2021 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct) | 978-1-6654-1298-8/21/$31.00 ©2021 IEEE | DOI: 10.1109/ISMAR-Adjunct54149.2021.00014

CubeMuseum: An Augmented Reality Prototype of Embodied Virtual Museum

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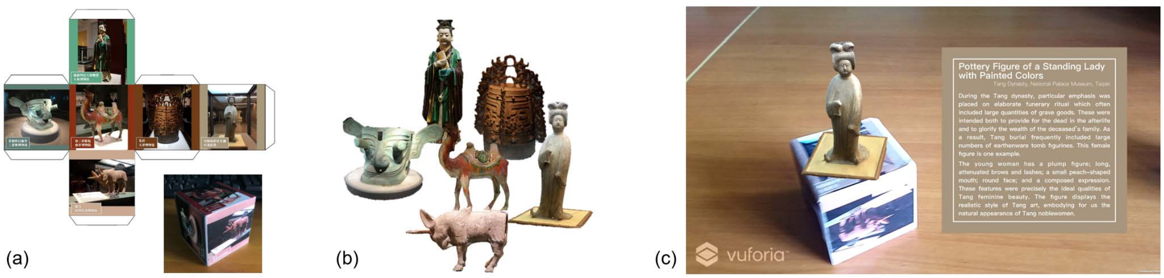

Figure 1: CubeMuseum. (a) The physical cube with 2D image targets; (b) Sample 3D virtual museum objects that can be augmented on the physical cube; (c) A screenshot of what users can see from their smartphones using CubeMuseum AR, including the physical cube in the real scene and the virtual objects and labels augmented on top of it.

Abstract

An Augmented Reality (AR) prototype, CubeMuseum, is proposed in this paper to present an embodied experience with virtual museum collections. With a cost-effective cube and a smartphone application, users can view and interact with 3D museum objects embodied on the cube. Detailed design of the prototype is presented to illustrate the approaches to visualize, present, and interact with virtual objects. CubeMuseum has been evaluated by hundreds of users in both laboratory studies and public exhibitions. The results indicated that the prototype is simple yet effective. It demonstrates several benefits and potential implications in supporting user engagement and learning experience. This research provides insights to researchers and practitioners in designing interactive cultural heritage experiences using a cost-effective approach.

Keywords: human-computer interaction, cultural heritage, digital heritage, virtual museum, augmented reality, mixed reality, embodied interaction

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Prototyping

1 Introduction

Cultural heritage in museums and cultural institutions is often presented in the form of physical collections with static labels to communicate history and stories. Recent development in virtual heritage shows that museums are actively digitizing their collections to store, distribute, and share the collections with a broader audience [**?**]. The adoption of interactive technologies in presenting museum collections has significantly increased in the last few years, promoting the diffusion of culture by developing creative narratives to support education and recreation [25]. Such digital experiences offer opportunities to see an increased number of collections than possible during physical museum tours [8].

The recent advances in Virtual Reality (VR) and Augmented Reality (AR) are witnessed by the general public from consumer-level devices and applications. These technologies are becoming increasingly accessible and are used for more general purposes, including entertainment, education, social networking, e-commerce, and marketing [5]. Many museums have explored using AR to provide visitors with augmented information and interactive storytelling in combination with physical objects and environments. However, systems set up within the sites or as a part of museum exhibitions are of limited accessibility. Recent development in photogrammetry has made the creation of 3D models faster and easier [24], and the presentation of virtual objects is no longer confined to the limited physical spaces of museums [3]. It is now possible to access digital presentations of cultural heritage outside of cultural institutions through ubiquitous devices, such as mobile devices.

This paper presents CubeMuseum (see Figure 1), an AR prototype that supports the presentation of embodied museum collections with a cost-effective cube and a smartphone-based AR application. It allows users to interact with high-quality 3D models of museum collections outside the museum spaces. Our evaluation of CubeMuseum demonstrates several benefits and implications: 1) it requires minimum equipment and devices while enabling engaging user experiences with museum collections outside the museum space; 2) the embodied interactions afforded by the prototype support users' learning of cultural heritage; 3) with both physical embodiment and digital interactivity, CubeMuseum can be an innovative way to continue visitors' museum trajectory and has great potentials to be designed for hybrid gifting [10], a new kind of gift with both physical artefacts and digital interactivity.

2 Related Work

2.1 Virtual Museum and Augmented Reality

The means to establish access, context, and outreach by using information technology is defined as Virtual Museum (VM) [19]. The scope of VM is broad and is often used interchangeably with digital museum, online museum, web museum, electronic museum, etc. [20]. As indicated by these names, VM is essentially an ex-

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978-1-6654-1298-8/21/$31.00 ©2021 IEEE
DOI 10.1109/ISMAR-Adjunct54149.2021.00014

tension of physical museums that presents content in any digital form, such as photographs of museum exhibits, online collections and museum archives. Most of the previous virtual museums and online exhibitions presented object information using images and texts, but very few used 3D reconstructions [18]; there was even less presentation of museum collections using VR and AR. This research is concerned with the presentation of museum collections in 3D with the use of AR technologies.

Previous VM research has studied the use of AR technologies to present museum objects with interactive cultural heritage experiences. Some used marker-based AR to superimpose information on top of exhibits, such as aligning expert drawings on top of digital images of animal engravings in caves [4], augmenting information on photographs [28], and supplementing information for animal specimen [16]. Researchers also explored the use of markerless AR to present onsite guide information for visitors, such as the ARCHEOGUIDE system for the ancient Olympia [23], the simulation of the ancient life in ancient Pompeii [17], and augmenting virtual reconstructions and visual highlights for interactive storytelling in the Acropolis Museum [28]. Chatzidimitris et al. [2] found that the combination of virtual information and physical objects triggers curiosity and exploration, and that visitors can easily pick up and master mobile AR interactions. These have demonstrated the benefits of AR in supplementing information on museum objects and enhancing exhibition experiences.

2.2 Experience Outside the Museum with AR

AR has great potential to make cultural heritage experiences widely accessible to the general public. Current advances in 3D object reconstruction and affordable access to digital devices have contributed to the adoption of AR in museums. For example, a recent study presented the use of consumer-level devices and photogrammetry techniques to create digital copies of museum objects [9]. The authors argued that this approach is cost-effective and practical for museums to adopt to create interactive experiences with education functions. More importantly, the online resources of cultural heritage also make it possible for users to interact with museum collections outside the museum spaces. For example, the 'Cultural Heritage and History' category on Sketchfab[1] provides a wide range of collections that can be downloaded for free and viewed in AR. These high-quality assets include contributions from many museums and cultural institutions, such as the British Museum. Current technologies are making it possible for museums to open up their collections to the public with increased accessibility, not only to the images and texts, but 3D models and interactive experiences as well.

One of the approaches to create an interactive experience is through embodied interaction [7]. It provides users with a control of virtual information through tangible interactions with physical objects [1]. For example, D'Agnano et al.'s Tooteko [6] application used a 3D printed replica of an architecture to enable the triggering of audio information. Previous research has also demonstrated that embodied interactions with virtual object information can contribute to the sense of control [14]; the embodied presence of others, such as virtual avatars, can facilitate communication behaviors [21]; and embodied interactions in simulations could enhance student engagement and learning [15]. A recent survey on AR in cultural heritage identified that it is important to consider the environment in which future AR systems are executed [22]. Museums are known for restricting physical access or touching their collections. When developing AR applications for uses outside the museum spaces, it would be beneficial to support embodied interactions with virtual objects, and providing users with some form of sense that they are touching or physically interacting with museum collections. This could contribute to users' learning and interactive experience with cultural heritage.

[1]https://sketchfab.com/3d-models/categories/cultural-heritage-history

3 CubeMuseum: A Prototype for Embodied Interaction with Virtual Museum Objects

This section provides details of the design and implementation of CubeMuseum. The prototype is used to present 3D museum collections with AR. Thus, we describe our approach based on the three attributes of the VIP framework of virtual objects [11], namely, 1) reconstructing digital museum collections (visualization), 2) setting up 3D models and image targets for AR display (presentation), and 3) implementing the AR display and interactions with virtual objects (interaction). Table 1 provides a summary of making CubeMuseum.

Table 1: Summary of making CubeMuseum.

	Visualization	Presentation	Interaction
Digital assets	Digital images of objects	Image targets; Information labels	3D models; Image targets; Information labels
Physical assets		Cube; Paper and scissor	Assembled AR cube; Smartphone
Software and SDK	Autodesk ReCap or RealityCapture; Blender		Unity; Vuforia
Results	3D models	Assembled AR cube	CubeMuseum

3.1 Visualizing Virtual Objects

We construct digital copies of museum collections using the digital close-range photogrammetry technique [26, 27]. This technique allows the use of digital images that are captured with a camera at a close range to measure objects and create accurate 3D models. Autodesk ReCap[2] and RealityCapture[3] are used to process the digital images, and the generated 3D models are further processed using a 3D modelling software, Blender[4]. The generated 3D raw models then need to be processed in order to be used for AR development. The processing of 3D models usually includes axis fixing, scaling, retopology, normal map baking, and texture baking. The detailed workflow for generating and editing a model is summarized in Figure 2.

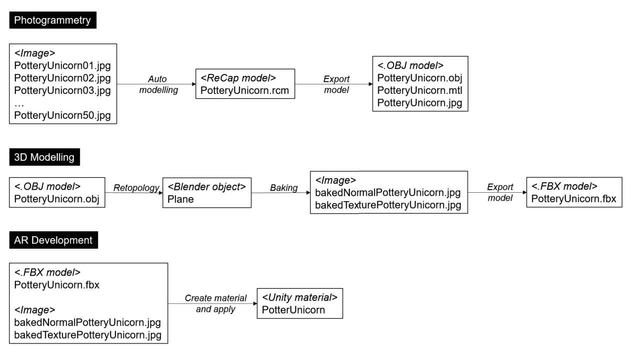

Figure 2: The workflow of visualizing virtual objects.

3.2 Presenting Virtual Objects

Once the virtual objects are reconstructed and processed, they are imported to Unity for AR interaction design and development. Unity accepts models in .FBX format, which contains information about object meshes and materials (see Figure 3). The baked texture and

[2]https://www.autodesk.com/products/recap/
[3]https://www.capturingreality.com/
[4]https://www.blender.org/

normal map images obtained from the reconstruction workflow are imported to Unity assets together with the .FBX model file.

Each object in Unity has a Mesh Renderer and a Material applied to the mesh. By default, the texture image is included in the Material's Albedo under the Main Maps. The normal map generated in the 3D modeling process is applied to the Normal Map property of the Material to a more realistic look.

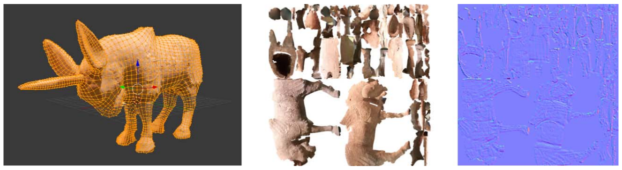

Figure 3: Screenshots of virtual object meshes, baked texture and normal map.

Virtual objects are presented to users with a smartphone AR application and a physical cube, with each one of its faces having a 2D image target. We can prepare information labels for each virtual object and use photos of objects situated in museums as image targets for the smartphone camera to recognize and track (see Figure 4). This is a better option than random patterns because it creates a connection between the 2D images and 3D models of the museum collections. In this way, the physical AR cube embodies the presentation of the six museum objects.

Figure 4: Image targets and information labels.

To make the physical CubeMuseum, we align the image targets to a cube paper pattern and print them out on a piece of A4 paper. It can then be cut out, glued to a wooden cube, and assembled (see Figure 5). This way engages users in handcraft to make their own CubeMuseum with objects of their interest. By selecting six object images, users can form a museum collection with minimum materials and skills. The image targets can also be easily replaced to update a collection.

3.3 Interacting with Virtual Objects

Interactions with virtual objects are developed in Unity with the Vuforia[5] AR SDK. Image targets are uploaded to the developer database and an ARCamera prefab is applied to simulate the smartphone camera. When a user positions the smartphone camera towards a face of the cube, it will recognize the image target and trigger the augmentation of the linked 3D model on top of it (see Figure 6).

Once augmented, the 3D model starts to rotate on the z-axis to enable a comprehensive view. An object can also be viewed from different angles by manually rotating the cube, as the virtual object follows the movements of the cube. This applies the embodied interaction design principle [7], where users are allowed to manipulate virtual objects through tangible interactions with the cube. The information label of an object is augmented next to it by default, but users can tap on it to dismiss it. Labels can also be brought up by tapping on the virtual object.

[5]https://developer.vuforia.com/

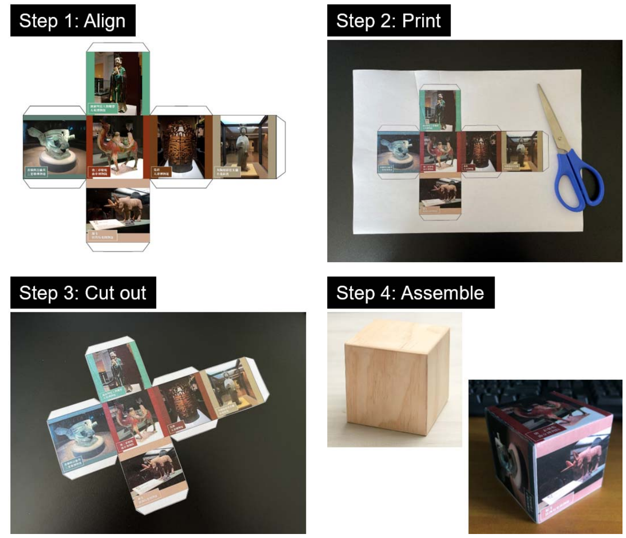

Figure 5: The 4-step process of making the physical CubeMuseum.

Figure 6: A user accessing a museum collection with CubeMuseum.

4 Evaluating CubeMuseum

CubeMuseum has been evaluated by hundreds of users in both laboratory studies (see [12] and [13]) and in-the-wild research. It has been used as a part of two user studies in laboratory settings. 112 participants are involved, most of which are university students. CubeMuseum has also been featured in the following three public exhibitions at international research engagement events, where a wider range and a more significant number of audiences were reached for in-the-wild observations (see Figure 7).

- UKRI Impact Festival, Beijing, 8 November 2018
- SPARK: The Science and Art of Creativity, Hong Kong, 19 January 2019
- AHRC UK-China Creative Industries, Shanghai, 2 December 2019

We prepared questionnaires and conducted semi-structured interviews in laboratory studies to evaluate user experience with CubeMu-

Figure 7: CubeMuseum being used by children, adults and seniors.

seum. Users have also voluntarily provided their feedback through questionnaires in public exhibitions. All studies have been reviewed and approved by the University of Nottingham Ethics Committee prior to any data collection. Statistical results were reported in [12] and [13]. Below we summarize several key findings and lessons.

4.1 Tangible and Embodied Interactions

The most important contribution of CubeMuseum is its support for tangible and embodied user experience with cultural heritage. Users reported that holding the cube with virtual objects is comparable to holding an object in hand. Many users reflected that such experience was novel and new to them, and the way to control the virtual objects (via the physical cube), such as rotating them, was intuitive and easy to pick up. This is largely supported in our public exhibitions as the visitors barely required any tutorials. Engaging interactions with the cube also provides users with a sense of control of the often unreachable museum objects. Some users reported the impression that the cube embeds the museum collections and that the smartphone camera is the key to unlock them. CubeMuseum provides users with combined physical embodiment and digital interactivity in their experience with museum collections. AR with embodied interactions was shown to be effective in virtual object control [14]. The current evaluation results on CubeMuseum AR have further supported its use in presenting cultural heritage.

4.2 User Engagement and Learning with AR

We observed great 'wow effects' from users when they successfully triggered the first augmentation with CubeMuseum. Users found the 3D models to be of great vividness and high quality, and acknowledged the appropriate use of AR to present the museum objects. Many users compared the AR presentations with the traditional way of communicating history, i.e. with images and texts, and reported that the AR approach provides greater details and more up-close experiences with a sense of the shape and texture. They suggested that their interactions with the virtual objects have supported their engagement better and motivated their learning. Many users agreed that CubeMuseum is a great tool for teaching culture and history, and they also showed great support for adopting AR in classroom teaching.

4.3 Mapping Image Targets with Augmentations

Users reported that they could feel the objects 'came alive' when seeing the 3D models augmented on top of the 2D images on their cube. The connection between the object images and models in CubeMuseum helped support users' mental model. Users have creatively envisioned that the smartphone camera can recognize a museum object and 'transform' its 2D image into an equivalent 3D model. This is especially true for users with less knowledge about how the image recognition technology works, such as children and seniors. We received a significant amount of positive feedback from this design of mapping in CubeMuseum, indicating that it is important to prepare meaningful image targets and good mapping for augmentations when using image-based AR. A reasonable connection between the physical and the digital will contribute greatly to the user experience.

5 Discussion

Museums are lacking in space and appropriate conditions for displaying their collections and archives. Many collections are preserved in specialist warehouses due to their sensitivity to light and humidity. In the meantime, current digitization technologies are getting increasingly mature. It was shown that virtual objects could stimulate interest from a broad array of viewers and even result in greater levels of engagement with the physical museum collections [8]. As such, many museums are digitizing the collections in 3D, presenting them using digital technologies, and opening up their collections to the public. We believe that such digital collections will become increasingly accessible to the public, and physical tangibles like CubeMuseum presented in the current work represent an appropriate and engaging approach to present virtual museum collections.

Our studies have shown that AR supports the presentation of virtual objects with rich information and affords interactions that are otherwise infeasible in physical museum visits. On top of that, users' tangible and embodied interactions with CubeMuseum have further engaged them in learning cultural heritage. These two aspects (AR presentation and embodied interaction) are the prominent advantages demonstrated in our current evaluation of CubeMuseum.

CubeMuseum is a cost-effective prototype that has been proven to be successful in supporting user engagement and learning experience with cultural heritage. We further identify that CubeMuseum has implications on hybrid gifting, a recent work by Koleva et al. [10]. They present it as a new kind of gift with both physical artifacts and digital interactivity. Based on their proposed framework, CubeMuseum presented in our work can be designed as a physical gift item with digital wrapping. More digital content such as audio recordings and text messages can be embedded as parts of the AR application, and sent together with the virtual museum collections embodied in the physical CubeMuseum. Meanwhile, the involvement of other people in gifting indicates social interactions, which are also essential for the museum learning experience. Using CubeMuseum as a hybrid gift will also support the continuous trajectory of visitors' museum experience and allow them to experience cultural heritage and continue learning outside museums.

6 Conclusion

This research presents CubeMuseum, a physical manipulative for an embodied experience with virtual museum collections. We present the making of the prototype with a wooden cube, printed paper and an AR application. Our evaluation showed three key findings. First, the tangible and embodied interactions are intuitive and easy to pick up. The sense of control obtained from the cube, and consequently the museum objects, contributed to the user experience with cultural heritage. Second, using AR to present 3D museum objects supports user engagement and motivates users' learning experiences with cultural heritage. Third, meaningful mappings between physical image targets and virtual augmentations affect user experience positively.

CubeMuseum requires minimum equipment (like a common mobile phone) but enables engaging user experiences with museum collections outside the museum spaces. The embodied interactions afforded by CubeMuseum supports users' learning experience of cultural heritage. CubeMuseum employs both physical embodiment and digital interactivity. We suggest that it can be an innovative way to continue visitors' museum trajectory and has great potentials to be designed for hybrid gifting.

Acknowledgments

The experiments and evaluations took place at the NVIDIA Joint-Lab on Mixed Reality, an NVIDIA Technology Centre at the University of Nottingham's China campus. This work receives financial support from the Xi'an Jiaotong-Liverpool University (RDF-20-02-47 and TDF20/21-R22-142).

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