Moving Inside the Box:

Interacting with Interpretation of Historical Artefacts Through Tangible Augmented Reality

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Figure 1: Left: ARcheoBox. Middle: A participant at user study. Right: A close-up of a participant hands inside ARcheoBox.

ABSTRACT

We present ARcheoBox, a walk-up-and-use prototype for interacting with interpretation of historical artefacts using tangible augmented reality. ARcheoBox enables users to manipulate virtual representations and interact with interpretation of historical artefacts using cylinder-shaped generic proxies. We also leverage the user interactions with interpretation using three interaction techniques "Move", "Rotate", and "Flip" as output modalities in AR. The prototype consists of a wooden box, a tablet display, and generic proxies, which means ARcheoBox does not require any head-mounted displays (HMDs), handheld controllers, or haptic gloves. We conducted a user study with 25 participants in which the findings demonstrate the advantages of tangible AR over more conventional interaction modalities presented in museums such as touch screens. Finally, we present a set of design recommendations for designing tangible AR that enhances the user's interaction experience with historical artefacts.

CCS CONCEPTS

• **Human Computer Interaction (HCI)**; • **Interaction Paradigms** → Mixed / augmented reality; • **Interaction Design**; • **Interaction Design Process and Methods** → Interface Design Prototyping;

MMAsia '23, December 06–08, 2023, Tainan, Taiwan

ACM ISBN 979-8-4007-0205-1/23/12…$15.00
https://doi.org/10.1145/3595916.3626408

KEYWORDS

Tangible interfaces, Augmented reality, Interaction techniques, Prototyping, Historical artefacts, Cultural heritage

ACM Reference Format:
Suzanne Kobeisse and Lars Erik Holmquist. 2023. Moving Inside the Box:: Interacting with Interpretation of Historical Artefacts Through Tangible Augmented Reality. In *ACM Multimedia Asia 2023 (MMAsia '23), December 06–08, 2023, Tainan, Taiwan.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3595916.3626408

1 INTRODUCTION

The Handling rare and ancient artefacts in museums has always been a restricted practice for the public and is often preserved only for curatorial practitioners. This is due to many factors, such as handling protocols and the fragility of the artefacts. On the other hand, museums are now greatly influenced by the rapid developments in digital technologies, where Augmented Reality (AR) and Virtual Reality (VR) applications are becoming widely implemented to provide rich multisensory experiences [19, 41]. Current interactive exhibits limit user interactions with artefacts to direct manipulation via screen-based touch interfaces [12, 45]. While some successful examples allow museum visitors to experience historical artefacts in a more tactile way using 3D prints and smart replicas, many of these exhibits would involve custom-made interfaces or specialized pieces of equipment that require more complex processes and resources [28].

In this paper, we present ARcheoBox (Figure 1) a walk-up-and-use prototype for manipulating virtual representations and interacting with interpretation of historical artefacts using cylinder-shaped generic proxies. We also leverage the interactions with interpretation using three interaction techniques, "Move", "Rotate", and "Flip as output modalities in AR. ARcheoBox aims to foster richer interactions with interpretation of historical artefacts while keeping all interactions embedded within the same physical objects (generic proxies) to remove physical barriers with the artefacts and produce an intuitive and engaging user experience. The interactions with the interpretation are expressed by the hand gestures, as the case when examining an artefact from different angles, building on human motor skills [9].

The design process was carried out through a collaborative research process with multiple stakeholders, including cultural heritage professionals and archaeologists to develop design features and heritage content. We followed a prototype-led inquiry [10] and research through design process [47]. We also conducted co-design interviews, a method that has proven to be successful in the cultural heritage domain to elicit ideas and engage stakeholders in the design process [3, 34].

The paper is organised as follows: First, we position our research in relation to previous works in the field of tangible and gestural interactions, virtual objects manipulation, and tangible interaction in cultural heritage. Second, we discuss the co-design process, including the first prototype design, and co-design interviews. This is followed by describing ARcheoBox design and implementation. We then discuss the findings from the user evaluation. And finally, we conclude by presenting the limitations and future work.

2 RELATED WORKS

This section presents an overview of the literature on tangible and gesture interactions, virtual objects manipulation, and tangible interactions in cultural heritage.

2.1 Tangible and Gesture Interaction

Access to digital information through manipulating physical objects is an established area of research rooted in tangible user interfaces (TUIs) [15]. Many projects such as mediaBlocks [39], metaDESK [40], and Tangible Viewpoints [30] have showcased the benefits of using atoms to manipulate pixels. Subsequently, the scope of tangible user interfaces was conceptualised through several tangible interaction frameworks, which include embodied interactions [6], and user bodily movement and spatial interactions as important aspects of tangible interactions [13]. Embedding physical objects with gestural interactions can amplify user experience due to the intuitiveness and natural expression of gestures to communicate digital information [14]. Holding, touching, moving, and shaking are all gestural interactions supported by human motor skills to interact with physical objects. Gesture Objects Interfaces combine tangible interfaces with gestural interactions to facilitate communication between gestures and objects, for example, researchers introduced gestural interactions in children's toys, which allow the children to produce film clips by gesturing toy figures using an embedded camera and algorithm [42].

Harrison et al. [16] investigated physical manipulations that are directly integrated with the object that is being controlled using embedded sensor technologies. Smart-Its Friends [18] allows the user to establish a connection between smart devices by simply shaking them. Additionally, White et al., [43] added shaking gestures to flat AR markers to augment further information around the virtual content. While these projects demonstrate how tangible interactions can empower user experience and advocate ubiquitous computing, some of them involve multiple input devices, connected networks, and complex systems. We aim to extend the advantages of tangible user interfaces, by keeping communication between the tangible interface and augmented reality system simple and intuitive. We explore how the physical objects can have different input modalities in AR without applying any sensors technology, by attaching augmented reality markers to the artefact.

2.2 Virtual Objects Manipulation

Advances in immersive technologies and the commercialisation of VR headsets and controllers such as Google cardboard and Oculus Rift paved the way for further investigation into 3D user interfaces to manipulate virtual objects and allow a closer to reality user experience. While our focus is on reviewing the manipulation of virtual objects using tangible interfaces and augmented reality [1, 11, 22], other common approaches for manipulating virtual objects surfaced such as mid-air gestural [37], as well as the use of haptic interfaces [2, 46]. Tangible proxies have also emerged as a very common tangible approach to manipulate virtual objects, either by using commercial controllers like HTC VIVE or by adopting a more generic approach using primitives [8] and everyday objects [17]. In the domain of cultural heritage, virtual manipulation of historical artefacts is becoming a popular research area as more interest arises in engaging the public through a material encounter with historical artefacts using tangible proxies [23, 25], 3D prints, and HoloLens [35, 36]. The concepts that emerged from the literature so far form a valuable background for our research to establish design principles in tangible AR for exploring virtual objects. To our knowledge, we are the first to investigate the combination of (cylinder-shaped) generic proxies as input controllers for augmented reality applications in the cultural heritage domain.

2.3 Tangible Interaction in Cultural Heritage

Tangible interaction applications in museums aim to emphasise the importance of material engagement with artefacts as highlighted in museum studies [7]. This has led to much research on tangible interactions, such as "*Physical Keys to Digital Memories*" [4], an interactive installation called *Reminisce* based in an open-air museum where visitors collect physical and digital tokens to access audio recordings of characters' memories using a mobile phone application. Further examples of tangible interaction applications in museums include the Internet of Things as a material encounter with museum artefacts [33], and The Loupe [5], an embedded mobile phone in the shape of a magnifier that allows museums visitors to point the device at the artefacts cabinet and overlay text and audio content. Prior works also explored the use of generic objects (cubes) in AR for augmenting archived historical collections, however, the interactions were limited to overlaying 3D models in AR, while information still had to be accessed using a screen-based interface [20]. Our work contributes to this body of work by proposing a *walk-up-and-use* prototype using generic proxies and interaction techniques in AR to provide an intuitive and immersive user experience while maintaining all the interactions embedded within the physical objects.

3 CO-DESIGN PROCESS

In this section, we present the first prototype design and the co-design process which informed the development of ARcheoBox.

3.1 First Prototype Design

We developed an initial prototype (proof-of-concept), and we conducted a pilot study with eight heritage experts. The initial prototype served as an externalisation tool which facilitated sharing concepts with the heritage experts [29]. The pilot study aimed to capture the heritage experts' early impressions and elicit their feedback about the use of the technology. For the initial prototype, we used flat AR markers as tangible interfaces which allowed the heritage experts to reach their hands inside the box, hold an AR marker, upon which a virtual representation of a digitized historical artefact is positioned, and manipulate the artefact from different angles. The preliminary feedback from the heritage experts suggested that the prototype has great potential to offer an engaging experience for manipulating virtual representations of historical artefacts. Following the pilot study, we built on prior work by Kobeisse and Holmquist [24] in which they compared four different tangible interfaces for AR (touch screen, flat AR marker, 3D-print replica, and a cylinder-shaped generic proxy). Their findings indicate that using generic proxies such as cylinders can offer intuitive tangible interfaces for AR over the traditional touch screen and flat AR marker.

3.2 Co-design Interviews

The co-design interviews aimed to generate insights on what kind of design features and heritage content we can create to engage the users with interpretation of Bronze Age artefacts. We interviewed eight heritage experts remotely using Microsoft Teams teleconferencing application. All heritage experts had extensive archaeology and cultural heritage experience. The heritage experts answered a set of open-ended questions which were recorded and transcribed for analysis. We then identified a set of design features and heritage content.

A common approach for interacting with AR applications in a heritage context is using hand-held devices (i.e., tablets, mobile phones) where visitors scan through the surrounding environment [27] or aim the device at artworks in the exhibition [21]. The heritage experts stated: "Constantly what you're doing with that is making your experience of the artefact through a screen" (E3). Hence, this approach limits physical interaction with the artefacts. Through the co-design interviews, the notion of using physical objects (generic proxies) to manipulate virtual representations and interact with interpretation of historical artefacts responded to some of these challenges, as well as they would allow physical access to historical artefacts which wouldn't be previously possible due to museum protocols.

3.2.1 Design Features. Interaction Techniques. The inherent affordances of the physical objects extended to incorporating interaction techniques as output modalities in AR to unlock the interpretation of the artefacts. The interaction techniques intended to be an expression of the hand gestures when exploring an artefact to interact with interpretation, as one heritage expert suggested: "If you turn it that way you can see it was used for and if you turn it the other way you discover who used it"; "this would be definitely be a new approach than to the traditional panel interpretation looking at it in a glass display" (E7). The experts also highlighted that physically holding an artefact in hand while listening to their interpretation, would enhance the user's understanding of the artefacts interpretation and foster a close connection between the user and the artefacts. The interaction techniques as output modalities in AR would also allow access to multifocal narrative such as artefact manufacturing, use, and community practices, as one of the heritage experts stated: "You are looking at objects in a way where it connects to its landscape, and it connects to its context" (E1). Other suggestions by the heritage experts for interaction techniques included, that holding the physical objects over time can result in different types of output modalities in AR.

Visualisation. To support the implementation of the artefacts' context in the virtual environment, the heritage experts suggested incorporating graphical visual and audio assets, such as maps and photographs, as well as audio interpretation and ambient sounds inspired by the landscape. The visual and audio assets aim to immerse the user in the context of the original artefacts and offer the feeling of being there to connect with the landscape. Additionally, the heritage experts also stated that the visitor should be able to explore the virtual representations separately in explore mode to have a full appreciation of the details of the artefacts, and then introduce interaction with interpretation in interpret mode.

3.2.2 Heritage Content. Moving Inside the Box. The box's internal structure provides a three-dimensional space to support a spatial configuration that responds to the interaction techniques by calculating the relative position between the tablet camera and the AR markers to display the corresponding content in the virtual environment. Additionally, the box creates defined boundaries that potentially could prevent the user from moving the generic proxies in random directions outside the tablet camera's field of view and losing tracking of the AR markers.

The Narrative. The Breamish Valley situated in the Northumberland National Park, in the North East of England, UK, holds some of the best-preserved archaeological landscapes in the Cheviot Hills. The excavations (1994 - 2003) revealed three fascinating Bronze Age food and drinking vessels which were carefully removed, restored, and conserved. The Bronze Age artefacts date back to the Early Bronze Age (4,000 Years BP or 2,000 BC) and depict important information about the life of the people and their rituals in the Bronze Age. The artefacts contained the remains of an infant who died after suffering from meningitis. Early suggestions indicate that these types of artefacts were used as a funeral pot and contained food to be used by the deceased in the afterlife. In collaboration with the heritage experts, we crafted the heritage content for three Bronze Age artefacts (an Urn, a food vessel, and a beaker).

4 ARCHEOBOX DESIGN AND IMPLEMENTATION

ARcheoBox (Figure 2) was developed through an iterative process using co-design interviews with heritage experts. The box consists of a wooden container manufactured with laser-cut birch wood. A tablet display (Samsung Galaxy S7 tablet) is placed on top of

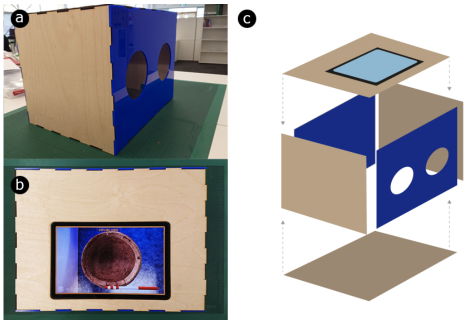

Figure 2: a) ARcheoBox prototype; b) top view of ARcheoBox; c) ARcheoBox structure diagram

Figure 3: Screenshot of the welcome screen; b) virtual 3D model in Explore mode; c) Interpret mode showing artefact info; d) Interpret mode showing artefact map.

the box and two holes are cut in front of the box to allow the user to reach in and hold what is inside the box, in this case, wooden cylinder-shaped generic proxies with attached augmented reality markers for tracking

4.1 Designing Interaction Techniques

We designed three interaction techniques, "Move", "Rotate", and "Flip as output modalities in AR . The three interaction techniques are mapped to three output modalities in AR "Zoom", "Select", and "Switch". The interaction techniques are designed to provide a direct mapping between the physical objects (generic proxies) and the augmented reality application. The interactions are intended to be intuitive and similar to the gestures the user would perform when manipulating a real artefact in their hand. The output modalities in AR work by registering the relative position between the camera and the AR markers to display the corresponding virtual 3D model and related interpretation. Each interaction technique allows to select its related interpretation and interact with one of the aspects of interpretation (visual, text, audio).

Move – Users can move the generic proxy closer to the camera to activate panels including text, maps, and photographs. The audio for the interpretation is also controlled by moving the generic proxy either close to the camera to play it or further away to pause it. This action would minimise any degree of disruption when handling the artefact, in case the user moves the AR maker away from the camera view.

Rotate – Users can rotate the generic proxy to select various pieces of interpretation. The interpretation is attached to two AR markers attached to the sides of the generic proxy.

Flip – Users can flip the generic proxy to switch between the Explore Mode and Interpret Mode. The flip action is executed by turning the generic proxy into an upside-down position and flipping it back to its original positioning.

While we considered adding visual hints [44] such as floating text around the virtual 3D model or adding an extra AR marker as a controller [38] for the virtual environment, we anticipated that this would distract the user from the task at hand while manipulating the artefacts. Therefore, we opted not to add touch screen buttons. We wanted to keep the focus on the virtual representations of the historical artefact, while also being able to interact with interpretation using the same physical object.

4.2 Augmented Reality (AR) Application

The augmented reality application (Figure 3) was built using the Vuforia SDK and Unity games engine software. The digital 3D models were acquired through 3D scanning and photogrammetry techniques. We then used Blender, a 3D modelling software to process geometric data and reduce the number of polygons while conserving the smooth texture of the 3D models. The application consists of two modes: "Explore Mode" presents the 3D models and allows the user to fully immerse in their fine details and get a close-up view of the beautifully decorated artefacts with thumbnail print marks. The "Interpret Mode" presents the interpretation of the artefacts. When the user picks up one of the physical objects, they can interact with each interpretation marked on the artefact, for example, photographs, short text, and maps of the national park.

5 USER EVALUATION STUDY

We evaluated ARcheoBox with heritage experts and end-users. The goal of the study was to gather the participants' feedback on the prototype interface design and identify any potential features and shortcomings with the application while still in the evaluation phase.

5.1 Participants

The study consisted of 25 participants, 14 females and 11 males, age range 29 - 63, mean age 44.64. Participants were recruited using the affiliated network of the heritage organisation, on a voluntary basis without any compensation. The study was conducted during the COVID-19 pandemic, hence, all the necessary safety measures were taken into consideration, like wearing masks, social distancing, sanitising station, as well managing the airflow in the study room. The participants comments were recorded and transcribed later for data analysis. Participants were given an information sheet explaining the study protocol, then they were asked to sign a consent form and fill out a demographic questionnaire.

5.2 Procedures

After a brief introduction to ARcheoBox, participants were left to interact freely with the prototype. Participants were asked to provide feedback on the interface design features. The researcher observed the participants' interactions while standing nearby following COVID-19 social distancing measures and assisted participants by answering questions when needed, also took notes of any comments made by the participants. At the end of the session, participants were asked to complete a questionnaire with 15 Likert-type scale questions [26] each rated on a 5-points scale from "Strongly Agree" to "Strongly Disagree" to assess the prototype. The questions were grouped into six categories which are adapted from interface design usability guidelines [31]. We also added a comment section below each of the Likert-type scale questions to further identify any issues that were not covered by the questions. Additionally, participants were asked to describe what they most liked about ARcheoBox and what they liked the least and add any further comments.

5.3 Findings

Participants took approximately 30 seconds to be familiarised with ARcheoBox unique interaction techniques. Once the participants understood the principles for interaction, they started exploring the different interactions and had no issues recalling the interaction techniques. Through informal interviews with the researcher, the participants reported ease of use, intuitiveness, and enjoyment throughout the study. Finally, participants stated that they appreciated the tactile sense carried by the generic proxies.

The results from the Likert-type scale questions are presented in Figure 4. The majority of participants (92%) stated that the application is clear and visible, where appropriate visual feedback is given to familiarise the user with the application interface. The match between the application and the real world also scored highly with the participants stating that the application corresponded to the real-world environment. The interface control yielded favourable results with participants stating that they felt in control while using the application. Additionally, participants stated that application functionalities were easy to remember, and that text and visuals were clear and readable. Overall, participants stated that the application is well designed, and the aesthetics are pleasing, "Sleek and well designed, extremely informative and detailed" (P4), "I love how it is like holding the artefact and having someone talk you through" (P1). Furthermore, all participants stated that they enjoyed the experience, and that the application is useful to manipulate virtual representations and interact with interpretation of historical artefacts. "It is a really fun interactive application that will really help with the different ways individuals learn and interact with objects" (P14).

We also gathered some valuable feedback from the participants to improve the AR application. P20 suggested including hotspot labels for the interpretation. Other suggestions included adding a map of the excavation sites of the artefacts. Additionally, participants also stated that having different colours in each interface mode enabled them to easily distinguish between Explore mode and Interpret mode. Participants also stated that ARcheoBox offers a great opportunity of making historical artefacts accessible using unique interactions, P8 stated: "What I liked is the accessibility side of things, where I don't need to come with my own technology, I don't need to download an app, I put that away and just enjoying the experience". It doesn't require any other interaction from me

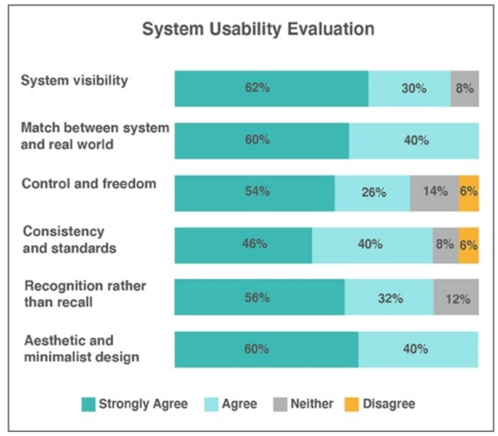

Figure 4: Evaluation results chart.

except using it.", P7 added: "I think this would make a great asset to an exhibition or exploration activities and suitable to all ages".

When asked what they liked most about ARcheoBox, participants stated that physically holding and manipulating virtual representations of historical makes the whole experience a lot more captivating, "I liked the ability of the prototype to connect me tangibly to the object, I can hold it, something I can never do with the actual object" (P3). Additionally, participants identified other benefits fpr tangible AR beyond museums exhibitions, including knowledge sharing among other experts, supporting early career researchers in studying artefacts, and providing an opportunity for enthusiastic users to get a closer look and learn more about the artefacts.

6 DISCUSSION

We reported on the design and implementation of ARcheoBox as a walk-up-and-use prototype that allows users to manipulate virtual representations and interact with interpretation of historical artefacts. Next, we discuss a set of design recommendations based on our findings from the evaluation study and iterative co-design process. We also reflect on how 'moving inside the box' informs unique interaction techniques to interact with interpretation of historical artefacts using generic proxies.

Communicating Interaction Semantics

Our findings show that participants 'felt in touch' with the Bronze Age artefacts because they could hold the artefacts in their hands and interact with Interpretation at the same time. Our findings are confirmed by previous research that tangible interaction in museums provides a sense of engagement with exhibits [32], versus more limited interactions via screen-based touch interfaces. ARcheoBox walk-up-and-use approach differs from most immersive museum exhibitions, which require wearing head-mounted displays and using handheld controllers. Participants were not required to operate any additional gear, offering an intuitive and engaging user experience for manipulating virtual representations and interacting with interpretation of historical artefacts.

From one side, the cylinder-shaped generic proxies shared a familiar resemblance with the virtual 3D models and offered mutual affordances. Moreover, designing interaction techniques as output modalities in AR requires careful consideration to clearly communicating the semantics of the intended interactions between the physical objects (generic proxies) and their output modalities in the virtual environment. We suggest that designers can explain the semantics of the interaction techniques to users to test their practicalities. Designers can also provide further visual cues, for example by designing icons related to the different types of output modalities and attaching them to the AR markers.

Designing for Immediate Interaction with Artefacts

Participants noted that one of the benefits of using physical objects (generic proxies) to manipulate virtual representations and interact with interpretation of historical artefacts is the immediate interaction with the artefacts, such as their ability to interact with the artefacts without downloading any applications to their smartphones or operating additional devices such as head-mounted displays or handheld controllers. Accordingly, we suggest the following guidelines to design for immediate interaction with artefacts: 1) Re-purposing of physical objects by using a single physical object (generic proxy) whose shape resembles the virtual representation but without exactly corresponding to it, which would enable physical manipulation of multiple historical objects; 2) New way to access archival information by embedding the interaction techniques within the same physical objects (generic proxies) as AR output modalities to interact with interpretation of artefacts. This would minimise the physical barrier that usually exists when users interact via buttons on a touch screen as the user does not need to switch to another device; 3) Customisable interactions, by customising the AR markers on the generic proxies so that each side becomes a potential point for interaction to unearth the artefact narrative. This would enable museum curators to modify or replace the application contents to fit their museum exhibits.

Co-designing Tangible AR with Heritage Experts

We incorporated co-design methods in our interviews with heritage experts to establish design features and heritage content that can 'bring to life' a collection of Bronze Age artefacts. Co-design provided us with the opportunity to connect with multiple stakeholders, bringing rich perspectives when designing digital technologies for heritage. The heritage experts regarded tangible AR as a medium that could offer museum visitors a unique way to interact with interpretation by holding the objects in their hands. We also worked with other stakeholders from the organisation to audio record some excerpts of the interpretation, bringing a hands-on approach to the community of collaborators as part of the co-design process.

We followed an iterative design process, where each iteration validated the prototype features and elicited conversations through formal and informal discussion. Prototyping for AR is still an exploratory design space with very few tools that exist to help with the ideation process for 3-dimensional and virtual spaces. Consequently, we developed a sketching sheet to help non-designers such as the heritage experts, brainstorm different concepts for the prototype. The sketching sheet structure contains two sections: the first section, Interactions in AR, is to brainstorm concepts for interaction techniques in AR using generic proxies. The second section, heritage content, is to compose the interpretation of the artefacts. The sketching sheet served as an inspiration tool and enabled participants to establish connections between analogue methods of ideation and AR technologies, as well as generate ideas about interaction techniques using generic proxies. Once, the heritage experts identified more specific ideas, we then initiated discussions around potential technological implementation.

7 LIMITATIONS AND FUTURE WORK

During user observations, we noticed that some participants occasionally lost tracking of the AR markers. As AR technology keeps advancing, we aim to further investigate different tracking techniques to improve occlusion. In future work, we will investigate additional interaction techniques using the generic proxies' additional degrees of freedom and explore how different interaction techniques can support different output modalities in AR, such as proximity for interaction between two physical objects to reveal interpretation embedded within the artefacts.

8 CONCLUSION

We presented ARcheoBox, a *walk-up-and-use* prototype for manipulating virtual representations and interacting with interpretation of historical artefacts. We also designed three interaction techniques, "Move", "Rotate", and "Flip, with output modalities in AR, "Zoom", "Select", and "Switch". ARcheoBox enables users to hold historical artefacts in their hands, and inspect them closely, while also being able to interact with interpretation using generic proxies, removing physical barriers commonly exist in museum exhibits. We also conducted co-design interviews with heritage experts and a user evaluation study. Finally, we introduced a set of design recommendations that contribute to designing tangible AR that enhances the user's interaction experience with virtual representations of historical artefacts.

ACKNOWLEDGMENTS

We would like to thank Northumberland National Park Authority in the UK for their support and the participants for taking part in the user evaluation study.

REFERENCES

[1] Billinghurst, M., Kato, H., & Poupyrev, I. (2008). Tangible augmented reality. ACM SIGGRAPH ASIA 2008 Courses, SIGGRAPH Asia'08, January. https://doi.org/10.1145/1508044.1508051

[2] Cheng, L. P., Ofek, E., Holz, C., Benko, H., & Wilson, A. D. (2017). Sparse haptic proxy: Touch feedback in virtual environments using a general passive prop. Conference on Human Factors in Computing Systems - Proceedings, 2017-May, 3718–3728. https://doi.org/10.1145/3025453.3025753

[3] Ciolfi, L., Avram, G., Maye, L., Dulake, N., Marshall, M. T., Van Dijk, D., & McDermott, F. (2016). Articulating co-design in museums: Reflections on two participatory processes. Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW, 27, 13–25. https://doi.org/10.1145/2818048.2819967

[4] Ciolfi, L. and Bannon, L. (2002) 'Designing Interactive Museum Exhibits: Enhancing visitor curiosity through augmented artefacts', Eleventh European Conference on Cognitive Ergonomics. pp. 1–7.Conference Name:ACM Woodstock conferenceConference Short Name:WOODSTOCK'18

[5] Damala, A., Hornecker, E., van der Vaart, M., van Dijk, D., & Ruthven, I. (2016). The loupe: Tangible augmented reality for learning to look at ancient Greek art. Mediterranean Archaeology and Archaeometry, 16(5 Special Issue), 73–85. https://doi.org/10.5281/zenodo.204970

[6] Dourish, P. Where the Action is; MIT Press: Cambridge, MA, USA, 2004; p. 233.

[7] Dudley, S. (2012). Materiality Matters: Experiencing the Displayed Object – Working Papers in Museum Studies. Museum Studies, 8 (8), 1–9.

[8] Feick, M., Bateman, S., Tang, A., Miede, A., & Marquardt, N. (2020). TanGi: Tangible proxies for embodied object exploration and manipulation in virtual reality, ISMAR 2020. https://doi.org/10.1109/ismar50242.2020.00042

[9] Gibson, J. J. The theory of affordances. Perceiving, Acting, and Knowing (1977).

[10] Gill, C., Sanders, E. and Shim, S. (2011) 'Prototypes as inquiry, visualization, and communication', DS 69: Proceedings of E and PDE 2011, the 13th International Conference on Engineering and Product Design Education, (September), pp. 672–677.

[11] Hornecker, E. (2012). Beyond affordance: Tangibles' hybrid nature. Proceedings of the 6th International Conference on Tangible, Embedded and Embodied Interaction, TEI 2012, 175–182. https://doi.org/10.1145/2148131.2148168

[12] Hornecker, E. (2008). "I don't understand it either, but it is cool" - Visitor interactions with a multi-touch table in a museum. 2008 IEEE International Workshop on Horizontal Interactive Human-Computer System, TABLETOP 2008, 113–120. https://doi.org/10.1109/TABLETOP.2008.4660193

[13] Hornecker, E. and Buur, J. (2006). Getting a grip on tangible interaction: a framework on physical space and social interaction. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.

[14] Hoven, E.V., & Mazalek, A. (2011). Grasping gestures: Gesturing with physical artefacts. Artificial Intelligence for Engineering Design, Analysis, and Manufacturing, 25, 255 - 271.

[15] Ishii, H., & Ullmer, B. (1997). Tangible bits: Towards seamless interfaces between people, bits, and atoms. Conference on Human Factors in Computing Systems - Proceedings, March, 234–241.

[16] Harrison, B. L., Fishkin, K. P., Gujar, A., Mochon, C., & Want, R. (1998). Squeeze me, hold me, tilt me! An exploration of manipulative user interfaces. Conference on Human Factors in Computing Systems - Proceedings, April, 17–24. https://doi.org/10.1145/274644.274647

[17] Hettiarachchi, A., & Wigdor, D. (2016). Annexing reality: Enabling opportunistic use of everyday objects as tangible proxies in augmented reality. Conference on Human Factors in Computing Systems - Proceedings, 1957–1967. https://doi.org/10.1145/2858036.2858134

[18] Holmquist, L. E., Alahuhta, P., Beigl, M., & Gellersen, H. (2001). Smart-Its Friends: A Technique for Users to Easily Establish Connections between Smart Artefacts. Ubicomp 2001: Ubiquitous Computing. 2201(September), 273–291. https://doi.org/10.1007/3-540-45427-6

[19] Jiménez Fernández-Palacios, B., Morabito, D., & Remondino, F. (2017). Access to complex reality-based 3D models using virtual reality solutions. Journal of Cultural Heritage, 23, 40–48. https://doi.org/https://doi.org/10.1016/j.culher.2016.09.003

[20] Kalinda, D, Hrynyshyn, L, Resch, G, Nathan, A, David, Ra and Mazalek, A. "Tangible Augmented Reality for Archival Research: Using Augmented Reality to Research Cultural Heritage Items." MW20: MW 2020. Published January 15, 2020. Consulted November 15, 2021. https://mw20.museweb.net/paper/tangible-augmented-reality-for-archival-research-using-augmented-reality-to-research-cultural-heritage-items/

[21] Katifori, A., Karvounis, M., Kourtis, V., & Kyriakidi, M. (2014). CHESS: Personalized Storytelling Experiences. 7th International Conference on Interactive Digital Storytelling, ICIDS 2014: Interactive Storytelling, January 2019, 232–235. https://doi.org/10.1007/978-3-319-12337-0

[22] Kato, H., Billinghurst, M., Poupyrev, I., Imamoto, K., & Tachibana, K. (2000). Virtual object manipulation on a table-top AR environment. Proceedings - IEEE and ACM International Symposium on Augmented Reality, ISAR 2000, 111–119. https://doi.org/10.1109/ISAR.2000.880934

[23] Kobeisse, S. 2023. Touching the past: developing and evaluating tangible AR interfaces for manipulating virtual representations of historical artefacts. PhD Thesis. Northumbria University.

[24] Kobeisse, S., Holmquist, L.E. (2022). "I Can Feel It in My Hand": Exploring Design Opportunities for Tangible Interfaces to Manipulate Artefacts in AR. In Proceedings of the 21st International Conference on Mobile and Ubiquitous Multimedia, 28-36. https://doi.org/10.1145/3568444.3568446

[25] Kobeisse, S. and Holmquist, L.E. (2020). ARcheoBox: Engaging with Historical Artefacts Through Augmented Reality and Tangible Interactions. UIST '20: The Adjunct Publication of the 33rd Annual ACM Symposium on User Interface Software and Technology. https://doi.org/10.1145/3379350.3416173

[26] Likert, R. (1932). A technique for the measurement of attitudes. Psycnet.Apa.Org. Retrieved from https://psycnet.apa.org/record/1933-01885-001

[27] Madsen, J. B., & Madsen, C. B. (2015). Handheld visual representation of a castle chapel ruin. Journal on Computing and Cultural Heritage, 9(1), 1–18. https://doi.org/10.1145/2822899

[28] Marshall, M. T., Dulake, N., Ciolfi, L., Duranti, D., Kockelkorn, H., & Petrelli, D. (2016). Using tangible smart replicas as controls for an interactive museum exhibition. TEI 2016 - Proceedings of the 10th Anniversary Conference on Tangible Embedded and Embodied Interaction, 159–167. https://doi.org/10.1145/2839462.2839493

[29] Mason, M. (2015). Prototyping practices supporting interdisciplinary collaboration in digital media design for museums. Museum Management and Curatorship, 30(5), 394–426. https://doi.org/10.1080/09647775.2015.1086667

[30] Mazalek, A., Davenport, G., & Ishii, H. (2002). Tangible viewpoints: Physical Navigation through Interactive Stories. Proceedings of the Tenth ACM International Conference on Multimedia - MULTIMEDIA '02, June, 153. https://doi.org/10.1145/641034.641037

[31] Nielsen, J., & Molich, R (1990). Heuristic evaluation of user interfaces. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pages 249–256, New York, NY, USA.

[32] Not, E., Cavada, D., Maule, S., Pisetti, A., & Venturini, A. (2019). Digital augmentation of historical objects through tangible interaction. Journal on Computing and Cultural Heritage, 12(3). https://doi.org/10.1145/3297764

[33] Petrelli, D., Dulake, N., Marshall, M. T., Roberts, A., McIntosh, F., & Savage, J. (2018) 'Exploring the Potential of the Internet of Things at a Heritage Site through Co-Design Practice', Proceedings of the 2018 3rd Digital Heritage International Congress, Digital Heritage 2018 - Held jointly with the 2018 24th International Conference on Virtual Systems and Multimedia, VSMM 2018. doi: 10.1109/DigitalHeritage.2018.8810061.

[34] Petrelli, D., Ciolfi, L., Van Dijk, D., Hornecker, E., Not, E., & Schmidt, A. (2013). Integrating material and digital: A new way for cultural heritage. Interactions, 20(4), 58–63. https://doi.org/10.1145/2486227.2486239

[35] Pollalis, C., Fahnbulleh, W., Tynes, J., & Shaer, O. (2017). HoloMuse: Enhancing engagement with archaeological artefacts through gesture-based interaction with holograms. TEI 2017 - Proceedings of the 11th International Conference on Tangible, Embedded, and Embodied Interaction, March, 565–570. https://doi.org/10.1145/3024969.3025094

[36] Spence, J., Darzentas, D. P., Huang, Y., Cameron, H. R., Beestin, E., & Benford, S. (2020). VRtefacts: Performative substitutional reality with museum objects. DIS 2020 - Proceedings of the 2020 ACM Designing Interactive Systems Conference, 627–640. https://doi.org/10.1145/3357236.3395459

[37] Song, P., Goh, W. B., Hutama, W., Fu, C. W., & Liu, X. (2012). A handlebar metaphor for virtual object manipulation with mid-air interaction. Conference on Human Factors in Computing Systems - Proceedings, 1297–1306. https://doi.org/10.1145/2207676.2208585

[38] Tan, D., Poupyrev, I., Billinghurst, M., Kato, H., Regenbrecht, H., & Tetsutani, N. (2001). On-demand, In-place Help for Mixed Reality Environments. Ubicomp 2001 Informal Companion Proceedings, 9(August).

[39] Ullmer, B., Ishii, H., & Glas, D. (1998). MediaBlocks: Physical containers, transports, and controls for online media. Proceedings of the 25th Annual Conference on Computer Graphics and Interactive Techniques, SIGGRAPH 1998, 379–386. https://doi.org/10.1145/280814.280940

[40] Ullmer, B., & Ishii, H. (1997). The metaDESK. 223–232. https://doi.org/10.1145/263407.263551

[41] Van Der Vaart, M., & Damala, A. (2015). Through the Loupe: Visitor engagement with a primarily text-based handheld AR application. 2015 Digital Heritage International Congress, Digital Heritage 2015, 2, 565–572. https://doi.org/10.1109/DigitalHeritage.2015.7419574

[42] Vaucelle, C., & Ishii, H. (2008). Picture this! Film assembly using toy gestures. UbiComp 2008 - Proceedings of the 10th International Conference on Ubiquitous Computing, 350–359. https://doi.org/10.1145/1409635.1409683

[43] White, S., Feng, D., & Feiner, S. (2009). Interaction and presentation techniques for shake menus in tangible augmented reality. Science and Technology Proceedings - IEEE 2009 International Symposium on Mixed and Augmented Reality, ISMAR 2009, 39–48. https://doi.org/10.1109/ISMAR.2009.5336500

[44] White, S., Lister, L., & Feiner, S. (2007). Visual hints for tangible gestures in augmented reality. 2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality, ISMAR, July, 47–50. https://doi.org/10.1109/ISMAR.2007.4538824

[45] Ynnerman, A., Rydell, T., Antoine, D., Hughes, D., Persson, A., & Ljung, P. (2016). Interactive visualization of 3D scanned mummies at public venues. Communications of the ACM, 59(12), 72–81. https://doi.org/10.1145/2950040

[46] Zhu, K., Chen, T., Cai, S., Han, F., & Wu, Y. S. (2018). HaptWist: Creating interactive haptic proxies in virtual reality using low-cost twistable artefacts. SIGGRAPH Asia 2018 Virtual and Augmented Reality, SA 2018, 1–13. https://doi.org/10.1145/3275495.3275504

[47] Zimmerman, J., Forlizzi, J., & Evenson, S. (2007). Research through design as a method for interaction design research in HCI. Conference on Human Factors in Computing Systems - Proceedings, 493Journal Name:ACM Trans. Graph.