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Short Paper

Interacting with Ancient Egypt Remains in High-Fidelity Virtual Reality Experiences

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Abstract

With the continuous advancement of Virtual Reality (VR) and related technologies, it is possible to envisage ever new ways to let users experience cultural heritage. Like in any application domain, however, one of the limitations to the effectiveness of VR is related to the level of immersion and presence that can be delivered. This paper presents the pipeline that has been developed to create narrative experiences in which users are immersed in a visually realistic virtual environment, where a curator of the Museo Egizio in Turin guides them in the interaction with some of the objects of the Museum's collection.

CCS Concepts

• ***Human-centered computing*** → ***Virtual reality;*** • ***Computing methodologies*** → ***Shape modeling; Animation;***

1. Introduction

Extensive research has been conducted to investigate the benefits that can be brought by the use of eXtended Reality (XR) and Human-Computer Interaction in the preservation, representation and dissemination of cultural heritage (CH) [BPF*18]. The literature includes various works that presented approaches and tools devised for educational, explorative, and exhibition enhancement purposes [BC19]. In particular, virtual museum experiences that are created by leveraging Virtual Reality (VR) technology have gained increasing popularity over the last years, thanks to the new ways they offer to showcase CH content, complementing existing physical museums and their collections [HGLS22].

Through VR, users from any location worldwide can engage with different multimedia content [Ric17]. Virtual museums also offer users the opportunity to explore and interact with 3D replicas of historical sites or remains in ways that are not possible in physical museums. In fact, these replicas could represent fully preserved, partially preserved, damaged or even non-existent physical elements [HGLS22]. This opportunity is often regarded as the most cost-effective and dynamic approach to incorporate a culture's environment, artifacts, and associated knowledge [MDC18]. However, virtual reconstructions that only encompass inanimate environments may provide a limited engagement. Hence, a recent trend is to populate these environments with virtual humans, which are expected to exhibit appearance and behaviour that closely resemble those of the real people [MDC18]. The specific role played by virtual humans in CH applications can vary depending on the complexity of their implementation, ranging from decorative elements to knowledge curators or intelligent guides [CLD*16].

To make the virtual journey as effective as possible, thus enhancing the cognitive, perceptual, and communicative aspects of CH content [BFPR02], it is essential to offer high-fidelity, interactive experiences that are able to extensively stimulate the human-sensory system, thus boosting users' immersion and presence [PRR*12]. This paper tackles this need, investigating techniques to create high-fidelity curated VR experiences. In particular, the paper reports on the design of a pipeline that has been developed to integrate virtual objects (i.e., Egyptian remains) from the collection of the Museo Egizio in Turin with a high quality reconstruction of a curator who accompanies the users in their experience. The paper summarizes the outcomes observed during the process that, from the initial idea, led to the first VR prototype (overall all the stages of the pipeline were realized in six months). Besides involving experts from the Museo Egizio, who provided the historical support and took part in the content generation process, the team encompassed researchers from Politecnico di Torino, who took care of the design and development of the VR experience.

2. Related Work

The use of high-fidelity environments, objects, and avatars in VR experiences has been considered in many literature works. For instance, the VR experience presented in [ŠRC*20] allows users to explore a realistic 3D reconstruction of an archaeological submerged site. The experience was developed by integrating inter-

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active elements in 360° videos to ensure a high degree of visual realism and scientific soundness. Another example is given by the work in [ASJ21], which focused on the reconstruction of a heritage building, i.e. the Victoria Theatre in Newcastle, Australia. The work addressed the challenge of creating a faithful reconstruction of an entire historical building with limited sources (e.g., photos, drawings, sketches). The work in [PRR*12] presents a VR application to make visitors explore a virtual reconstruction of an Etruscan tomb in Cerveteri, Italy. The reconstruction of the archaeological site was the result of continuous multidisciplinary research. Artefacts found in the tomb were also reconstructed, by making use of different techniques including laser scanning, photogrammetry, and computer graphics. By interpreting the sources and leveraging iconographic comparisons and similarities, it was possible to digitally restore the deficient objects and decorations.

Focusing on works targeted to 3D object reconstruction, it is worth mentioning, e.g., the methodology proposed in [AR23] to converts CT scans of CH elements into high-resolution, photorealistic 3D objects. The methodology has been applied to build a 3D replica of the Antikythera Mechanism, a mechanical computing system from Ancient Greece, demonstrating its applicability in scenarios where other techniques like, e.g., photogrammetry, cannot be used due to specific constraints. The work in [FP22] focused on colour fidelity of digital models reconstructed by means of 3D scanners. Specifically, a method is proposed to measure the colour fidelity of reconstructed 3D models (i.e. archaeological remains) with the aim of identifying potential quality issues. Then, a technique for data collection and processing is proposed to improve fidelity by applying calibration processes used in photography.

For what it concerns 3D avatars, previous studies have shown that their use can have a significant impact on users' engagement, promoting attention and participation [GSD*20]. Realistic virtual humans, in particular, can make the narratives conveyed in virtual environments more credible, influencing user experience in a positive and constructive way [KPP*21]. Virtual avatars can be manually created using general purpose 3D graphics suites or specialized tools like, e.g., Character Creator (https://www.reallusion.com/character-creator/) or MakeHuman (http://www.makehumancommunity.org/). An automatic approach that makes use of RGB-D consumer sensors, such as Microsoft Kinect or Intel RealSense, to capture either the static or dynamic geometry of real human subjects but with lower fidelity is presented in [LVG*13]. A complete pipeline for the generation and animation of realistic avatars that can serve as virtual storytellers in CH applications is addressed in [KPP*21]. The pipeline encompasses all the stages of avatar creation and visualization into an immersive environment, focusing on aspects pertaining to appearance, movement, and speech.

There are also a number of high-fidelity virtual experiences focused on CH not belonging to scientific literature. An example that is indeed worth to be mentioned is the VR application named "Hold the World" (https://tinyurl.com/5589ef9r). The application offers a hands-on experience at the London's Natural History Museum, where Sir David Attenborough's avatar shows some archaeological rare finds and makes the users explore areas of the museum that are usually not accessible. Another example is "Eye of the Owl – The Hieronymus Bosch VR experience" (https://tinyurl.com/txuvn6nz), a VR application that allows users to go back in time in Bosh's studio and offers them tools to explore the painting "The Garden of Earthly Delights". An avatar of the artist provides information regarding the masterpiece. The digitalization process of the painting encompassed an ultra-high resolution scan that makes it possible to see brushstrokes.

Although the analysed works offer users the possibility to live realistic experiences, more research is needed, especially in the CH field [PRR*12]. One of the reasons is that it has been observed that the perceived fidelity is strictly correlated with the specific VR content shown and the context of the application [KRY20]. Moreover, studies become soon outdated, due to the continuous advancements in technologies [AJT22]. Moving from these observations, this paper presents the work that is being carried out by the Museo Egizio in Turin to let users engage in high-fidelity VR experiences encompassing a virtual curator and manipulate digital replicas of remains from the Museum's collection.

3. Material and Methods

3.1. Virtual Curator

For reconstructing the curator's avatar three approaches were considered. The first approach was volumetric video. This is the technology used, e.g., in "Hold the World", where tens of RGB-D sensors are used to gather a very high quality footage of the curator's performance. The key advantage is indeed the level of fidelity that can be reached. The main limitation, besides cost and complexity, is related to the fact that each experience requires a dedicated shooting, and interactivity is thus constrained. Hence, a rather recent alternative represented by MetaHuman, a plugin of Unreal Engine, was explored. The MetaHuman framework is designed to create fully rigged, photorealistic human characters. In particular, a tool named MetaHuman Creator was investigated. With this tool, it is possible to create an avatar by starting from a library of reference models and operating on a number of controls. Despite the intuitiveness of the tool, it was difficult to reach a sufficient similarity with the real curator. The third approach considered consisted in using an acquisition technique to create a static 3D model of the curator, to be later animated using conventional tools. By using, e.g., photogrammetry, high quality results could be obtained. Unfortunately, the main issue with this approach would have been to reach satisfying levels of fidelity, due to the complexity of the rigging and skinning steps.

Based on the above analysis, it was chosen to combine the second and third approach, thus leveraging their advantages and getting rid of their respective drawbacks. The steps of the pipeline (and time requested to implements them) are reported in the following. 3D acquisition was obtained via photogrammetry. After several experiments performed to find the proper setup, the pipeline was applied to Dr. Martina Terzoli, one of the curators of the Museum. 60 photos of the curator's head were shot (30 min) using a Reflex camera D3500 Nikon with 50mm f1.8 lens. Photos were preprocessed by means of a common raster graphics editor with the aim of correcting white balance and exposure (2 h). 3D reconstruction and texture extraction were performed using Agisoft Metashape in

Figure 1: *Reconstruction of the curator's head.*

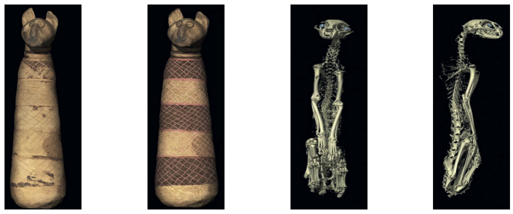

Figure 2: *Reconstruction of the mummy and research data.*

Figure 3: *Interactive experience in the immersive environment.*

5 h (2 h of manual work, 3 h for software processing). The output was post-processed with ZBrush (3 h) to get a refined mesh. The process is depicted in Figure 1.

The mesh and the texture (further refined using Adobe Photoshop) were then imported in Unreal Engine 5. The "Mesh to MetaHuman" tool was employed. The tool analyses provided information and extracts a number of keypoints that are used to calculate the proportions of the avatar's head. Just few modifications were required to make the automatically extracted keypoints match the real ones. When done, the tool performs a so-called "identity solve" operation, which compares obtained information with the MetaHuman library of virtual heads to find the most similar one. Control parameters of the model are automatically adjusted by the tool to align the avatar's head with the input mesh. The automatically generated model was slightly refined using manual functionalities offered by the framework. To this aim, a photo of the curator's face was loaded as a blueprint. Then, with the "blend" functionality, facial features (eye, eyebrows, nose, mouth, chin, etc.) were fine-tuned by having MetaHuman suggesting plausible variations from existing presets. With the "move" functionalities, spatial adjustments were made to the individual features above. Finally, the "sculp" functionality was exploited to precisely alter smaller areas of the face using predefined control points (30 min). Once the avatar's face was finalized, the hairs were created using MetaHuman "hairstyle" controls. Unfortunately, it was not possible to use real-time physics, since not properly working yet in VR. Thus, a static mesh was baked. To complete the model, the avatar's body was chosen among the alternatives offered by the framework.

3.2. Virtual Remains

Regarding the remains to be included in the experience, the first idea was to use objects not on display (e.g., in the warehouses, under restoration, etc.). In the end, it was chosen to use some of the objects included in the temporary exhibit "Archeologia Invisibile" (March 2019 – January 2022) for two reasons: firstly, high quality 3D models had already been created via photogrammetry; second, together with the models, additional research material was also available, that could help to create an effective narration. Three objects were selected from the exhibit's catalogue: the mummy of a cat (C. 2348/1), shown in Figure 2, and two alabaster vases originally containing sacred oils (S.8441 and S.8442). For both the mummy and the vases, neutron/CT scan images showing the interior (animal remains, in the former case, oil, in the latter case) had been performed, and were added to the models as overlays to be activated by the users. For the mummy, an additional texture showing the reconstructed textiles was also included in the model so that its visualization could be activated in the experience.

3.3. Virtual Environment, Interaction and Narration

For the virtual environment, the warehouses of the Museo Egizio in Turin were initially considered, but were later excluded since the location may not be capable to have a strong, visual impact on the user. Other locations in the Museum would have to be visually altered to host the experience. In the end, a high-realism 3D model of an interior inspired by the Bodleyan Libraries at the Oxford University was chosen. The lighting, furnitures (including tables and chairs), and books on the shelves were considered as ideal for preparing the users to the experience.

After wearing the VR headset, the users find themselves seated in front of the curator (Figure 3). The mummy and the vases are placed on the table. The curator introduces herself, the experience and the VR controls, then invites the users to choose the object to start with by grabbing it from the table using the controllers.

Depending on the selected object, based on the descriptions developed for the exhibit, the narration starts. Periodically, the curator stops, and waits for the users to observe the handed object. Objects can be rotated and scaled. To continue in the narration, the users have to press a button on the controller. For the vases, neutron scan and current aspect are described; for the mummy, reconstructed textiles, CT scan and current aspect are illustrated. The corresponding visualizations can be activated by the users by acting on the controllers. At the end of the experience, the users are invited to enjoy the rest of the collection by visiting the Museum.

3.4. Animations

After having defined the narration, the avatar's voice and movements had to be reconstructed. To maximize flexibility, a possibility could have been to use a speech synthesizer to create the audio

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from a script, and to use lip sync approximation to animate the face; library-based animations could then be used for the rest of the body.

However, with the goal to achieve high-realism also in terms of animations, motion capture techniques were used to record the performance of Dr. Terzoli and transfer it to her avatar. More specifically, a plugin of Unreal Engine named "LiveLink Face" coupled with an Apple iPad Pro 2 (to leverage face scan technology) were used to record the curator's face while playing the script in several shoots. The motion capture session lasted 1 hour, plus 30 additional minutes to correct the interpolation curves and obtain smoother movements. Keypoints extracted by the plugin were then used to control the animation through the MetaHuman facial rig.

During the virtual experience, the curator suggests the users to look at specific elements using her head and body movements. For the body animations, a different approach was exploited. Instead of transferring Dr. Terzoli's movements to the avatar via motion capture, traditional keyframing was used on the 3D model rig using the shoots as blueprints, in order not to overcomplicate the acquisition process (the body animation was completed in 1 hour). A video showing a user interacting with the mummy is available for download at `https://tinyurl.com/ysbmnz5y`. The application was deployed for the Oculus MetaQuest 2.

4. Conclusions and Future Work

In this paper, a pipeline has been investigated to create high-fidelity VR experiences in which users are accompanied in the discovery of Ancient Egypt remains by a virtual curator. High quality reconstructions of the curator's avatar and of the objects are used, with the aim to maximize the realism of the experience.

Although positive feedback was gathered from both curators and visitors regarding immersion and presence when showcasing the VR application in public events, more rigorous and formal evaluations are needed. Moreover, the goal is to further work on the pipeline in order to widen its flexibility. In fact, although the choice of combining photogrammetry with a parametric avatar's model generated with MetaHuman helped in this direction, the need for dedicated shooting sessions to record the curator's performance complicates the generation of new experiences with other remains.

The plan is to evaluate different approaches to manage the avatar's voice and movements, not resorting to motion capture and acting recording. By generating, e.g., animations in real-time, it would be possible to create experiences in which the users can interact with the curator and the objects without following a predefined script. For instance, conversational agents or telepresent avatars could be used. In this way, even though visual and audio fidelity may decrease, together with immersion, other aspects relevant for a VR experience like presence could be improved. Moreover, the lack in visual and audio quality may be compensated by the introduction of other sensorial stimuli, e.g., by resorting to haptic feedback. Experiments could then be performed to evaluate the impact of all these factors on the overall user experience.

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