Touching the Untouchable: Playing the Virtual Glass Harmonica

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Abstract. Cultural heritage museums around the world are embracing new approaches to redefine their mission and roles by combining preserved knowledge with immersive technologies. This paper focuses on a virtual reality (VR) installation project within The Danish Music Museum, which showcases a glass harmonica. The project aims to provide visitors with an immersive and interactive experience, resurrecting a forgotten instrument and presenting its history, sound and interaction. Through a qualitative evaluation at the museum, it was found that the installation establishes a connection between the virtual instrument and the physical glass harmonica on display, offering an engaging and enjoyable experience. However, challenges such as disturbances caused by bystanders affecting the functionality of hand tracking were observed. Overall, the project proposes a VR experience, bringing a historical instrument back to life, offering visitors at The Danish Music Museum an immersive encounter with cultural heritage.

Keywords: Glass Harmonica · Museum · Virtual Reality · Physical Models · Cultural Heritage

1 Introduction

Cultural heritage museums around the world are redefining their mission and roles by combining consolidated and preserved knowledge with novel forms of experience [15,27]. The emergence of immersive technologies has provided new approaches to overcome the physical environmental limitations of cultural heritage exhibitions and proposes new opportunities to virtualize and augment the visitor experience. The use of multimodal and interactive capabilities of VR transforms visitors into proactive explorers of cultural heritage by providing an educational, entertaining, escapist, and aesthetic experience within a fully immersive virtual environment (VE) [15,26,27].

While traditional exhibitions often limit visitors to passive observation, VR allows close inspection and interaction with artefacts, inviting them to actively participate [24,33]. Museum professionals' perceptions of the use of VR

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technology found that this emerging technology had created a fundamental change, necessitating a rethinking of traditional concepts [24]. Trunfio and colleagues produced similar findings, not only suggesting an overall increase in visitor satisfaction and experience, but also posits the emergence of novel visitor profiles, drawing on John Falk's museum visitor experience model [8, 27].

This project takes part in the larger initiative of The Danish Music Museum *Music History - Taken out of the Box*. Drawing inspiration from the idea of freeing instruments from their display cases, this paper introduces a VR installation that allows visitors to experience the glass harmonica in a fully immersive environment, as depicted in Fig. 1. The installation is situated within the exhibition hall at The Danish Music Museum in Copenhagen, deployed standalone on the Meta Quest 2 using hand-tracking. The real exhibited glass harmonica hails from the 19th century, and though it remains in good condition, it is regrettably non-operational in compliance with preservation regulations. As musical instruments are interactive in nature and difficult to fully appreciate through visual inspection alone, this presents challenges to the museum. This project seeks to explore how the use of an interactive virtual replica of the glass harmonica can enrich the visitor experience and educate them about the instrument. The objective of the installation is to familiarise visitors with the historical background and interaction of the glass harmonica through an interactive VR experience. This paper provides a comprehensive overview of the museum installation project, covering all aspects of its development and execution. It examines the related work in the field to provide context and background for the project. It describes the design and implementation of the glass harmonica, and, finally, discusses the evaluation of the project.

Fig. 1. Glass harmonica displayed in a virtual environment (VE) inspired by the 18th century.

Glass instruments have a rich history that can be traced back to the early days of glassmaking. Among the earliest types of glass instruments were those that produced distinct tones through the striking of differently sized glass bowls. An early account of musical glasses appears in 1741 with the invention of the glass harp, an instrument invented by Richard Puckeridge; consisting of stemmed glasses filled with water, altering the frequencies of the sounds produced. It was not until 1762 that Benjamin Franklin introduced the glass harmonica in its modern form [14]. Franklin's design, heavily influenced by Puckeridge, uses glass bowls spun by a horizontal axle, with one side dipping into a trough of water. Sound was produced from exciting the bowls by touching the rim of the rotating glass with a wet finger [22]. The glass harmonica quickly gained popularity among artists such as Mozart and Beethoven, but association with negative events led to a decline in popularity during the 18th century [14]. In current times, what once was an instrument seemingly destined for permanence was by 1830 a forgotten instrument, a museum piece.

2 Background

As younger generations are more exposed to rich media and interactive content, this is increasingly expected in recreational and educational facilities [19,28]. The benefits of incorporating digital technologies into cultural heritage do not limit themselves to experiential matters. In [5], Chong et al. describe how various studies and efforts incorporate digital technologies as a preservation medium. Their findings reveal positive results for engaging and further motivating greater awareness of society's cultural content. Thus, the author highlights virtual heritage as essential to reconstruct the past and safeguard the current heritage digitally. In [24], the authors acknowledge the need to acquire new knowledge and strategies to implement and evaluate these technologies in museum settings. Their paper offers a holistic assessment of the current use of VR through interviews with museum professionals, who found that the most common use of VR is to allow visitors to experience "impossible" spaces or time travel; providing historical context for the exhibits. This is reflected in the multitude of works describing VR experiences depicting historical sites for museums [4,9,10,29].

Although research suggests advantages of virtual cultural heritage, the impact of VR applications on the spatial and social experience of museums remains a concern for museum professionals. The disruption caused by the loss of visual connection between visitor actions and their physical environment raises questions about the benefits of incorporating virtual elements into museum spaces [18,24]. As the digital space in VR remains concealed from those outside the headset, the process of people watching suddenly lacks meaning. Symptomatic of this are reflexive concerns about how the visitor might appear to others if they inhabit this digital space themselves [18,24]. This has sparked efforts to explore methods for facilitating co-located asymmetric interaction between head-mounted display (HMD) users and bystanders (non-HMD users) [21].

2.1 Virtual Reality Musical Instruments

Digital Musical Instruments (DMIs) are defined as systems enabling gestural control of sound production through controllers mapping gestures to sound parameters [30]. As the focus on VR systems has grown, the field of musical instruments for VR has expanded, and various authors have surveyed different aspects of this broad field. In [23], Serafin et al. surveyed VR musical instruments, differentiating between virtual musical instruments (VMIs) primarily focusing on sonic emulation and virtual reality musical instruments (VRMIs) which incorporate visual elements through head-mounted displays or immersive systems. They also presented nine design principles aimed at enhancing functionality and creating engaging and natural VR experiences. The importance of minimising latency is further emphasised in a study presented in [17], which found that low latency is desirable for VRMIs. Furthermore, in [3] 3D interaction techniques for musical control in VEs are explored, and [1] provides an overview of recent musical work in VR. Certainly, the field of VRMIs has much to offer in terms of how to design well for multimodal VR, especially considering design for public spaces.

According to [5], VR has been recognised as a preservation medium. Consequently, there is an ongoing effort to create VRMIs for historical instruments, as it enables visitors to interact while simulating instrument acoustics [2,16,20]. When looking at VRMIs in museum contexts, these often suffer from a lack of evaluation within actual museum settings [12,25,31,32]. As discussed in [5,24], VR's immersive capabilities effectively provide historical context to exhibited artefacts via narratives or representational virtual environments. Historical appreciation of forgotten instruments goes beyond narration, as it is closely intertwined with the interactive experience of playing them. Therefore, faithful replication of acoustic qualities, gestures, and movements can enhance understanding and appreciation.

3 Design and Implementation

The objective of the installation is to familiarise visitors with the historical background and interaction of the glass harmonica through an interactive VR experience. Based on the notion that the glass harmonica should transgress its display case and become playable in VR, the connection between the virtual and the real instrument plays an important role. The VR experience should augment the visitor experience by adding a layer of narrativity and historical context through the VE, in addition to faithfully replicating the aesthetics, acoustics and real interaction of playing the instrument. The application was targeted a Meta Quest 2 used as a standalone device. Because of the reduction in hardware maintenance and allowing natural interaction, this project utilises the hand-tracking capabilities offered by the Meta Quest 2, enabled through Oculus Integration for Unity. This section will delve into the specific design decisions that were made and the reasoning behind them, along with the implementation of these.

The design of the installation was collaboratively undertaken through co-design activities over the span of several months, involving two graduate students and a professor from Aalborg University, Copenhagen, as well as three museum employees. The research team took on various aspects of the development process, focusing on technical factors such as application development and usability evaluation. Concurrently, the museum personnel, with their expertise in public engagement and pedagogy, provided valuable information on what would be effective within a public and educational setting. A 3D sketch of the installation is shown in Fig. 2. The VR installation was strategically positioned to face the display case with the exhibited glass harmonica, ensuring that when visitors removed the HMD, they were immediately confronted with the real instrument. The installation was designed to aesthetically integrate with the surrounding exhibition space. A screen was mounted on the wall, displaying a looped mute screen-capture of the VR experience to accommodate bystanders. It was originally intended to provide a live-stream of the HMD view, aiming to grab attention and provide entertaining for queuing visitors, but further technological development will be needed for this.

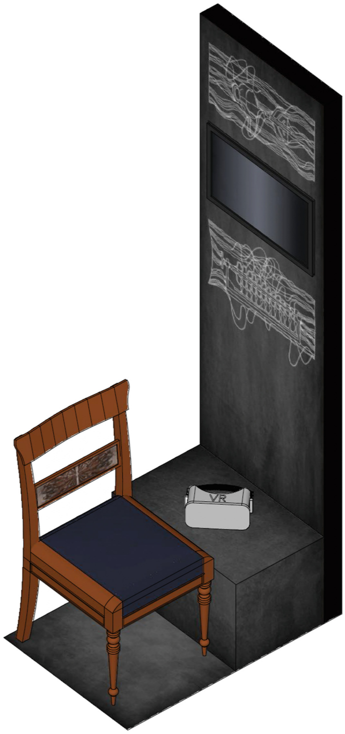

Fig. 2. Isometric 3D visualisation of the installation.

3.1 Interface

To educate the visitor about how to play the original counterpart, the interaction has to be replicated close to its nature. First, the instrument affords control of the sound by touching the rim of the rotating glass bowls with the index finger, as shown in Fig. 3, implemented using the *PokeInteractor* from Oculus Interaction SDK for Unity. The interface offers polyphonic playing, as the user can excite two bowls simultaneously. The speed of rotation is set to an approximated fixed speed, opposite to user-controlled in an original instrument. The design of the virtual replica is illustrated in Fig. 1, with the assigned notes displayed in Fig. 4.

Visual Feedback

The VR experience was built using Unity version 2021.3.11f1 with the universal rendering pipeline, and the virtual glass harmonica was modelled using Blender version 3.3.1, replicating the instrument exhibited at The Danish Music Museum.

Fig. 3. Participant interacting with the final installation at the museum (the charger is not constantly attached)

The VE was designed to resemble the study room of its inventor, Benjamin Franklin, from the 18th century, according to the time of invention, as depicted in Fig. 1. The application was implemented as a standalone VR application to run on the Meta Quest platform, at a device refresh rate of 72 Hz. As suggested in [13], to compensate for the absence of haptic cues, visual feedback was implemented by modifying the colour of the bowl with which the user interacts, as shown in the VR application screenshot in Fig. 5. Furthermore, throughout the experience the user can initiate animated elements which were made with Blender and Cartoon Animator 5.

Auditory Feedback

The audio is delivered through the built-in headphones of the Meta Quest 2 headset. This decision was made to minimise the need for additional hardware within the museum setting. The immersive soundscape includes atmospheric sounds such as the wind outside and the crackling of the fireplace. The auditory feedback for the instrument was synthesised using a physical model of a glass

Fig. 4. Illustration of the interface with notes and corresponding frequency displayed in Hz.

harmonica, acquired from the FAUST Physical Modelling Toolkit, which was compiled and exported as a Unity audio plugin. The physical model produces the sound of playing glass cylinders of different sizes using a technique called banded waveguides as described in [7]. Using the *FaustVariableController* script, the parameters can be modified either in the Unity inspector or by scripting using *getters* and *setters*. The physical model exposes the following parameters:

- Basic Parameters (frequency, gain: 0.8)
- Physical Parameters (base gain: 1.0, bow pressure, excitation selector: 0, integration constant)
- Nonlinear Filter Parameters (modulation frequency, nonlinearity)
- Reverberation (reverb gain: 0.9, room size: 2)
- Spat (pan angle: 0.5, spatial width: 0.5)

The frequency of each bowl can be seen in Fig. 4. Unfortunately, it was not possible to measure the frequency from the original instrument, the frequency used were therefore estimated based on samples from other glass harmonicas. For this project, the user-controlled parameter was *bow pressure*, the parameter in the physical model related to applied force, when contact was initiated with the bowl. Addressing the challenge of creating meaningful mappings of movement to sound, as mentioned in [11], while the user kept finger contact with the bowl, the bow pressure would be mapped to a constant of 0.85. This value was estimated listening to recordings of other glass harmonicas, as the attack time, determined by the physical model, was perceived to be too long in the lower end bow pressure values. By setting a higher constant bow pressure, the sound would intrude more rapidly, resulting in a closer resemblance to the real instrument. Furthermore, adjusting the parameters of *room size* and *reverb gain* parameters to their maximum value was found to attenuate the sound more authentically, when the user lifts the finger off the glass bowl. The remaining parameters were similarly estimated by instrument recordings.

Fig. 5. Visual feedback when player touches the glass bowls.

3.2 Narrative Elements

The narrative elements of the experience extend beyond a historically relevant VE, but also include a storyline narrated by an animated portrait of Benjamin Franklin, as shown in the VR application screenshots in Fig. 6. The storytelling component provides information about the origin, popularity, and causes of the eventual decline of the instrument, accompanied by audio clips featuring Mozart's "Adagio for Glass Harmonica" and other relevant sounds that align with the narrative content (applause from audience). Additionally, animated figures are incorporated to further enhance the storytelling experience, such as ghosts emerging from the bowls, as the instrument was viewed as haunted by many. The narrator not only provides context for the user, but also offers instructions, prompts them to engage with the story, compliments their playing, and serves as a guide throughout the experience. Within the VE, there are two labelled buttons located near the instrument (see Fig. 6), which allow the user to initiate the storytelling or a visual tutorial that demonstrates the interaction using animated hands similar to Fig. 5. The tutorial element enables visitors to have a successful experience without requiring the assistance of museum personnel by providing clear guidance for independent navigation and interaction with the instrument.

Fig. 6. Left: button activating the narrative and tutorial. Right: talking portrait of Benjamin Franklin

4 Methodology

This section provides an overview of the approach and strategies employed during the installation development. Collaborative design, known as co-design, was chosen as the primary method, involving active collaboration with museum personnel. The following steps outline the strategies employed throughout the process:

1. **Initial consultations:** Meetings were held with museum personnel to understand their requirements, objectives, target audience, and physical space considerations for the installation.
2. **Ideation and prototyping:** The design of the virtual space was conceptualised through brainstorming sessions and drawing inspiration from source material suggested by museum personnel. Their valuable input contributed to the refinement of ideas.
3. **Informal testing:** The prototypes were subjected to informal testing at Aalborg University, Copenhagen, to collect feedback and identify potential usability flaws. Adjustments were made based on feedback and discussions were held with museum collaborators for significant design changes.
4. **Implementation and evaluation:** The final design was implemented and installed at the museum. The implementation mainly took place at Aalborg University, Copenhagen, while the surrounding components, such as the wall-mounted screen, were installed by personnel from the museum. The installation was evaluated through observations and interviews with museum guests. The museum personnel would record, summarize, and document the responses in an Excel spreadsheet.

5 Evaluation

The VR installation was established within the exhibition hall as a permanent component of their exhibit. The evaluation was carried out by three museum professionals who briefly interviewed visitors during museum opening hours, covering three days. There were 22 participants between the ages of 6 and 78 (Mdn 31.0, SD 23.9). Unfortunately, the gender of the participants was not recorded. They had visited museums between 0 and 8 times a month and 84% had previous knowledge of The Danish Music Museum before visiting that day. The participants were selected based on their voluntary interaction with the installation. During the interactions, museum staff observed participants, noting noteworthy behaviors. Subsequently, participants were invited to engage in brief interviews, during which their responses were recorded, summarized, and documented in an Excel spreadsheet. The following questions were defined and asked by museum personnel:

1. What words can describe your experience?
2. To what extent were you motivated throughout the experience?
3. What did you think was good/bad?
4. What do you think was difficult/easy/too easy?
5. Did you experience the involvement of multiple senses during the experience?
6. Did you experience the installation alone or with others?
7. Did you perceive a connection between the object in the display case and the experience?
8. Would you expect there to be other similar installations in the exhibition?
9. We have the hypothesis that one can get closer to objects by conveying them in new ways. What do you think about this?
10. If you had to give us one piece of advice the next time we build an installation at the museum, what would it be?
11. Is there anything else you would like to tell us?

5.1 Observations

Participants who interacted with the VR installation were observed to spend up to 10 min (Mdn 4.0, SD 1.9). Though the time spent was recorded by the museum staff and can therefore vary in reliability. Initially, most participants showed hesitancy. However, as time progressed, they became more relaxed and began to enjoy the experience; expressed by laughter and smiles. Most of the time, multiple individuals (up to five), often families, would participate in the experience together, actively helping each other with the HMD and interactions. Bystanders would also gather around, observing the screen and engaging in conversations with the person immersed in VR, and would frequently capture photographs of each other. While immersed, participants would exclaim words such as: “That is fun” and “Really cool” and encourage each other to try. Additionally, it was observed that younger participants would verbally respond to the narrator in the VE. However, it was observed that children would frequently playfully touch the fingers of the immersed participants, this would startle the people wearing the HMD and disrupt hand tracking, resulting in a poorer experience.

5.2 Interviews

Looking at the responses related Question 2, 68.2% explicitly stated that they where motivated or *highly* motivated throughout the whole experience. This is reflected in the response of most participants to Question 1, describing the experience as *fun*, *impressive* and *different*. When asked about difficulty (Question 4), most participants found the interaction to be easy. This was supported by observations, as even the youngest participants had a successful time playing and enjoying themselves. Concerning Question 3, about what was good/bad, some participants expressed they did not succeed in creating sound, leading to frustration and feeling "impatient". Some participants were likewise frustrated due to technical errors, particularly one of the buttons not responding correctly during the initial day of testing. This was fixed after the first day.

The social aspect of the experience was evident as nearly all participants answered that they experienced the installation with others (Question 6). As mentioned, some visitors would touch the hands of the immersed person, disrupting the tracking. One participant explicitly mentioned this in the interview, describing it as their "hands flying around", while another participant found it very uncomfortable. The challenges with hand tracking were exacerbated by the installation's location in a heavily trafficked walkway, leading to instances of tracking loss. Participants experienced this as their virtual hands got "stuck" or "poorly calibrated", expressing that they would want improved hand tracking (Question 10).

When asked Question 7 about the perceived connection between the installation and the display case, the majority (73.6%) of the participants confirmed a clear connection between the real glass harmonica and the interactive installation upon exiting the virtual experience. This is supported by observation, as participants would approach the real instrument and demonstrate how it should be played, using the correct gestures they had learnt in the VE. When asked Question 9, all participants similarly expressed that the installation brought them closer to the instrument; expressed as "I absolutely think so. Touching things creates understanding and connection", and "Yes, one gets a sense of what it would do", and "Many of the instruments hanging here are dead, so they become accessible again here (in VR)".

6 Discussion

This section will present a comprehensive analysis of several components of the glass harmonica VR installation project. These components include technical issues, overall impression, and the connection established between the virtual representation and the displayed glass harmonica.

First, it should be noted that staff familiarity and expertise with the technology are important factors when implementing and evaluating VR for museums, as emphasised in [24]. In the case of The Danish Music Museum, the staff were already used to working with VR, and were responsible for setting up and closing down the application. Furthermore, as the limited sample size hinders the ability to establish trends, the findings merely provide suggestions, as drawing conclusions would necessitate a larger number of participants. The evaluation questions were formulated by the museum team, and it is evident that questions 7 and 9, in particular, are phrased in a manner that may elicit biased responses.

Although the interactive experience was novel for participants, some exhibited familiarity with VR technology. Consequently, certain expectations arose, such as the desire to stand up and move around within the virtual environment. A technical solution was therefore implemented, having the VR view be occluded with a sign to sit back down if the HMD y-position exceeded a specified offset from the floor. Furthermore, physical movement in the HMD xz-plane was mitigated by utilizing the pass-through guardian on the device. In addition, it is important to note that the orientation of the VE is established the moment participants mount the HMD, necessitating them to sit down and face forward to ensure the accurate positioning of the virtual instrument. Exploring technical solutions to enhance system predictability and reliability would be valuable in addressing the absence of a reset-orientation button on the Touch controllers, thus reducing the potential for user errors. Currently the solution implemented after testing was to install a sign telling people to sit down before mounting the HMD.

Although hand tracking seemed to generally function well, the heavily trafficked location and movement in front of the cameras on the HMD led to occasional tracking loss, rendering interaction impossible. Experiencing these errors had a detrimental effect on the overall experience of the VRMI, in correspondence with [23]. To combat this issue, markings on the floor could indicate the virtual space to discourage bystander interference, though completely negating the issue is difficult with hand tracking.

According to the concepts discussed in [18], the social experience is important in museum settings. The findings underline the importance of implementing the live stream from the HMD to facilitate cooperative exploration and potentially mitigate feelings of impatience. Furthermore, this observation indicates the relevance of the asymmetric interaction between HMD wearers and bystanders in museum settings.

The VR installation received positive feedback and prompted suggestions for including additional instruments. During the interviews, the participants expressed significant importance in the storytelling aspect of the experience, highlighting its role in creating an enjoyable experience and effectively guiding them throughout. The connection between the virtual and the exhibited instrument was evident among many participants, as they engaged in gestures that mimicked playing while describing the instrument to their peers, all while recounting the narrative from the virtual environment. This observation supports the decision to prioritise faithful replication of the interaction in the context of musical heritage and the preservation power of VR. However, it should be noted that some younger participants, in particular, tended to resort to dynamic movements resembling striking piano keys if they were unable to produce sound within a short period of time. Therefore, the slow nature of the interaction may not be suitable for visitors who prefer more dynamic and active experiences; such as replicating traditional percussion instrument, where the player strikes the instrument.

The choice of VR as the technical solution suggested by the museum staff can be supported by looking at the responses for Question 5, as around half of the participants (47.0%) explicitly stated that they believed that they experienced a sense of touch, despite the absence of haptic stimuli. They acknowledged this perceptual illusion, as they were aware of the lack of haptic feedback, but the other sensory modalities contributed to the perception of touch. The phenomenon of pseudo-haptic illusion, which is evoked by the use of cross-modal illusions, has been subject to comprehensive investigation in prior research [6]. Although it did not constitute the central area of emphasis for this project, it aligns with the museum staffs conception that VR could be a technical solution for the lack of touch in museum setting. While VR offers a captivating and immersive experience, it's essential to acknowledge its limitations. The unreliability of the current hand-tracking, absence of haptic feedback and the potential for isolation from other visitors are concerns. Alternative solutions, such as touch screens, may provide better accuracy and ease of use, with the added advantage of haptic feedback. While VR undoubtedly elicits a 'wow' effect, it's important to recognize that this effect can be short-lived. A critical view on the technology employed in this project is not only valuable but also necessary for future enhancements and to ensure an inclusive and engaging experience for all museum visitors.

7 Conclusion

In conclusion, this paper has discussed a project aimed at virtually resurrecting and presenting the long-overlooked Glass Harmonica instrument from the collection of The Danish Music Museum. A VR installation that provides visitors with an understanding of the sound, interaction, and history of the instrument, through co-design. This paper provides a comprehensive view of the development and execution of the project. The evaluation of the virtual glass harmonica was carried out at the museum, which provided valuable insights into the user experience of the VR installation. However, it is important to acknowledge the limitations stemming from the small sample size and the occasional incomplete responses from participants. These factors underscore the need for future research to expand upon our findings.

The results indicates that the VR installation was engaging and enjoyable for the majority of visitors, as the participants smiled and laughed, as well as positive statements recorded in the interviews. Nevertheless, the experience wasn't without challenges, as disruptions caused by bystanders led to a loss of hand-tracking functionality for the immersed participant. From observations, we acknowledge the significance of taking into account the social dimension of museum visits. Consequently, future iterations of this project will incorporate the live-streaming feature, aiming to enhance the connection between VR users and onlookers.

Nonetheless, the project successfully established a connection between the virtual instrument and the glass harmonica in the display case, for the majority of the participants. By employing faithful interaction replication, acoustics, and storytelling, this project proposes a VR experience, bringing a historical instrument back to life, and letting visitors at The Danish Music Museum touch the untouchable.

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