Design and Development Approach for an Interactive Virtual Museum with Haptic Glove Technology

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With a rise in the use Virtual Reality (VR) applications in museums and exhibition displays, digital heritage has still shown limitations in what a visitor can experience from the intersection of technology and history. Traditionally, interpretative narrative within the museum has been communicated through text panels offering limited context from a largely connoisseurly perspective. In addition to these interactive digital resources are often data base orientated via touch screen technologies with no multisensory immersion. This paper addresses the digital changes in these educational landscapes and the way it is being handled to co-create digital tools for exhibitions to educate and entertain museum visitors. This paper explores the use of haptic technology in conjunction with virtual reality to facilitate multi-faceted modes of interpretation, that offer novel access to an artefact's history from a range of perspectives. It also provides evidence of increased visitor engagement with a ceramic display through these immersive methods to communicate a narrative. This research bridges the gap between history and technology to offer an immersive experience of visiting a museum virtually and providing an intimate one-one experience to interact with artefacts and learn about history. As its focus, this research digitally reconstructs a collection of East-Asian ceramics bequeathed by Ernest Thornhill in 1944 to North Staffordshire Technical College (Now known as Staffordshire University). The digital prototype was developed to replicate the museum environment without the restrictions to access artefacts and handle them. This experience offers visual insights to contextualise the history of a ceramic to be utlised as an education tool to enhance learning within a museum setting. Evidence showed a significantly positive response to this prototype in museum and gallery settings, responses revealed these methods of interaction did assist in learning about ceramics, with a distinct majority of participants confirming these installations would encourage future visits, shaping the possibilities of how history can be combined with technology to create new and innovative solutions to learn about an artefact.

CCS CONCEPTS • Virtual Reality • Digital Heritage • Haptic Technology

Additional Keywords and Phrases: Museum Heritage, Design and Development, Education.

1 INTRODUCTION

Virtual Reality (VR) comprises of computer-rendered visuals in a fully immersive environment, to create an alternate, artificial reality to real-life. Commonly VR is experienced through two of the five senses: Sight and Sound. However, this paper brings the addition of touch to the experience to create an innovative alternative to how visitors can interact with an artefact.

The use of Virtual Reality has significantly increased in popularity and has steadily shown a growth in becoming a top recognised gaming platform with an expanding worldwide market [1]. With the early stages of Virtual Reality primarily for entertainment purposes, VR is being explored to offer alternative educational applications, supporting the ever-growing demand to teach immersive digital content [2]. However, the use of technological advancements appears underdeveloped within museums and tourism with strong evidence from existing research that this could strengthen engagement with outdated displays and enhance a visitors museum experience [3].

Hassan Taher published a thesis study on the various effects of digital technology on museums and how Malmö Museum can develop new interactions for their visitors [4], they highlighted the effects of Covid-19 and the importance for museums to reach their visitors through multi-medias and creating a digital presence. Through testing a Norwegian method- Tingens Metod (Method of Things) with the Malmö Museum, they have shown collaborative digital workshops with participating groups that have led to evidence showing a new-found appreciation for history and participants would like to use digital tools and interactions in their exploration of museum displays [4].

An article published by Claire Browning, a Curator at Iziko Museum of South Africa discusses the concerns on when exhibitions no longer reflect our current understanding of how life and Earth evolved, however old displays can be preserved by technology to transform them into a digital version. Iziko partnered with the Zamani Project; a non-profit heritage documentation organization based at the University of Cape Town. This article highlights the usefulness of 3D scanning technologies in the preservation of history, this project offered valuable accessibility to connect with a wide range of visitors in a virtual environment during the Covid-19 pandemic [5], which for a majority of museums had to be closed until the virus was under control.

This project introduces a model surrounding multisensory opportunities with haptic glove technology, that allows visitors to use their sense of touch to handle ceramic artefacts. Introducing haptics opens new possibilities in the way museums can contextualise and interoperate a ceramic's historiography through technology. History can now be interpreted in an intimate 1-1 experience and provide unique opportunities for interactivity to educate museum visitors. This project allows innovative ways of incorporating technology to engage young and contemporary audiences, while attracting the attention of technology enthusiasts to come and experience history with an alternative incentive.

A defining factor for a lack of young adults (18–30-year-olds) visiting can be a lack of interpretation, heritage sites generally do not cater to younger demographics. A survey with 2000 18– 30-year-olds by OnePoll in 2018 found that 19% those surveyed had never visited a museum and 36% never visited a gallery. However, 52% of 18-30 years old stated that a heritage sites online presence would encourage them to visit in person [6].

Visitors attend museums for various outcomes, insightful knowledge, visual gaze, and entertainment but this is difficult to achieve with limited methods of interpretation. Text or audio alone can be difficult to communicate the significance of an object and what effect it had on history.

This research demonstrates how the 3D reconstructions of historic objects accessed via a virtual reality prototype, can stimulate cross-sensory interactions that facilitate a greater understanding of their significance and develop deeper contexts into their journey through time.

1.1 Research Questions

Question One: How can the visual and tactile characteristics of historic ceramic artefacts from the Thornhill Collection be recorded, displayed and experienced through innovative modes of digital dissemination?

Question Two: How can the historic context of ceramic artefacts be experienced through immersive Virtual Reality, to educate and inform museum audiences?

Question Three: What innovations can the use of haptic glove technology bring to modes of interpretation of ceramics selected from the Thornhill Collection?

Question Four: How could this prototype be applied to a museum environment to increase engagement for the future benefit of learning about history?

Question Five: How can the design and development of this prototype be extended to enhance engagement at multiple levels of complexity?

2 EXISTING TECHNOLOGY IN MUSEUMS

Curatorial and security protocols within museums, galleries and exhibitions have traditionally limited the visitor's sensory experiences, as text panels and audio sources used to mediate display information quickly outdate are insufficient as a way of sustaining audience engagement.

Leeds Museums and Galleries, for example, have guidelines for text displays to offer the easiest and most comfortable reading experience, their intention is to provide text panels that are accessible and welcoming for as many types of visitors as possible [7]. This use of language is an effective way to communicate complex information to a broad range of visitors, however, this limits the visitor to the interpretation of text alone. This approach is unlikely to suit every style of learner and would be limited to the single language used.

Exploring other avenues of communication could be a huge benefit, since multiple senses can engage a visitor into retaining information more easily [8]. A secondary issue would be international visitors, text panels feature one language with the occasional second translation, meaning visitors outside these languages would not be able to understand the written text. Audio devices are useful in these circumstances as the technology can be set up with a multi-lingual system, however, audio relies on the visitor consistently keeping up with the words that are said, therefore can be easily disturbed with distractions in the room or technical issues.

Physical interaction is universal, most human beings can interact visually or physically to understand an objects physicality or context. Other alternatives include the Amsterdam Museum who introduced a solution using a QR code for multilingual visitors to access information in 10 different languages [9]. This solution still finds limitations in visitors who speak a language outside of the 10 offered and limits the user to reading text or listening to audio to acquire any information.

The prominent function of any museum is to preserve culture and disseminate knowledge to a universal audience. As part of this role, museums have been exploring the opportunities to combine digital content with displays that can enrich, engage, entertain, and educate a visitor. Digital media has been employed into museums but restricts the visitor's ability to interact. Displays can include digital content that consists of short texts, short films, audio guides, recorded interviews, podcasts, and web pages [10] but this limits the visitor to a flat, tablet screen for a source of interaction.

Recent innovations in Virtual Reality technology demonstrate how immersive digital content can increase engagement and create a lasting impact. Mariapina Trunfio & Salvatore Campana [3] found considerable evidence from testing a Virtual experience in The Ara Pacis Museum in Rome. This project called “The Ara as it was” project, examined the impact of AR and VR experiences on museum service aspects and overall, analysing the visitors experience and satisfaction. The experience was developed by ETT, an international digital and creative company who specialise in supplying engaging experiences using advanced technologies and innovative story telling. This experience was set up next to the Ara Monument to provide further context to the Ara reliefs to life and making them regain their original splendour and colours [3]. Virtual reconstruction is becoming a frequently used technique to be able to see a full 360° view of an object and how it looked in its primary form.

Virtual tours within museums are not an unknown concept and these are utilised as a valuable tool to show potential visitors 3D museums and collections to entice them to physically visit. Virtual screen tours are frequently used to offer viewers an alternative to 2D images and text. This has been demonstrated by the British Museum with ‘The Museum of the World’ [11], who have combined a digital archive of artefacts with an interactive scene, allowing the user to click on the timeline to find out about objects in the museum.

However, in most cases these tours are limited to the user staring at a flat screen and using a mouse to navigate around the environment, and do not have the immersive potentials which Virtual Reality can offer. Some sources such as SketchFab [12] do offer VR platforms to view 3D models, but the user would not be able to interact with objects freely as it would require a controller instead of a haptic device that would mimic hands on interaction.

Additional motives for the development of technological alternatives come from the recent events of Covid-19 causing a worldwide pandemic and forcing museums to close for over a year, this showed difficulties in how history can be accessed and highlighted many museums current relationships with technology. The literature review showed how limited a visitor is to interact with an artefact. This research offers a display design to attract contemporary audiences by incorporating technology to offer multisensory methods of learning.

Through the forced closures of the Covid-19 pandemic, virtual museums and tours have hit an all-time high at being accessible around the world by remote visitors and has sparked a huge interest in how digital heritage could be utilised to document and display history whilst remaining accessible through the internet. A blog article by Vision Direct featured eight virtual museum tours they recommended during the self-isolation period at the start of the Covid-19 pandemic in 2020 [13] and Deutsche Welle, an international broadcaster in media outlets posted an article on ‘Six Museum to explore virtually during lockdown’ which was also released in 2020 [14]. These examples displayed a desire to still access museum content during a time when in person visits were prohibited, these articles boast upon the accessibility of these museum being ‘one click away’ and viewed from the comfort of the viewers own home environment.

A virtual tour can be found on The National Museum of Natural History [15] located in Washington DC, USA on their interactive website designed by Loren Ybarrondo who created a self-guided navigation experience to explore different areas and rooms of the museum. With the feature of high-definition panorama on compatible devices the navigation is done by clicking on available arrows that point in the direction you will go.

The Natural History Museum [15] claims that some of the virtual tours feature previously unseen archives and holdings which gives them a unique attraction to use this with the addition of visiting in real-life, the high-quality content makes this experience useful for viewers to see what exactly is on display and have the ability to zoom in without losing detail. However, content on signs for the intended displays can be difficult to read making it not suitable for viewers who want a reliable source of information for the object that they are viewing, with no option to access external context whilst using the virtual tour this makes its uses limited to navigation and examining the visuals of the object alone.

Through the success of existing VR applications, this research aims to use VR technology within museums to provide visitors with an additional motive to attend and learn about history, through the ability of interacting with artefacts directly, museums can offer a unique addition to already existing virtual experiences.

2.1 Haptic Technology in Museums

Existing research (Stephen Brewster [16], Mariza Dima [17] and Radu Comes [18]) have explored the possibilities of combining haptic technologies in a museum or exhibition environment, however, each piece of research has shown a slightly different dynamic of what the visitor will experience.

Different technologies have been introduced to this field of research to experiment with how a visitor can interact with a historic ceramic artefact and what type of haptics can be achieved. Stephan Brewster [16] researched the impact of haptic touching technology on cultural applications. The main haptic device used was the PHANToM device from SensABLE Technologies. This device acts as a stylus pen that can be held and moved freely around the area connected to the device, when the device encounters an object, it will apply force to resist the user's movement and mimic contact with an object. This device has interesting opportunities to interact and feel where a surface and edge would be but still limits the user to holding a stylus pen-type shape where the pen can only travel as far as the base will allow by its handle.

Figure 1: Phantom Omni Device. Image published by Herbet Rodrigues (Public Domain), via Research Gate.

(https://www.researchgate.net/figure/Figura-1-Dispositivo-HapticoPHANToM-Omni-da-SensAble-Technologies-Inc_fig1_228579672)

Mariza Dima [17] proposed two methods of interaction to go hand in hand to create the closest experience to touching the original artefact. The first method consisted of a 3D laser scan of the artefact and 3D printing to create a plastic replica. This would give visitors an insight into the positive and negative space but is not able to replicate the material properties or roughness of the original, however, this does provide an alternative to handle curated objects of high value or restricted by conservation protocol.

The second method involved using a haptic device called the Omni instead of the user's hands. This is placed next to the replica print to act as a guide for where to direct the haptic device as it will be invisible for the user. This method uses a stylus pen for haptic feedback making it limited in what the user can feel, despite this paper being sixteen years more current than Brewster's it has still implemented a similar style haptic device.

Radu Comes [18] research paper examines the haptic devices found within museums. This research confirmed the use of a similar haptic device called the Geo Magic Touch System. This system involves the use of a stylus pen-like device that can mimic force feedback responses; however, evidence did show it was not possible to show mass properties and can only travel around the stationary object. This system shows major restrictions when compared to the SenseGlove haptic device which can offer the freedom to pick up and handle an object with each fingertip.

It is clear from the time these papers were published that their options in technology were limited the older the research was conducted. However, even the more recent papers still show similarities in the way the technology functions and how it is used. These limitations come from the way the device is designed, limiting the user to a pen like handle meaning the user cannot handle the ceramic and interact with an object freely, therefore reassuring the new contributions to knowledge in this research through the use of force-feedback haptic gloves in Digital Heritage.

Recent research from the Manchester Museum [19] proposed a project that introduces digital touch replicas by laser scanning artefacts to create a digital replica. This research creates a physical prototype and integrates novel touch sensors, allowing information to be strategically placed on to the object. When a sensor is touched information is delivered as images, audio or video on a screen to communicate associating information. This concept helps create a more engaging experience for visitors as the small interaction and mixed medias are more entertaining and easier to maintain focus than a text panel display. However, this prototype still limits the user to a flat screen for information and does not provide enough context as to what extent you can interact with the 3D digital replicas.

3 METHODOLOGY

The methodology adopted in this project includes a practice-based research approach [20], to implement multisensory technology into museums.

As there exists no prescriptive 'procedure' to conduct practice-led research the methodological framework applied in this project has developed an individually tailored approach. This has derived partly from an analysis of other examples including Paul Greenhalgh [21] who developed an object analysis framework to breakdown a ceramics historiography and to benefit the way that information can displayed to educate a visitor. The procedure involves breaking down a ceramic to understand:

- The makers personal and social background
- The consumers personal and social background
- The role of the object (What function it served)
- The class of the object (Compared value with other ceramics in the same genre)
- Value within the current marketplace
- Current political and social trends
- The material properties
- The crafting techniques and creation timeline

Object analysis is a process of breaking down the contextual information of an object's physical properties. there are three primary areas of analysis to conduct to understand the substance of an artifact, these include the material, aesthetic, and interactive qualities, followed with sourcing information on their social and cultural contexts. This information can then aid the interpretation of displaying these objects virtually or physically and give them meaning and purpose to their history.

These sources of information can be used within this project to visually reconstruct the answers and create relating interactions to feel a personal connection to the ceramics and its story.

The academic social research in this study approaches the changes in society and how we have incorporated technology into our daily lives, there was a clear lack of use with technology within museum settings to reinvent the way history is communicated. Social research is essential for generating new knowledge and expanding our understanding of contemporary social life [22]. This was found to be an ideal research method to apply to this project, as its core aim is to incorporate new technologies into a traditionally outdated environment. This research is essentially a concept aiming to explain a theory, in which history can be shown in a new and exciting form that brings words to life and offers multiple layers of contextual visuals and interactions.

Theory-research relates to the qualitative data collected by exploring a research question and pursuing the theory for the research to formulate an answer [22]. This theoretical technique was found suitable for this research as this will drive the collection and analysis of data from a social environment to effectively analyse how technology can change the way visitors experience museums.

There were a few factors with the technology that highlighted limitations with the object analysis framework in this research. The SenseGlove haptic device used in this project was unable to provide a weighted simulation and the ability to use your fingertips to feel texture precisely. These limitations impacted the extent interpretation could be achieved, but virtual reality opens new doors in the way we can communicate the artefacts information. This includes the ability to transport the user into an environment that represents a similar original to where the ceramic was found. This provides the opportunity to demonstrate how it was utilised and show where its former origin was before appearing in a museum cabinet. Certain details on an object may not be understood to a viewer, however VR will offer the ability to show them alternative visuals to show what something means, this also becomes very useful if an artefact is damaged and virtual reconstruction can fill in these gaps to show the object in its original form.

Figure 2: The Nova Glove. (Permission Granted by SenseGlove).

(https://www.senseglove.com/product/nova/)

Another defining limitation was costs, most museums will only have so much funding to budget what they spend on a display, haptic technology ranges in price but is often in the thousands such as the SenseGlove's Nova glove for £3826 [23].

Making it a commitment to invest in the technology, projects such as this one shows the potential and results show the positive response from visitors; however, museums need the ability to see how they can utilise this technology in various displays and functions to justify the price point.

3.1 Methodology- Practical

Photogrammetry was chosen for the digitising process of this project due to other research supporting this method for the digitisation of an artefact. Photogrammetry is a technique used to take a physical object or environment and deconstruct it into a 3D digital model using high-quality photographs [24]. These photographs hold the essential data that will measure up the coordinates in a 3D reconstruction software to find links and process a 3D replica model. This method is commonly used among the digital heritage sector [25], [26], [27], with multiple benefits to the preservation, representation, and accessibility of artefacts around the world [28].

Figure 3: Photogrammetry setup used by the researcher.

This is due to the versatility of photogrammetry, whereas laser scanning requires a trained handler to use the technology due to the complicated nature and value of the device, photogrammetry can be achieved with little previous experience to achieve the desired results. Also, laser scanning does not create the material texture automatically when creating the 3D model, which means photogrammetry would need to be used additionally to create the texture. It, therefore, made more sense to use photogrammetry solely.

Digitisation is the method employed to digitally reconstruct the data collected from the photographs into a full 3D model. Digitisation is a process of converting physical information into a digital format. This process consists of taking the photographs from the photogrammetry phase and processing them in a 3D re-construction software, this then processes the photographs to link matching points in the data and create a full 3D mode [29].

Other research in digital heritage does support using Photogrammetry as the most suitable method to digitise artefacts, including the VR experience for the Tate Modern Museum who worked with Factory 42 which used photogrammetry to recreate the museum and hologram of Sir David Attenborough, as well as the individual artefacts [30].

Figure 4: When Sir David met Sir David in the VR Experience at the Tate Modern Museum. (Public domain) Via Natural History Museum. (https://www.nhm.ac.uk/discover/news/2018/march/explore-the-museumwith-sir-david-attenborough.html)

A study was made at the beginning of this research in 2019 to discover what haptic devises already exist and what they offer as part of their experience. Results showed that a limited number of devices offered a full force feedback in their design, all 8 devices found used motion tracking to let the player use their hands as controllers within VR and be able to see them in the scene. Most devices did not offer anything additionally with motion tracking and relied solely on the visuals of the hands for the player to use them, 2 devices used vibrations to alert the player they are interacting with an object and 2 devices offered a full force feedback experience. This project had a strong focus on incorporating full force feedback as that was a unique aspect to the museum experience to be able to interact with artefacts freely without limitations.

The device chosen from this research was the SenseGlove haptic device, due to their ability to adjust to different sized hands so being suitable to the public domain and this device was available at the time of gathering research, whilst offering VR and AR compatibility with a pre-made software development kit (SDK), which makes the device simple to set up and get started with within a game engine.

3.2 Methodology- Data Analysis

When deciding how to sample the data for this research it was decided that two locations would be selected to receive a secure and adequate number of participants. This research focused on evaluating the behaviour and response from participants when testing the prototype in the museum setting, to gauge levels of user satisfaction and interaction.

This research adopted a User Interface Satisfaction Questionnaire (QUIS) method to compare responses and evaluate the software and hardware used for the user testing phase. The Questionnaire for User Interface Satisfaction is a usability testing tool designed to gauge a user's subjective satisfaction with the computer interface, or in this case The Thornhill experience.

The QUIS contains a demographic questionnaire that measure users' satisfaction based on screen factors, terminology, and system feedback, learning factors and system capabilities [31]. When applied to this research the questionnaire assessed whether museum visitors enjoyed the 3D visuals, understood how the information was displayed about the artefacts, if they learnt about the ceramics during the testing phase and how this experience can adapt in the future based on the user's feedback. This data analysis structure helped to assure the right questions were asked when receiving feedback and that the research questions were addressed when analysing the data collected.

The questionnaire was created to assure a positive experience from participants filling it in, this includes a short set of questions to avoid it taking longer than 5 minutes to complete and all questions consisted of multiple-choice answers to make for a simplistic layout.

4 DESIGN AND DEVELOPMENT PROCESS

The design and development process focuses on the building of The Thornhill Experience. The first stage begins using photogrammetry to digitise the Thornhill ceramics, digitisation is a process of taking a real-life object and turning it in to a virtual 3D model replica [32].

A plan was created with 4 core interactions for the experience, this included allowing the player to hold the ceramic and the ability to break it. The third follows with further context to the Musician on Horseback by bringing a replica Tang Dynasty drum into the room to show what the musician is holding; the player can pick the drum up and play the authentic sound with their hand or drumstick. The fourth interaction involves visual context by transporting the player into an environment that replicates the tomb the ceramics were discovered in.

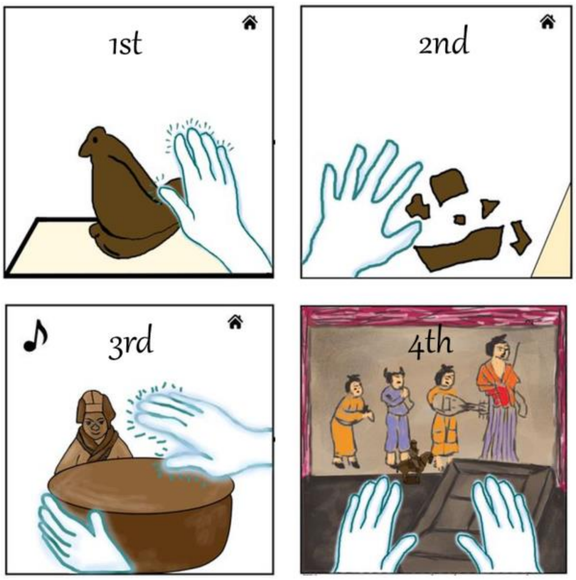

Figure 5: Visual Storyboard for interactions.

A selection process was made to decide which ceramics will feature in the experience. These decisions were based on the object analysis breakdown in the methodology of this research.

The chosen ceramics date back to the Han and Tang dynasty period to keep them within a similar timeline, this was to create consistency in the second environment the player would teleport into, the tomb represented the ceramics former use to demonstrate where they were discovered and communicate that the ceramics were offerings to the afterlife.

The environment was designed to replicate a traditional Tang Dynasty tomb that would have featured ceramic offerings in their burial rituals. The murals on the walls were direct projections of murals found in an existing uncovered Tang tomb. Additional objects were created including a ceramic goose lamp and a decorative coffin that accurately represented the resting place of Lady Dai, a female aristocrat who dies during the Han Dynasty [33]. The tomb also featured descriptions relating to each ceramic for additional context.

Finally, a puzzle was added to the final environment to quiz the player on knowledge they should have learnt throughout the experience, this interaction was added to assess the success of players retaining information through a multisensory experience.

4.1 Digital Creation

To digitise a ceramic, the photographs were processed in a 3D reconstruction software to produce the 3D model, Multiple software's were tested and noted with pros and cons to decide the most suitable software for this project.

Here are some examples of other software's tested in this phase:

- Autodesk Recap- This had a very limited UI with a lack of editing abilities, the results were ok but usually had a poor resolution on the texture quality making it unsuitable to show off real-life replicas of objects. This is a good starter software as it is simplistic in nature and provides quick results compared to the other options.

- Reality Capture- This was a highly rated software known for its fast results [34]; however, this software can become expensive as it charges for every export you make on a model, the software was complex in nature meaning it would take adequate time to understand the UI to achieve good results. The potential of this software is great with the ability to create some clean precise results, but this was found unsuitable for the timescale of this project.

- 3DF Zephyr- This was the close second in comparison to all of the others, this would have been the alternative software if Meshroom was not used. This software was free but offered quite a few limitations to encourage the user to pay for a full version, the limitations impacted to the results required for this project so was found unsuitable overall, many issues occurred including images often getting rejected due to it not recognising where they are in the world, this then results in errors in the final model, or the model not being created. This filtered in to requiring results within a certain time and finding it risky to provide what was needed.

Meshroom by AliceVision [34] was chosen as the most suitable software due to its thorough framework to flexibly adjust settings to suit certain ceramic scans, this gave the scans a higher success rate with minimal errors.

If errors occurred there was a breakdown of which stage failed in the process, this saved time to be able to understand the problem and fix it rather than running it repeatedly until the results were desired.

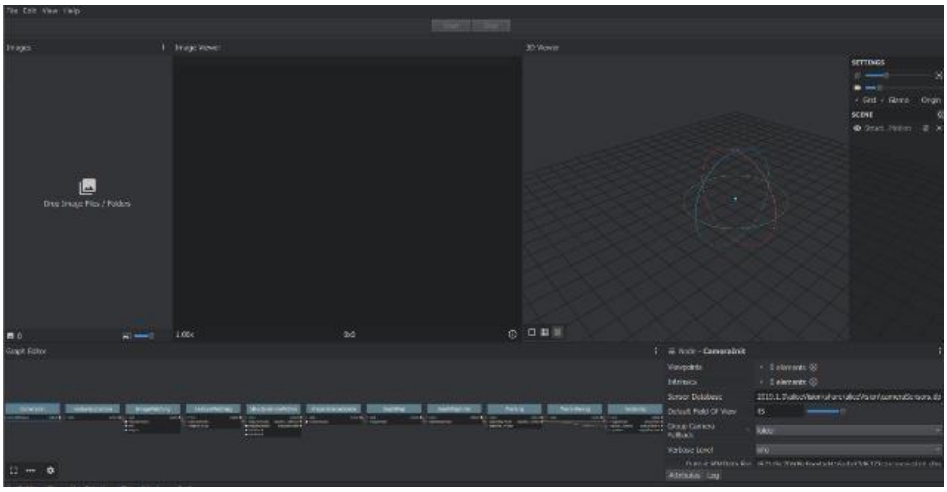

Figure 6: UI Layout in Meshroom. (Public Domain) via Meshroom Manual. (https://meshroommanual.readthedocs.io/en/latest/tutorials/sketchfab/sketchfab.htm)

The digitising process has 4 distinct stages of development, after the scan is completed in Meshroom, it is imported into a 3D modelling software to clean up any errors. This would then be a completed high poly version, for the experience 3D models are retopologised to create low poly versions so they are easier to render in the game engine software. You can see the low poly under ‘retopologise’.

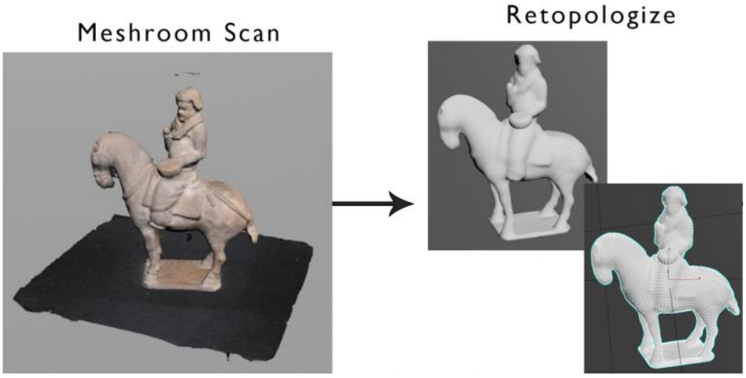

Figure 7: Retopologisation process for the Musician on Horseback.

After, the model has the high poly texture baked on to the low poly model to gain the colour details from the original scan. Once this is completed the model was ready to be imported into the experience.

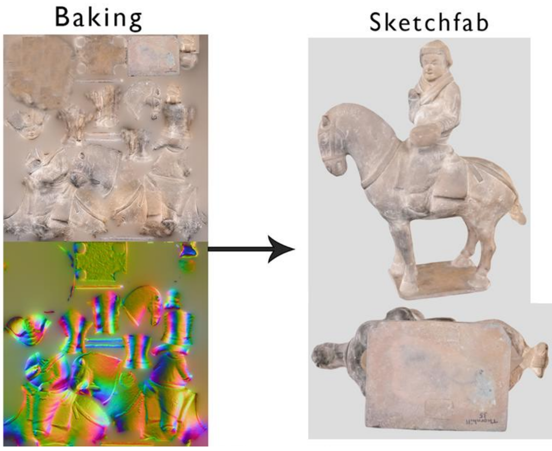

Figure 8: Texturing process for the Musician on Horseback.

The second stage demonstrates the process of creating the environments. This involved selecting an environment that will deliver visual information on a ceramic, the first room would consist of a classic museum that imitates the real-life perspective of where a visitor would usually see a ceramic artefact.

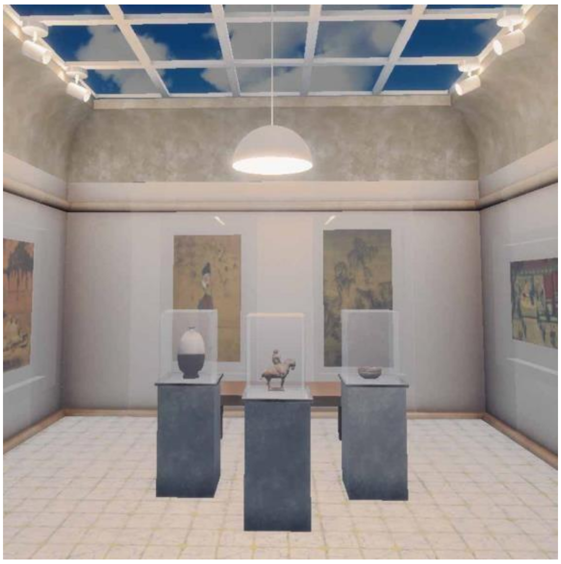

Figure 9: The Thornhill Experience Museum Room.

Followed with transformative journey in to a second environment to display a reconstruction of a Tang Dynasty tomb to visually communicate where these ceramics were discovered and recovered. This visual context can explain the former use of an artefact without the need of additional text, whilst creating an immersive interaction for a visitor to explore. The tomb symbolizes the ability to transport a visitor out of the typical museum room and give them a unique method of engagement with an artefact's history.

Figure 10: The Thornhill Experience Tomb room.

The third stage explains a breakdown of how the interactions were created and how the gaming elements were selected as the most appropriate for this experience. The interactions offer the ability to implement sources of information in an engaging alternative, these visual sources of information broke down what was achievable for the visitor to experience that would usually be difficult to replicate in the real-world museum and usually results in a text panel for context. These interactions included limitless accessibility to hold and observe the ceramics in a close-range, having surprise cues for certain ceramics to interact with relating objects to explain certain characteristics, showing the visitor a small amount of text to explain the ceramics dynasty and random fact, and finally quizzing the visitor on their knowledge of the ceramics to see what information was retained from the experience.

Figure 11: The Thornhill Experience, Puzzle room.

The fourth stage involves how SenseGlove has been integrated into the experience. SenseGlove has an efficient system to get a new user started in Unity. Unity is a game development platform used to create games and applications [35]. This engine software was chosen due to its compatibility with Augmented Reality and Virtual Reality to offer experimentation at the beginning of this research, Unity also offers compatibility with SenseGlove and their pre-made Software Development Kit (SDK) to import into a scene, SDKs are a set of tools from a third-party developer to produce certain applications in a game engine with their partnering technology [36].

The SenseGlove SDK provided everything needed to understand how to perform an initial set up and to test if the gloves were working via default applications that show you different interactions the gloves can do. When it comes to setting up the SDK, it included pre-sets of SenseGlove settings to be able to quickly setup the SenseGlove to work within play mode.

These settings gave flexibility in how the gloves behave and the properties that can be adjusted to manipulate what the player can feel, this process is doing using the pre-sets options combined with mesh colliders.
Mesh Colliders are applied to Mesh assets in a scene and given a collider cage, so the haptic gloves understand what type of material it is, such as hard and bendable. when the SenseGlove device reaches to pick up an object it can feel the density properties, these were used on all the objects within the scene to provide full interactivity.

More adjustments were made to the ceramic objects to try and mimic the way a ceramic would feel in real-life, including the density of the material and applying physics. Physics dictates how the object behaves in the scene, if the object is to be dropped it would fall and smash upon impact with another surface.

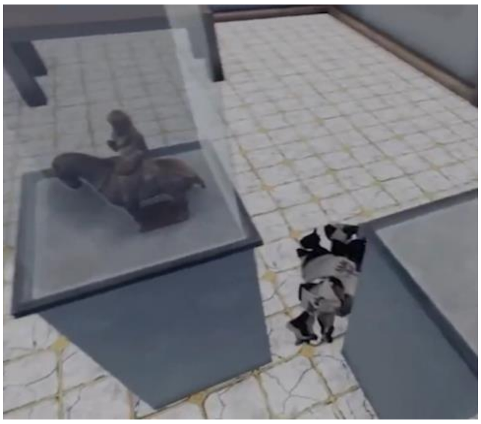

Figure 12. The Thornhill Experience, displaying a smashed ceramic.

5 THE TESTING PHASE

The data demonstrates qualitative results after conducting an analysis on a participant's behaviour and reaction to a virtual interactive experience in multiple settings. This research also includes a questionnaire response from each participant to gather feedback and thoughts on their experience.

This analysis highlights how easily a participant was able to navigate around the environment and any complications they found that impacted their experience, these results show what age ranges used the experience the most and who the target demographic could be if developed further.

This research uncovers how the public felt about haptic feedback gloves and if they provided a realistic sense of interaction with virtual ceramics and whether an experience such as this one can offer new ways to effectively learn about ceramics and understand new contexts of information through visual interpretations and interactions.

The first testing phase was conducted at the British Ceramics Biennial event, a ceramics festival celebrating and showcasing contemporary ceramics from across the world [37]. This took place in September 2021 from the 10th to the 17th. The second testing phase took place at The Potteries Museum and Art Gallery in November 2021 from the 5th to the 8th.

5.1 Structure for Questions

All questions were multiple choice for a simplistic layout that made it efficient to complete in less than 5 minutes and included 10 questions in total. This questionnaire employed a User Interface Satisfaction (QUIS) method, which gets a participants opinions based on the usability of an interface and assesses user satisfactory and acceptance of the system [38]. There was a final section of the questionnaire that was an open opportunity for participants to express any opinions they may have whether that be positive, negative or suggestions.

The questionnaire begins with quantitative formed questions for data collection such as age and gender. The remaining questions required qualitative data to record the visitor's responses to the technology and provide a voice to the targeted audience within this research.

Some of the questions required a more emotional response regarding how they felt during the experience, this was recorded using various faces to signal how satisfied the visitor felt. See Figure 13 to see an example question.

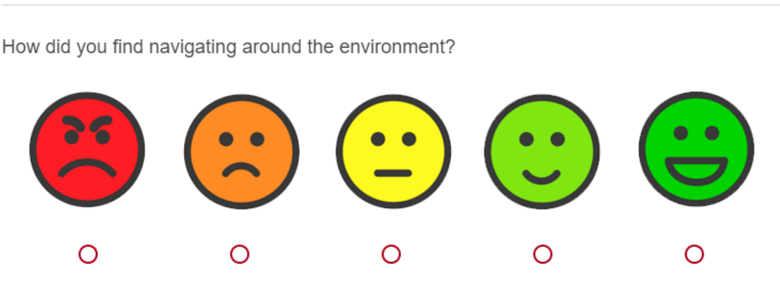

Figure 13: Example question using emotional responses to analyse user satisfaction with the experience.

The questions in this study are as follows:

1. How did you find navigating around the environment?
2. Do you feel like this experience helped you learn more about the ceramics?
3. Do you think haptic gloves provide a realistic sense of touch?
4. Do you think a digital surrogate is an effective alternative to interact with a ceramic?
5. Frequencies on 'Do you think haptic gloves provide a realistic sense of touch?
6. How important do you think interaction is to understand a ceramics physical properties?
7. What was your favourite part/s of the experience?
8. Do you think installations like this could encourage you to visit a museum?
9. Would you like to see more technology in museums in the future?

The questionnaire was completed primarily from guests who were attending a ceramic event or visiting the museum casually, however a range of experts within the museum and heritage field including archaeologists and museum curators also took part to include a range of knowledge and understanding.

After the first testing phase was completed the questionnaire and responses were assessed on any issues found to adjust for the second round of testing. It was found that the age ranges were not varied enough from the original 65+ as some participants were known to be 70+ and 80+ in a few cases so it felt the questionnaire was not as precise as it could be, this was changed for the second testing phase to feature more age categories.

5.2 Participant Backgrounds

Participants involved in testing phase one were visitors to the British Ceramics Biennial, this project was accepted positively due to the contemporary techniques to display ceramics virtually and offered advanced technology to create a unique exhibition for visitors. This project was installed for 1 week and acquired 35 participants in total.

Testing Phase 2 was conducted at The Potteries Museum and Art Gallery, a museum which showcases a technical section in their ceramic gallery illustrating the production techniques of pottery and includes multiple ceramic collections [39], The Potteries Museum has also featured more technology and shown a strong interest to experiment with how it can be implemented into different exhibitions, included the recent development of the spitfire gallery, an extension on the museum featuring an RAF Spitfire, along with virtual replicas of other spitfire designs on small screens [40]. This project was accepted to be showcased alongside the launch of the spitfire exhibition; this attracted a total sample size of 24 participants in the duration of 4 days.

The participants who took part in this experience were adults aged between 18-65+ in the first testing phase and 18-81+ in the second testing phase, this was due to observing the first round of testing and noticing a bigger demographic of senior ages that were interested in trying this project, it was evident that age did not have a cut-off point when it came to wanting to participate.

6 RESULTS

Results showed the largest age group of participants consisted of 18–25-year-olds confirming the evidence within the literature review that the younger audiences engage with technology more than any other age group. However, all the other age groups had a consistency in participants and showed that a large group of museum visitors would be willing to try this type of installation.

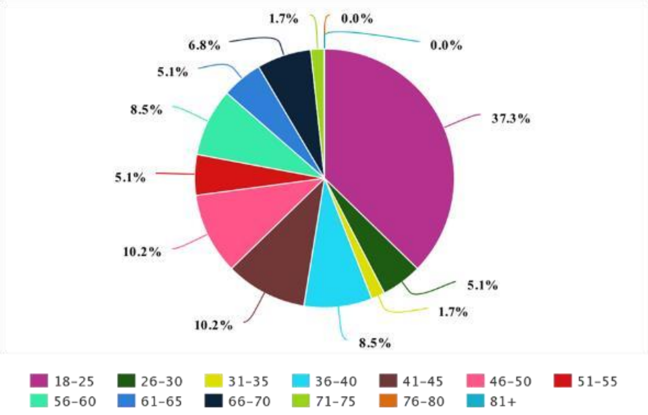

Figure 14: Demographic group chart for age.

Unfortunately, the two oldest age groups remain at 0% participation, however this would have been relevant in the first testing phase if implemented as a few participants asked why their age bracket stopped at aged 65 when they were in fact in their 70s or 80s.

The largest number of participants were female with a close evenness with males, showing a consistent interest across genders. This questionnaire did include a Third gender as an option to participants who do not identify solely as a male or female, this group totalled as 1.7% of the total results.

The results from the data collection show that the majority of participants found the environment easy to navigate and explore, showing a success in creating an environment that is suitable to a wide range of visitors, with no responses recording that they had a negative experience.

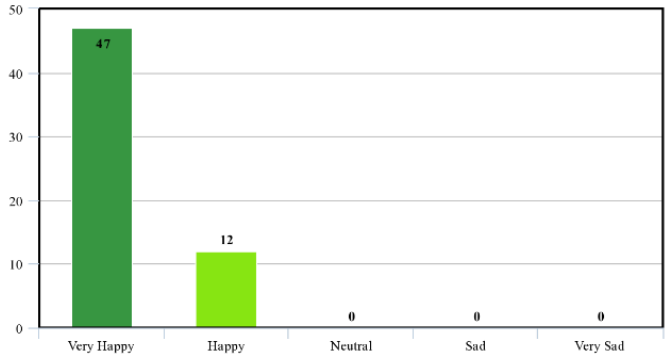

Figure 15: Frequencies on ‘How did you find navigating around the environment?’

The main aim of The Thornhill Experience was to demonstrate new and innovative methods to communicate history to help retain information through engaging content, results show that 28 participants out of 59 felt they definitely learnt about the ceramics through this experience, with a second highest amount of 21 who felt this likely helped them learn about the ceramics. The remaining 10 felt impartial to if they had learnt from the experience which could raise questions on the methods of delivering the content to suit a wider range of visitors.

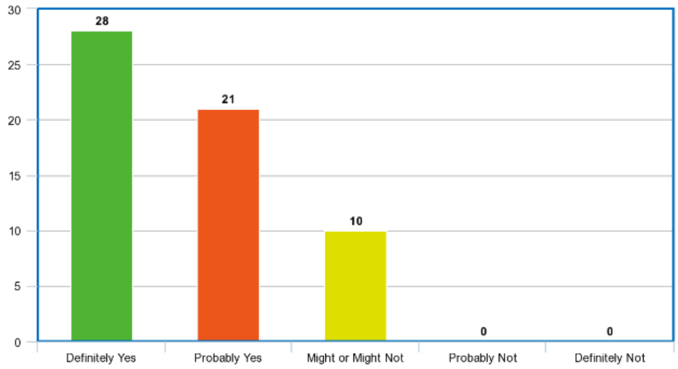

Figure 16: Frequencies on ‘Do you feel like this experience helped you learn more about the ceramics?’

When the questions came to the haptics it was asked if the participant felt as though the sense of touch was realistic to how it would feel physically, the questions were displayed with a series of faces to make the question visually simple to answer, with a sad face if they disagreed and a happy face is they agreed to the question. The most chosen response was a general yes with 23 out of 59, however this question did receive 10 in a neutral response, three with a sad face and 1 with a very sad face. This shows that some participants did not feel this technology gave them the realistic sense of touch they desired from the technology and experience.

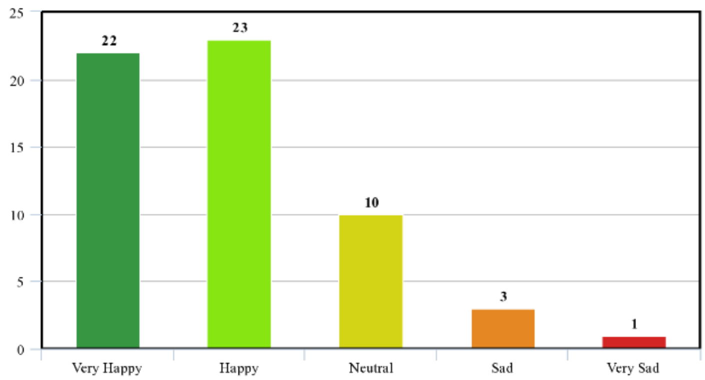

Figure 17: Frequencies on ‘Do you think haptic gloves provide a realistic sense of touch?’

This research offers an alternative solution to accessing museum objects via more holistic modes of interpretation that engage participants with a multi-sensory learning experience. The virtual handling of an object can facilitate access to details of the object limited by the fixed viewing planes within a vitrine. The SenseGlove haptic device cannot offer the ability to feel the weight and texture of an object, however it can offer the ability to feel the artefacts freely and view from every angle, without risk. The questionnaire asks, do you think a digital surrogate is an effective alternative to interact with a ceramic? Results showed most participants agreed that this was an effective alternative to hold a precious ceramic, however 10 out of 59 felt unsure, while three felt this is not an effective alternative. While it is understandable that you are limited to what you can experience with touch, this experience offers the ability to interact with an object that is usually prohibited or in this case currently with the Thornhill Collection, in storage and unavailable to view.

There are limited solutions to this limitation in museums that in most cases you must view the object behind a glass cabinet, making it difficult to engage with for more than a glance. It was clear from these results that participants understood they were not going to feel like they were touching a real ceramic, although what makes the experience unique is the way you can interact and gain context visually.

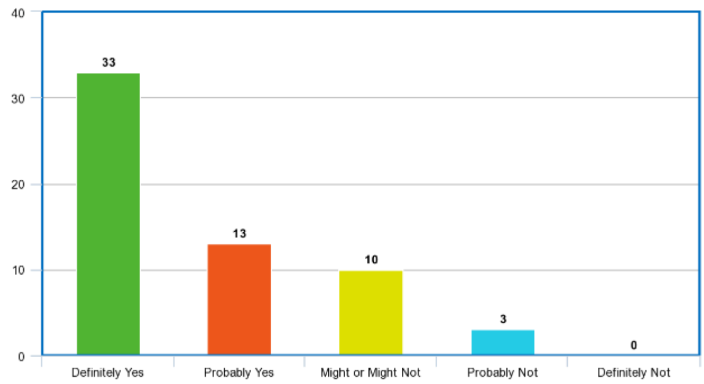

Figure 18: Frequencies on ‘Do you think a digital surrogate is an effective alternative to interact with a ceramic?’

Additionally to the previous question ‘if a participant felt as though a digital surrogate is an effective alternative to interact with a ceramic’, participants were asked if it was important to interact with a ceramic to understand its physical properties, with the results showed that 26 participants felt in was extremely important and 24 feeling it is very important, which is in most cases is impossible in traditional displays, reassuring a desire to explore these possibilities in how visitors can interact with ceramics and how important they feel that is to their experience.

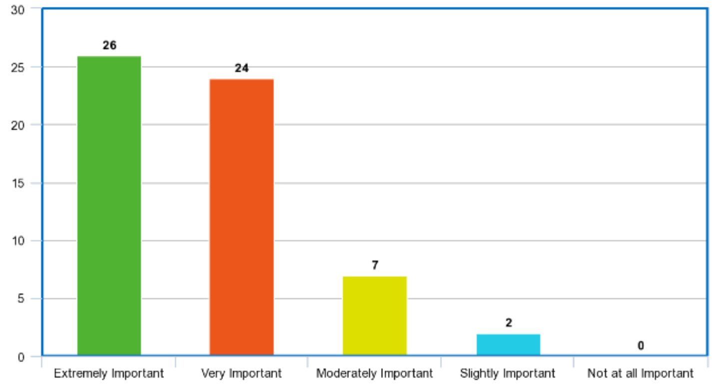

Figure 19: Frequencies on ‘How important do you think interaction is to understand a ceramic’s physical properties?’

Subsequent questions focused on the user satisfaction from the experience, participants were asked what the participants favourite part of experience was. This received a mix of responses with the majority voting that their favourite was interacting 1-1 with a ceramic object, followed with exploring the tomb showing a positive response from putting the participant in multiple environments. In this case the Participant was taken into a tomb to visually demonstrate where the ceramics were found and providing a reconstruction of what a traditional Tang Dynasty tomb looked like. The option with the least votes was the playing with the drum, which was an anticipated result, as the drum was added as a surprise interaction to see if the participant could discover it upon doing a certain action.

The action required dropping the musician on horseback ceramic whilst in the museum, the interaction aimed to show the musician was holding a drum by dropping a full-size Tang dynasty drum into the scene upon the ceramic smashing on to the floor, this also let the player pick up the drum and make authentic sounds upon touch the drum with a drumstick or hand.

This action acted as a discoverable source of information, this unpredictable interaction was implemented to encourage the visitor to stay engaged and maintain focus throughout the experience.

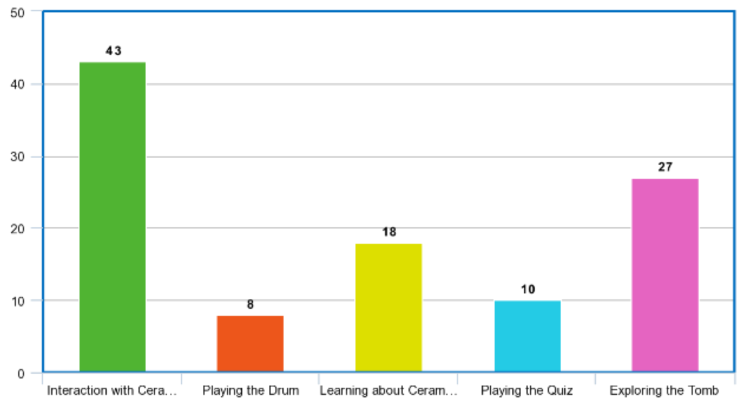

Figure 20: Frequencies on ‘What was your favourite part/s of the experience?’

After focusing on User Satisfaction, the questionnaire then went on to finding out about the desirability of this experience and if participants would want to try this again. Showing an overwhelming 43 out of 59 would definitely feel encouraged to visit a museum if they were previously informed of installations similar to this one, with 15 agreeing they probably would feel encouraged and 1 participant feeling impartial, however no participants answered that this would not encourage them to visit a museum.

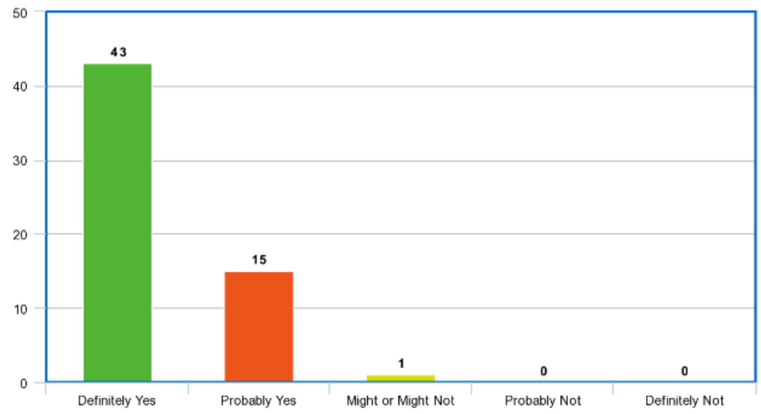

Figure 21: Frequencies on ‘Do you think installations like this could encourage you to visit a museum?’

This research focuses on exploring the possibilities of how museum can incorporate technology into museum settings to enhance a visitor experience, with this aim it was important to question the desirability from visitors to see technology incorporate into museums in the future. Results show a significant 54 out of 59 participants would like to see more technology in museums in the future, this shows a distinct desirability towards this research and therefore solidifies the significance to develop suitable technology for museum installations.

7 DISCUSSION

Results show some complications with the haptic gloves appearing realistic enough for participants to interact freely with the ceramics, however from observations it was clear the most important element of this experience was what the player could do additionally to understand deeper contexts to the artefact, such as transporting into a tomb to know where the artefact was found and understanding its former use.

Evidence also showed from testing that the visitor responded well to a playable source of information, interactions kept the visitor engaged until the experience ended. Easter egg like encounters, such as the drum appearing upon dropping the musician on horseback ceramic offered surprise motives to encourage the player to explore the experience thoroughly.

Data confirmed this experience offered an alternative method of accessibility to museum visitors that open new interactions with the object itself and surrounding visuals that would be impossible or very difficult to replicate in real-life. These unique interactions confirm the usefulness to incorporate this technology to help visitors use this experience as a tool for visual information and provide a role of creating engaging installations that show an artefact in a multimode of contexts.

This research was undertaken within museum development and to define the purpose of using digital heritage in the public domain. It was clear from the literature that there was a significant lack of technological advancement in the museum setting and therefore negatively impacting visitor engagement with ceramic displays. The displays showed a significant lack of context that could only be provided through audio guides or flat screen displays; however, these methods still limit the users’ senses and inability to engage with an artefact. The research starts with an overview of what current museums offer to a visitor, enabling the research to identify a new approach on developing a virtual reality system that introduces a limitless way of interacting and learning about the Thornhill ceramics. Studies showed that technology is being used more in recent years, but these exhibitions only remain temporary for a matter of weeks or months which limits the visitor to a time frame.

7.1 Conclusion

Museums have certainly seen an increase in experimentation to include technology in their installations, with the majority of consistent experiences offering virtual guides around the museum and the limitation of seeing the ceramic with no further interaction [11]. Figure 20 shows a traditional glass cabinet display in the Victoria & Albert Museum in London, United Kingdom.

Figure 22: Victoria & Albert Museum ceramics in display cases. (Public Domain) Via V&A Museum. (http://www.vam.ac.uk/content/articles/t/the-ceramicsgalleries-old-and-new/)

It is common practice to offer audio guides to visitors walking around the museums to offer an alternative source of context than the traditional text panel. This research assures the desire and intention to create exciting and new technological advancements within the history and heritage domain, therefore reinforcing the desire for this project. Haptic technology is still in its very early stages and has a long road of potential to create more vigorous and polished haptic gloves that can offer full accessibility in virtual reality to interact freely. This project proves the potential of how haptic gloves to better enhance a VR experience for visitors in a museum and how the added sense of touch adds a new dimension to what the visitor can do compared to physical displays.

The research undertaken has highlighted the issues with museums offering a range of experiences that avoid the traditional text panel format, this prototype contributes as an example model of technology can utilised within museum displays. The results from the design and development process show a solid workflow that can be applied to any museum artefact and implement it into a VR application.

This research project contributes practically with a reliable system to create digital replicas of ceramics that can serve as surrogate versions. This project exploits the potential of using haptic glove technology and how this can be utilised to enhance a museum visitor's experience and introduce a new dynamic of multisensory experiences that would alternatively be forbidden with the original artefact. Visualisation contextualises the ways visitors can learn about a ceramic's historiography and the ways this information can be constructed into innovative forms of interaction to appeal to a digital age of learners.

Figure 23: Set up of the SenseGlove haptic gloves with the HTC Vive headset, for The Thornhill Experience.

The innovation lies in the opportunity of how history can be interpreted into a digital alternative, and the ways visitors can learn through hands on interaction and multisensory experiences, these forms of interpretation create new concepts to visitors who wish to learn about history through an intimate, hands-on approach.

Results from the data collection showed this prototype enhanced engagement and helped assist the visitor retain information about ceramics. Therefore, bringing a sense of purpose and evident demand to bring various forms of Digital Heritage into mainstream museums and exhibitions.

REFERENCES

[1] T. Alsop, “Augmented reality (AR), virtual reality (VR), and mixed reality (MR) market size worldwide in 2021 and 2028,” 2022. [Online]. Available: https://www.statista.com/statistics/591181/globalaugmented-virtual-reality-market-size/#statisticContainer. [Accessed 13 October 2022].

[2] S. Evans, "Technology is bringing museums back to life," 2017. [Online]. Available: https://www.verdict.co.uk/technology-museums-back-tolife/. [Accessed 13 October 2021].

[3] M. Trunfio, "Innovating the cultural heritage museum service model through virtual reality and augmented reality: the effects on the overall visitor experience and satisfaction," *Journal of Heritage Tourism,* vol. 17, no. 1, pp. 1-19, 2021.

[4] H. Taher, "Digitalisation at," 17 09 2020. [Online]. Available: https://www.divaportal.org/smash/get/diva2:1480519/FULLTEXT01.pdf. [Accessed 26 07 2020].

[5] C. Browning, "Technology and planning help museums manage outdated exhibitions," The Conversation, 26 08 2020. [Online]. Available: https://theconversation.com/technology-and-planninghelp-museums-manage-outdated-exhibitions-143852. [Accessed 26 07 2022].

[6] M. Rowland, "Museums Association," 10 12 2018. [Online]. Available: https://www.museumsassociation.org/museumsjournal/news/2018/12/10122018-fifth-young-peoplenever-visit-museums/. [Accessed 13 07 2022].

[7] L. M. a. Galleries, "Leeds Museums and Galleries: A practical guide for text interpretation," 2017. [Online]. Available: https://www.museumdevelopmentyorkshire.org.uk/wpcontent/uploads/2017/12/Practical-guide-for-textinterpretation-2017.pdf. [Accessed 17 November 2021].

[8] P. Barron, "Visitor engagement at museums: Generation Y and ‘Lates’ events at the National Museum of Scotland," *Museum Management and Curatorship,* vol. 32, no. 5, pp. 473-490, 2017. [Accessed 17 07 2022].

[9] L. Ward, "6 Examples of Language and Technology in Museums," K International, 16 05 2019. [Online]. Available: https://www.kinternational.com/blog/language-and-technology-inmuseums/. [Accessed 14 07 2022].

[10] L. White, "Digital images in museums: Digital desires: What are museums up to?," *Bulletin of the American Society for Information Science and Technology*, vol. 34, no. 4, pp. 12-16, 2008. [Accessed 17 07 2022].

[11] B. Museum, "The Museum of the World," British Museum, 1] 2020. [Online]. Available: https://britishmuseum.withgoogle.com. [Accessed 13 07 2022].

[12] SketchFab, "SketchFab," SketchFab, 2012. [Online]. Available: https://sketchfab.com/. [Accessed 13 07 2022].

[13] V. Direct, "8 best virtual museum tours during self3] isolation," 2020. [Online]. Available: https://www.visiondirect.co.uk/blog/best-virtualmuseum-tours/. [Accessed 26 05 2022].

[14] S. Braun, "Six museums to explore virtually during 4] lockdown," DW, 13 04 2020. [Online]. Available: https://www.dw.com/en/six-museums-to-explorevirtually-during-lockdown/a-53073411. [Accessed 13 07 2022].

[15] N. M. o. N. History, "National Museum of Natural History - 5] Virtual Tours," National Museum of Natural History, 2021. [Online]. Available: https://naturalhistory.si.edu/visit/virtual-tour. [Accessed 13 07 2022].

[16] S. A. Brewster, "The Impact of Haptic 'Touching' 6] Technology on Cultural Applications," 2008. [Accessed 17 07 2022].

[17] M. Dima, "Touching the Past: Haptic Augmented Reality for Museum Artefacts," in *International Conference on Virtual, Augmented and Mixed Reality*, 2014.

[18] R. Comes, "HAPTIC DEVICES AND TACTILE EXPERIENCES IN MUSEUM EXHIBITIONS," *JOURNAL OF ANCIENT HISTORY AND ARCHAEOLOGY*, vol. 3, 2016. [Accessed 17 07 2022].

[19] M. Museum, "Digital Touch Replicas," 2022. [Online]. Available: HTTPS://MUSEUM.MANCHESTER.AC.UK/ABOUT/DIGITALT OUCHREPLICAS. [Accessed 17 07 2022].

[20] L. Candy, "Practice Based Research: A Guide," Creativity & 0] Cognition Studios, Sydney, 2006. [Accessed 17 07 2022].

[21] "Social Complexity and the Historiography of Ceramic," 14 1] 10 2001. [Online]. Available: https://ceramicsmuseum.alfred.edu/perkins_lect_series/g reenhalgh/. [Accessed 27 07 2022].

[22] T. Clark, Bryman's Social Research Methods, Oxford: OUP 2] Oxford; 6th edition, 2021. [Accessed 17 07 2022].

[23] SenseGlove, "The New Sense in VR for enterprise," 3] SenseGlove, 2022. [Online]. Available: https://www.senseglove.com/product/nova/. [Accessed 17 07 2022].

[24] J. Aber, "Small-Format Aerial Photography," Elsevier, 28 4] 05 2010. [Online]. Available: https://www.elsevier.com/books/small-format-aerialphotography/aber/978-0-444-53260-2. [Accessed 17 07 2022].

[25] T. L. Foundation, "A Simple Method for Reliable Creation 5] of 3D Artifact Models in the Field," The Leaky Foundation, 03 03 2016. [Online]. Available: https://leakeyfoundation.org/a-simple-photogrammetryrig-for-the-reliable-creation-of-3d-artifact-models-in-thefield/. [Accessed 17 07 2022].

[26] C. Walbridge, "Robot photogrammetry in Minneapolis," 6] SketchFab, 13 02 2018. [Online]. Available: https://sketchfab.com/blogs/community/robotphotogrammetry-minneapolis/. [Accessed 17 07 2022].

[27] DigVentures, "How To… Do Photogrammetry For Archaeology (Part 1)," DigVentures, 04 05 2016. [Online]. Available: https://projects.digventures.com/under-theuplands/timeline/diary/how-to-do-photogrammetry-forarchaeology-part-1/. [Accessed 17 07 2022].

[28] A. Knodell, "Photogrammetry for Documentation and 8] Sharing," ARCHAEOLOGY IN THE COWLING ARBORETUM, 2017. [Online]. Available: https://archaeologyinthearb.com/archaeology-pine-hillvillage/2017-fieldwork/artifact-analysis-2/. [Accessed 17 07 2022].

[29] T. Choukroun, "Digitisation vs digitalisation," You Sign, 9] 2022. [Online]. Available: https://yousign.com/blog/digitisation-vs-digitalisation. [Accessed 17 07 2022].

[30] M.-C. Eylott, "Museum to star in Sky VR experience with 0] Sir David Attenborough," National History Museum, 20 04 2017. [Online]. Available: https://www.nhm.ac.uk/discover/news/2017/april/muse um-to-star-in-sky-vr-experience-with-sir-davidattenborough.html. [Accessed 17 07 2022].

[31] B. D. Harper, "Improving user satisfaction: The questionnaire for user interaction satisfaction version 5.5 (1993)," in *Proceedings of the 1st Annual Mid-Atlantic Human Factors Conference*, 1993.

[32] Culture24, "1. What do we mean by digitisation?," Digital Pathways, 2022. [Online]. Available: https://digipathways.co.uk/what-do-we-mean-bydigitisation/. [Accessed 19 07 2022].

[33] D. C. E. Chaffin, "The search for immortality: The Tomb of Lady Dai," SmartHistory, 10 01 2022. [Online]. Available: https://smarthistory.org/tomb-of-lady-dai/. [Accessed 27 07 2022].

[34] A. Lewis, "The Top 10 Best Photogrammetry Software 4] 2022 (4 are Free!)," Sourced, 31 12 2021. [Online]. Available: https://www.3dsourced.com/3dsoftware/best-photogrammetry-software/. [Accessed 19 07 2022].

[35] Unity, "Unity 2022.2 alpha," Unity, 2022. [Online]. Available: https://unity3d.com/unity/alpha/. [Accessed 19 07 2022].

[36] L. Valdellon, "What is an SDK? Everything You Need to Know," CleverTap, 2020. [Online]. Available: https://clevertap.com/blog/what-is-an-sdk/. [Accessed 19 07 2022].

[37] BCB, "Festival 2021," British Ceramics biennial, 2021. [Online]. Available: https://www.britishceramicsbiennial.com/festival/bcb202 1/. [Accessed 19 07 2022].

[38] J. Chin, "Development of an Instrument Measuring User Satisfaction of the Human-Computer Interface," 1988. [Accessed 17 07 2022].

[39] PM&AG, "Galleries," 2022. [Online]. Available: https://www.stokemuseums.org.uk/pmag/galleries/. [Accessed 19 07 2022].

[40] PM&AG, "The Spitfire Gallery," 2021. [Online]. Available: https://www.stokemuseums.org.uk/pmag/exhibitions/spi tfire/. [Accessed 19 07 2022].

[41] L. White, "Digital Desires: What Are Museums Up To?," *Bulletin of the American Society for Information Science and Technology,* vol. 34, no. 4, pp. 12-16, April 2008.

[42] S. Brewster, "The Impact of Haptic 'Touching' Technology on Cultural," Glasgow Interactive Systems Group, Glasgow, 2001. [Accessed 17 07 2022].

[43] A. Lewis, "The Top 10 Best Photogrammetry Software 4] 2022 (4 are Free!)," 3DSourced, 31 12 2021. [Online]. Available: https://www.3dsourced.com/3dsoftware/best-photogrammetry-software/. [Accessed 28 07 2022].