Do Touch This: Turning a Plaster Bust Into a Tangible Interface

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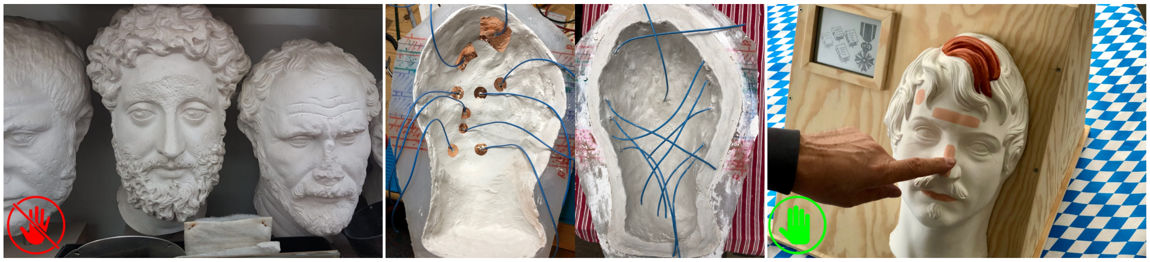

Fig. 1. Left: Multiple non-interactive plaster busts. Middle: Turning a plaster bust into a tangible interface by means of capacitive sensing. Right: User interacting with the final prototype.

Plaster busts are common exhibition pieces in museums, but they usually are off-limits for touch. While modern exhibition concepts increasingly involve interaction, this rarely includes touching a plaster bust. However, there may be a wealth of information associated with these cultural heritage objects, e.g., their making and their creator's craftsmanship, which tangible interaction could make accessible right on the object. We equipped plaster replicas of such a bust with capacitive sensors and developed a tangible prototype in collaboration with two domain experts from the art museum "Staatliche Antikensammlungen" (Munich, Germany), a curator and a sculptor, in an iterative design approach. Then we tested it in a lab study (N=12) and an in situ study in the museum (N=20). We describe our technical approach, which we also made public as a git project[1], and discuss our study results about busts as tangible interfaces in the art of sculpting.

CCS Concepts: • **Human-centered computing** → **Human computer interaction (HCI)**; **Interaction design**; • **Applied computing** → *Arts and humanities.*

Additional Key Words and Phrases: Tangible interaction, interactive bust, interactive museum, plaster, capacitive sensing

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[1]https://github.com/christian-mall/Do-Touch-This-Turning-a-Plaster-Bust-Into-a-Tangible-Interface, last accessed April 24, 2021

1 INTRODUCTION

The exploration of interactive experiences in museums, which make the interaction itself an essential part of the exhibition [11] has become an important research area in Human-Computer Interaction. Interactive installations enrich the visitors' experience [3] because they allow telling stories through visual, auditory, or tactile feedback. The combination of different types of output lets users interact with the interfaces in their own way, offering non-linear storytelling [3]. Tangible interaction with built heritage objects can stimulate people to connect with the social, cultural, and physical aspects of an art piece. Users can reflect on the object's history more than by just looking at it [18]. It facilitates the visitors' understanding and learning [12] which makes it a promising modality for museums. However, museums often still keep interactivity to a minimum and focus on increasing visitor throughput instead of the actual learning aspect [11]. Museums normally strictly prohibit touch interactions as those could damage the exhibition pieces. This limitation can be considered a missed opportunity [18].

On a conceptual level, tangible interaction has become a promising paradigm to convey qualitative information about built heritage objects [17]. Museums already introduced full-size, smart replicas of everyday objects, such as mugs to offer a multi-sensory experience including tactile senses [15] or employed replica miniature statues that can be moved around to trigger additional information on a screen [3]. Hence, full-size or smaller replicas are already used in exhibitions to create an enriched experience for visitors while still preserving the original art pieces. However, there has been little research on full-size interactive busts, even though their shape and material qualities tell a lot about their epoch and the craftsmanship of that time.

In our work, we focused on turning plaster busts into tangible interfaces. We approached the topic iteratively in collaboration with the Staatliche Antikensammlungen in Munich, Germany, an art museum for antique busts and statues. Most of their exhibition pieces are made from plaster but remain currently untouchable. They provided us with a plaster bust of Ludwig I, a former Bavarian king (1825-1848). We conducted two expert interviews in the first step, one with a curator and one with a sculptor, to discuss requirements and material qualities. Based on their feedback, we explored the conductivity qualities of plaster and how to integrate sensors. Simultaneously, we tested a first, non-interactive bust prototype with 12 participants in a lab for preferred touch areas and gestures. We mounted capacitive sensors according to this initial exploration results and tested the resulting interactive prototype in a second, in situ user study (N=20).

We try to bridge the gap between the ancient art form of sculpting and modern exhibition concepts involving touch with our work. We discuss the meaning of our results for museum exhibitions and the craft of sculpting. We start by introducing the current status of tangible museum interfaces and the art of sculpting, followed by a description of our general approach and methods, before presenting our three design iterations. We discuss and summarize our findings in the context of sculpting and museum exhibitions at the end.

2 RELATED WORK

2.1 Tangible Interfaces at Museums

Integrating technology in a museum exhibition is a complex process and requires careful consideration of the exhibition design, the interaction possibilities, and the overall visitor experience [4]. Exhibition pieces, such as busts, are not simple objects but inherently carry and communicate multiple types of information and values: quantitative information, such as construction dates, and qualitative information, such as architectural aspects [5] or aesthetic qualities [16]. While the former aspects can be conveyed to most museum visitors via audio guides or textual signs, the latter information is hard to convey using conventional ways. Tangible interaction is assumed to be particularly promising in this context as it delivers qualitative information [18] and communicates meanings through physical affordances [14]. It is an intuitive form of interaction and facilitates understanding [20]. Furthermore, it enables an active perception and interface exploration, which, in turn, facilitates information recall when applied in an educational context [10, 12, 23].

Prior museum exhibitions, such as the medien.welten at the Austrian Technical Museum in Vienna, increased their exhibition's attractiveness and visitor interest by integrating tangible interfaces, e.g., a digitally-augmented abacus which guided visitors through calculation examples by providing feedback and instructions on an adjacent screen [11]. Other examples in which smart replicas were introduced are the Virtex system at Keys to Rome [3], or prior projects by Marshall et al. [15] as well as Ciolfi & Bannon [4]. The Virtex technology allows the creation of 3D replicas that are turned into wireless, tangible interfaces [3]. In the Keys to Rome exhibition, visitors interacted with the small-scale, replicated statue of Augustus of Prima Porta. A system mapped the visitor's input using the physical replica to an additional digital model of the figure shown on an accompanying screen placed next to the statue. Although the statue was wireless, it was still used in a stationary context. Each touchpoint related to different information that the screen displayed. Marshall et al. [15] also designed tangible smart replicas of historical objects, such as mugs. For this purpose, they replicated some essential art pieces of their exhibition by using 3D printing techniques or cardboard and then digitally augmented the replicas (sound clips, photographs, videos). The authors ensured that the replicas have similar tactile and visual qualities as the original objects.

2.2 Sculpting

Sculpting is a creative process in which different materials such as clay, stone, or wood are used to create solid objects like persons, animals, etc.[2]. Another commonly used material for sculpting is plaster[3]. The oldest pieces of figurative art are about 40,000 to 35,000 years old. The Venus figurine, known as the Venus of Hohle Fels, which was found in the Schwäbische Alb, Baden-Württemberg, Germany about 40,000 years ago, is currently the oldest known example of figurative art[4]. The aesthetic aspects of this craft changed across different historical epochs. In earlier epochs, sculptors aimed at a perfect replica of living-beings, including their anatomy and an expression of liveliness. This changed in the 19th and 20th centuries. During this time, sculptors paid more attention to style and surface texture[5]. Herder argues that we do not experience a sculpture as a whole through vision alone [26]. According to Boehm [1] and Krauss [13], a plastic space manifests on the surface of the art object which acts as a membrane for the communication with the outside world, since users get a sense of an object's three-dimensionality and its surface details by touching it. Herder also suggests that people can get a feeling of the artistic craft that lies within an item this way [26].

Considering the presented prior work, we see a research gap in designing an interactive bust that engages visitors in the art and material communication, and that facilitates the understanding of implicit meta-information.

3 GENERAL APPROACH & METHODS

In the following paragraphs, we will present our iterative design approach and the methods we used. Overall, we conducted three design iterations. The first included requirements gathering in an interview with the museum curator (MC) and material exploration, and an interview with the sculptor who gave us an introduction to his craft and the material. Both experts are male and considered senior experts in their fields, with more than ten years of experience each. They both work for our collaboration partner, the Staatliche Antikensammlungen. We recorded the audio of

[2]https://dictionary.cambridge.org/us/dictionary/english/sculpt?q=sculpting, last accessed January 22, 2021
[3]https://www.newworldencyclopedia.org/entry/Sculpture, last accessed January 22, 2021
[4]https://www.latimes.com/archives/la-xpm-2009-may-14-sci-venus14-story.html, last accessed January 22, 2021
[5]http://www.beginnersschool.com/2015/05/04/history-of-sculpture/, last accessed January 22, 2021

the interview with the MC and took notes during the sculptor's material introduction. The other interview was not recorded because this was impractical at the sculptor's workshop, where a lot of the information was shared by enacting the process. In the second and third iteration, both experts gave feedback to our prototypes. They supported the further development by either refining requirements (MC) or advising on the choice of materials and how to process them (sculptor). We translated all direct citations from the experts' mother tongue to English.

The second and third iterations also included prototyping and testing in user studies. The first user study was conducted in a lab environment with 12 participants (five male, seven female). The second one was conducted in the museum context with 20 visitors (ten male, ten female). The lab study aimed at identifying preferred touchpoints and gestures so that we could place the sensors accordingly. For this, we prepared four different information themes (the foundation of the museum, Ludwig's wife, his artistic works, and his business communication). We selected these themes as, according to the MC, they were relevant for the museum and related to the life of Ludwig I. We asked our participants who all visit museums regularly to touch the bust replica at the places where they would expect to receive the information. In the in situ study, we observed museum visitors interacting with our second, high-fidelity prototype. For this study, we used the method of experience prototyping [2]: participants interacted with the prototype in a real-world scenario at the museum. The participants (one of which even turned out to be a sculptor) also filled out questionnaires containing demographic questions and yes/no, multiple-choice, and 5-point Likert-scale questions about the interaction with the bust. Since both studies were conducted during the global COVID-19 pandemic, all participants and examiners followed the required local hygiene and social distancing rules. We video-recorded both studies with consent by the participants according to GDPR and gathered additional qualitative feedback about the experience that the participants made in the final study. Participants were compensated for their participation by free admission. Below, we present the prototyping steps and results of each iteration.

3.1 First Design Iteration

The initial interview with the MC revealed that the museum only used audio guides as interactive interfaces but that the exhibition already included a table with plaster bust fragments for touching. The main challenges of introducing a tangible bust interface were to keep touchable and untouchable pieces separated and to provide means to clean and maintain the installation. However, the MC saw promising potential in letting the visitors touch exhibition pieces to get a better sense of their three-dimensionality. This would offer novel appeal to, e.g., school classes who usually get bored quickly. Also, visually impaired people would benefit from these types of installations. The tangible interaction could further improve the visitor's emotional access to the art objects and deepen the visiting experience.

In comparison, the sculptor introduced us to his collection of busts (see Figure 1, left image) and explained that each sculpted feature represents the epoch in which the bust was created. The draping of the hair, the hairstyle, or the eyes' size and components would allow many insights about the making and the way of life of each epoch. The sculptor confirmed that "by stroking the different beards, you can feel in what time it was created". For the prototyping, he further showed us fabrics to stabilize the shapes integrated into the plaster and which he used to stuff the interior. We also discussed the challenge of achieving a smooth surface on the outside of the bust. However, the sculptor was unfamiliar with the conductive characteristics of the plaster. Hence, we explored those by replicating a bust test object in our first iteration. We documented a step-by-step guide on git[6].

[6]https://github.com/christian-mall/Do-Touch-This-Turning-a-Plaster-Bust-Into-a-Tangible-Interface, last accessed April 24, 2021

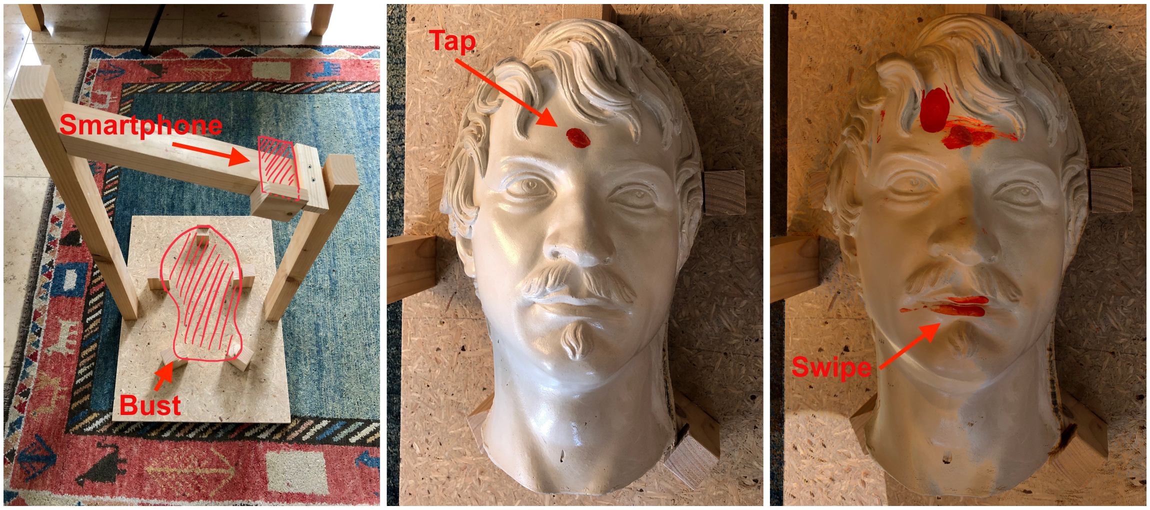

Fig. 2. Left: Wooden contraption which ensured that the pictures are taken from the same position and angle every time. Middle: Trace of interaction from one single participant. Right: Example image where six individual images got blended together.

3.1.1 Material and Technology Exploration. After creating a silicone mold as the bust's negative form, we focused on the material and technology exploration. We used a basic setup for tangible interaction using copper foil as capacitive sensors, an "ARDUINO UNO REV3" (powered by a USB connection to a laptop), a 1 MΩ resistor, and Arduino's "Capacitive Sensing Library"[7]. We focused on the copper foil as a capacitive sensor as it is very slim and as its size and shape can be adapted to different bust features, making such sensors more suitable for our project in comparison to many pre-made sensors that can be bought. We tested different plaster thicknesses (2 mm, 5 mm, 1 cm, and 1.5 cm), revealing stable measurements up to 5 mm. Hence, we needed to embed the sensors between two layers of plaster, one outer, thinner layer and one inner, thicker layer to maintain the bust's stability. To stabilize the measurements further, we added two more layers (a copper grounding foil as well as a hot glue layer for isolation) and integrated the "Adafruit 12-Key Capacitive Touch Sensor Breakout - MPR121"[8].

3.1.2 Lab Study. We tested for preferred touchpoints and gestures in the lab study to identify the best positions for the capacitive sensors. We tried three different tools for tracking the touchpoints: an infrared camera, UV colors, and watercolors. Watercolors offered the best solution because they enabled a reliable tracking of the individual touch gestures but were also removable from the bust. We first asked all participants for their opinion about the most interesting feature to touch. Afterward, we interviewed them about what parts of the bust they would touch to get information about the prepared themes (the foundation of the museum, Ludwig's wife, his artistic works, and his business communication). For hygiene purposes, participants wore gloves. We took calibrated pictures after each trial to blend the images in a graphics editor afterward and identify the main overlaps (see Figure 2). We tested whether the results differed depending on the position of the bust. Hence, six of 12 participants tried it in an upright position. The other six participants tested it lying horizontally on a table.

[7]https://playground.arduino.cc/Main/CapacitiveSensor/, last accessed January 22, 2021
[8]https://learn.adafruit.com/adafruit-mpr121-12-key-capacitive-touch-sensor-breakout-tutorial, last accessed January 22, 2021

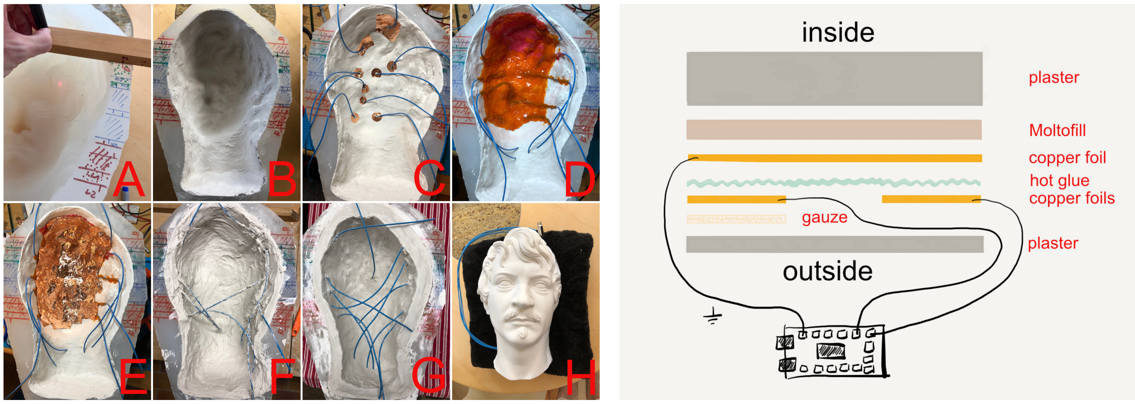

Fig. 3. Left: Different steps that were involved in creating the interactive bust (A: Marking the positions of the sensors. B: First plaster layer. C: Adding the sensors. D: Adding the hot glue. E: Adding a grounding layer. F: Adding the "Moltofill". G: Adding the last layer of plaster. H: Resulting bust). Right: Schematic drawing of the layers of the final prototype.

3.1.3 Lab Study Results. The nose (7/12) and the hair (5/12) were participants' preferred touchpoints. The touch gestures differed depending on the bust's position. In the horizontal position, participants mainly tapped, while in the vertical position, they mainly swiped. However, as none of the participants tried both positions, we only used these results to define the touch areas for the following iteration. Based on where the participants touched the bust and also how they touched it, the following decisions were made for the next prototype of the bust:

- Tapping on the forehead –> Information regarding the foundation of the museum
- Swiping across the lips –> Information regarding Ludwig's wife
- Swiping across the forehead –> Information regarding Ludwig's artistic works
- Swiping across the nose –> Information regarding Ludwig's business communication

As can be seen, the forehead was used for two types of interactions (tapping and swiping) because this part was the participants' most popular touchpoint. Although the hair was among the participants' preferred general touchpoints, it was only touched once regarding the four different information themes. This is why we first did not augment this area with capacitive sensors.

3.2 Second Design Iteration

The next prototyping iteration aimed at creating a new, augmented bust replica. We considered the previously identified touch areas to place the copper foil and brainstormed with the sculptor about the best making approach. The left image in Figure 3 shows the complete creation process. For every tapping interaction, we used one copper sensor, while we used two sensors for every swipe interaction. We marked the exact sensor positions with the help of a laser pointer drilled on a plank. Together with the sculptor, we prepared the plaster material using gypseous alabaster and adding gauze for structurally weak parts. The right image in Figure 3 shows a schematic drawing of all the layers of the final prototype. The gaps in the sketch are only for visibility purposes and are not included in the real prototype. It further includes two sensors. The left one has a layer of gauze under it to give more stability, while the right one is just left as-is (to depict the two approaches presented in the final prototype). Due to previous irregularities in the bust surface, we further added a leveling agent, making the surface smoother as the plaster is dispersed more evenly. As the MC

Fig. 4. A participant interacting with the bust. We applied watercolor markings because they would indicate interactive areas but keep the surface structure unchanged otherwise.

suggested to embed sensors into the hair part as a significant and prominent area of the bust, we added sensors in this area, triggering information about Ludwig's mistress on swipe.

Lastly, we decided to mark the interactive areas on the surface of the bust so that museum visitors get a visual aid where the bust is interactive. For this purpose, the MC suggested using a skin-colored watercolor on the face and brown color for the hair part to achieve a more natural look (see Figure 4).

3.3 Third Design Iteration

3.3.1 Final Prototype. After ensuring the prototype's functionality as a tangible interface, we discussed potential output modalities with the MC. We decided to use information channels that are already well-established in the museum: audio and a display. We drafted five texts (one for each of the five touch interactions) and recorded them as audio files (.mp3 format) onto a microSD card. The audio was played using an Arduino "DFPlayer Mini MP3 Player"[9] and an 8 Ω speaker in our prototype. For the visual output, we used an e-ink display due to its analog appearance [9], leaving the main focus on the tactile interaction with the bust. We used a "Waveshare 5.83inch e-Paper HAT"[10] with a two-color display capable of displaying black and white content only. To connect the display to the Arduino, we added the driver board "Waveshare E-Paper Shield"[11]. Additionally, we drew five images that accompanied the different audio recordings and built a box to hide the electronics and to give the bust a vertical stand.

3.3.2 In Situ Study. We conducted an in situ user study with visitors at the art museum during weekend opening hours. According to the MC, there would be more visitors during that time. The main goal was to test the effect of our interactive bust prototype in context. At the beginning of the study, we asked participants to fill out a pre-questionnaire, including questions about their demographics, such as gender, age, occupation, and questions about their habits and experiences of visiting museums. Half of the participants were male, the other half female, with an average age of 47

[9]https://wiki.dfrobot.com/DFPlayer_Mini_SKU_DFR0299, last accessed January 22, 2021
[10]https://www.waveshare.com/wiki/5.83inch_e-Paper_HAT, last accessed February 21, 2021
[11]https://www.waveshare.com/w/upload/c/c8/E-Paper_Shield_User_Manual_en.pdf, last accessed January 22, 2021

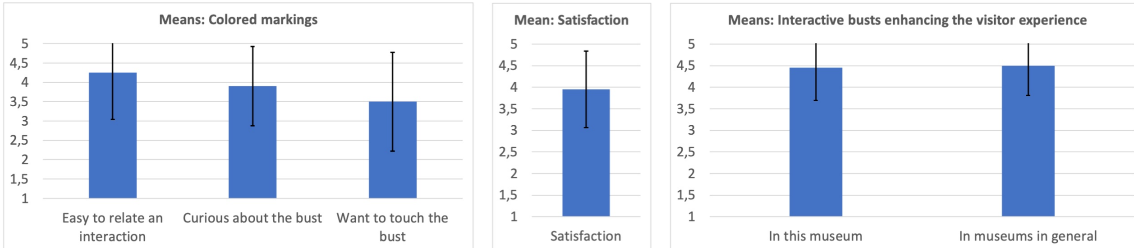

Fig. 5. Left: Mean scores for the questions how easy it is to relate an interaction to the colored markings, how curious the participants are about the bust, and how much they want to touch it. Middle: Mean score for the question how satisfactory the interaction with the bust was. Right: Mean scores for the questions how much interactive busts enhance the visitor experience in *this* museum and museums in general (1 = strongly disagree to 5 = strongly agree).

years (*SD* = 20.12 years). Participants were asked to interact with the bust prototype. They didn't receive any specific instructions on how they should interact with it to find out how self-explanatory the prototype was. Figure 4 shows a user exploring the bust. After the interaction with the bust, we asked them to fill out a final questionnaire.

3.3.3 In Situ Study Results. On a 5-point Likert-scale (1 = strongly disagree to 5 = strongly agree), participants were asked how easy it is to relate an interaction to the colored markings, how curious they are about the bust, and how much the markings make them want to touch the bust. They answered with mean scores of 4.25 (*SD* = 1.21), 3.9 (*SD* = 1.02), and 3.5 (*SD* = 1.28) which can be seen in the left chart in Figure 5. Participants rated their satisfaction of the interaction with a mean score of 3.95 (*SD* = 0.89) (see middle chart in Figure 5). The preferred outputs were "Audio" (90 %) and "Video" (75 %). Participants found the output of the prototype bust to be suitable (19/20). However, three participants mentioned that the correlation between the touched facial parts and the presented output was not fully clear. Others found the interactive bust to be "new, interesting, memorable and informative" (participant 5) and that "it makes the visitor engage with the sculpture more intensely" (participant 13). This would support them to "easier [...] remember" and learn "because of the unusual experience" (participant 6). Participant 13, a sculptor, praised the "smooth surface" of the bust and the fact that there's "no unevenness which distracts". When watching the video recordings, we could observe that the swiping gestures were sometimes a bit difficult to understand for the participants, while the tapping interactions didn't pose any issues. In general, the participants had fun interacting with the bust and found the experience engaging, which would overall enhance their visiting experience in *this* museum (*M* = 4.45, *SD* = 0.76). Furthermore, as it "amplifies and intensifies the art experience" (participant 13), it would also enhance the visitor experience in museums in general (*M* = 4.5, *SD* = 0.69) (see right chart in Figure 5).

4 DISCUSSION

4.1 Limitations

Our prototype was a first step toward an interactive plaster bust, including the material exploration and our implementation. Currently, our sensors have to be embedded between multiple layers to assure a stable signal and structural integrity, which requires a replacement of the whole bust when one sensor breaks. Further exploration is necessary to define a "best-practice" solution and to make the hardware maintainable. Regarding our in situ study, we would like to note that the study was conducted during the global COVID-19 pandemic, causing limited visitor numbers and reducing the number of available participants.

4.2 A Bust as a Tangible Interface

Our results suggest that interactive busts support a museum's goal of offering novel and engaging interactions [8], making the visitors' museum experience more interesting and immersive compared to already established interactive interfaces such as audio guides. By touching the bust and feeling its surface texture, the relationship between the user and the art object became more intimate. This confirms findings by Not et al. [19] who noted that the perceived distance between the visitors and the exhibition pieces could be reduced by offering to touch them, resulting in "an increased immersion", as indicated by participant 13. Our bust offered visitors an individual experience [3] by allowing them to interact with the marked areas according to their personal preferences. We confirm prior findings that a multi-sensory experience (notably including touch) increases the understanding of cultural heritage and makes it more appreciated. In turn, it results in a more valuable visitor experience [7] while also increasing the learning aspect, as we saw through our second user study. Participants also appreciated the art and craftsmanship behind making such a bust due to the felt smooth and fluent transition between the different parts. It shows that the tangible bust interface increases the visitors' connection to the art, the artist and their skills.

When comparing our approach with prior work, some distinct differences are found in our project. Most other prototypes were small heritage objects or statues that enable interactivity by either NFC [15]/RFID [4] or via pushbuttons [3]. The pushbuttons were visible on the surface of the bust, while our approach enables tangible interaction with the bust and the material while hiding the touch sensors inside. This kept the surface intact and lets visitors experience the material and the art of sculpting itself.

4.3 UX and the Art of Sculpting

The interdisciplinary collaboration between craftspeople and HCI researchers is not new [6, 21, 22, 25]. Prior work, e.g., by Suib et al. [24] showed the advantage of collaborating in pottery. They emphasized the benefit of the expert knowledge exchange leading to valuable, aesthetic material augmentations and user experiences. In our work, we designed an interactive museum installation that also communicated the sculpting process's embedded creativity and art as meta information. By creating a precise replica of the original, we kept essential surface qualities of the art object, which enabled the interaction with the "communicative membrane" [1, 13]. Hence, users could feel and explore the haptic surface qualities, including its three-dimensionality, the sculpted details, and the embedded artistic craft [26]. More specifically, it further fostered the experience of haptic intricacies, such as the draping of the bust's hair or the eyebrow's curved line, both indicators of the bust's original making period.

However, we also observed the design challenge to manage user expectations regarding the output and guide their interaction in a designer-intended way. In our approach, we applied watercolor marks to indicate which areas were interactive for selecting different chunks of information (see Figure 4). However, field study participants sometimes ignored different types of interaction, such as swiping gestures, or had trouble understanding them. Accordingly, we suggest considering a "one-sensor-fits-all-tactile-gestures" kind of approach and ignore the possibilities of multiple gestures implementations. This further raises the question of how much output variation we can offer and how to change the bust's design to enable a clear understanding of the interaction opportunities while keeping the original shape. It questions the balance between an accessible and clear interface design and the impression of interacting with a "true" artifact. To what degree should we adapt the interface and how relevant and necessary are user control or the level of recognition in such a context?

Lastly, our findings confirm those of Not et al. [19] about audio as a suitable output for tangible interfaces and more prominent objects, such as life-size busts. Pure audio feedback would enable users to keep their main focus on the tangible interface. However, we also observed some participants moving closer to the speakers due to surrounding noise. Audio zones or classic audio-guides might be a potential solution which could reduce the signal-to-noise ratio.

5 SUMMARY, CONCLUSION & OUTLOOK

We discussed our iterative approach of augmenting a plaster bust with capacitive sensors for inviting tangible interaction, connecting the ancient craft of sculpting and HCI. We conducted three design iterations: First, we gathered requirements in two expert interviews, one with a museum curator and one with a sculptor. We then conducted two user studies, one lab study, which helped us identify preferred touchpoints, and one in situ study in a museum to test the prototype in a real museum context. Our results confirm the engaging, interactive experiences that can emerge from such collaborations, benefiting the museum curators and conveying meta-level information about sculpting art.

We believe that this topic is worth further exploration in future projects, e.g., regarding the level of the museum exhibition's immersion and visitor learning experiences. So far, we have only explored tapping and swiping gestures and limited output modalities. This opens up the design space for interactive busts, which requires further exploration to define best-practices and established approaches. With our work, we hope to spark a discussion about the further potential of turning usually untouchable art objects into tangible interfaces in museums and enriching the art of sculpting in this way.

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