Application generally performs very well considering the INTUI [16] and the MMGS [10] questionnaires. Especially in view of usuability and learnability of the guide. However, in view of the Verbalizability aspect of the INTUI questionnaire, the application did not perform well. That means that the users felt that they were able to verbalize the operation steps for using the application, which stands in contrast to intuitive use of the application.
This behaviour may be caused by the background of the participants, since 85 % of them had a technical background, where they are trained for analysing and solving technical problems. In order to verify this assumption, a second user test must be performed. This user test should then take place in the museum to make sure the target audience for the user test is representative for the real target audience of the application.
Furthermore this second user study should also verify if the usability of the application is as good as the results above show or if they are also biased by the target group of the first user study. Additionally it could analyze the effect of the application on visitors immersion and whether they gain more knowledge through it than through traditional exhibition methods. However, even though a further user study can provide more insight on the issues mentioned above, the evaluation of the first user study already reveals that the users generally enjoyed using the application, that it provided an intuitive interaction, as well as great usability and learnability.

5. CONCLUSION AND FUTURE WORK

In general the application was received rather well, both by the museum and the testers in the user study. The use of projective AR proofed to be a great way to make an exhibition more interactive for the visitors. The results of the INTUI [16] and the MMGS [10] questionnaires show that the application is mostly easy and intuitive to use. This however does not mean that there is no room for future improvements. The following are some of the most requested features:

- Multiple concurrent users - As of the time of writing, the application only supports a single user connected at a time. Implementing an infrastructure for multiple users would allow for many instances of interaction during a shared time frame.
- Social network features - The application could make use of social networks to share the creations among others who are not currently in the exhibition, and would also not be out of place with social media's presence in every day life.

- Multiple projectors for 3D objects - As the Tombstone of Xanthippus is relatively flat, not complex setup of multiple projectors has been required. This would be the next step when undertaking a generalization of this to other objects, requiring complex projector setups.
- Integration into a museum app suite - Many of the other museum based augmented reality applications can be combined into a single one with their features, as an all in one museum visitor's app.
- Undo feature - Undo is a highly requested feature according to our user study, and is generally quite common among painting applications.
- Synchronization of files - Store drawings on the computer connected to the projector to allow multiple concurrent users and reduce load times.

References

[1] Deepak Bandyopadhyay, Ramesh Raskar, and Henry Fuchs. "Dynamic Shader Lamps: Painting on Movable Objects". In: *Proceedings IEEE and ACM International Symposium on Augmented Reality*. University of North Carolina at Chapel Hill, Mitsubishi Electric Research Lab. IEEE, Oct. 2001.

[2] Oliver Bimber and Ramesh Raskar. *Spatial Augmented Reality: Merging Real and Virtual Worlds*. Peters, 2005.

[3] Vinzenz Brinkmann and Raimund Wünsche. *Bunte Götter: Die Farbigkeit antiker Skulptur*. Staatliche Antikensammlung und Glyptothek, 2004.

[4] Areti Damala, Isabelle Marchal, and Pascal Houlier. "Merging Augmented Reality Based Features in Mobile Multimedia Museum Guides". In: *Proceedings of the XXI International CIPA Symposium, 01-06 October, Athens, Greece* (Oct. 2007).

[5] Paul Heckbert. "Survey Of Texture Mapping". In: *Computer Graphics and Applications, IEEE* 6 (Dec. 1986), pp. 56–67. DOI: 10.1109/MCG.1986.276672.

[6] Philipp Kurth et al. "Auto-Calibration for Dynamic Multi-Projection Mapping on Arbitrary Surfaces". In: *Transactions on Visualization and Computer Graphics, Vol.24(11)*. IEEE, Nov. 2018, pp. 2886–2894.

[7] Rozhen Mohammed-Amin. "Augmented Experiences: What Can Mobile Augmented Reality Offer Museums and Historic Sites?" PhD thesis. Sept. 2015.

[8] *Museum für Abgüsse klassischer Bildwerke München*. http://www.abgussmuseum.de/.

[9] Eslam Nofal. "Taking advantages of augmented reality technology in museum visiting experience". In: *Science and Technology for the Safeguard of Cultural Heritage in the Mediterranean Basin*. Proceedings of 6th International Congress. Athens, Oct. 2013, pp. 22–25.

[10] Mohd Kamal Othman. "Measuring visitors' experiences with mobile guide technology in cultural spaces". PhD thesis. 2012.

[11] Laia Pujol et al. "Personalizing interactive digital storytelling in archaeological museums: the CHESS project". In: *40th annual conference of computer applications and quantitative methods in archaeology*. Amsterdam University Press, 2012.

[12] Josef Riederer. "Die Pigmente der antiken Malerei". In: *The Science of Nature, Volume 69, Issue 2* (Feb. 1982), pp. 82–86.

[13] Josef Riederer. *Echt und falsch: Schätze der Vergangenheit im Museumslabor*. Berlin: Springer, 1994.

[14] Michael Schwarz, William Cowan, and John Beatty. "An experimental comparison of RGB, YIQ, LAB, HSV, and opponent color models". In: *ACM Transactions on Graphics, Vol.6(2)* (Apr. 1987), pp. 123–158.

[15] *Ubi-Interact*. https://wiki.tum.de/display/infar/Ubi-Interact.

[16] Daniel Ullrich and Sarah Diefenbach. "INTUI: Exploring the Facets of Intuitive Interaction". In: *Mensch & Computer*. Ed. by J. Ziegler and A. Schmidt. München: Oldenbourg, Jan. 2010, pp. 251–260. URL: http://intuitiveinteraction.net/.