3D Modelling and Virtual Reality for Museum Heritage Presentation: Contextualisation of Sculpture from the Tang Era

3D MODELLING AND VIRTUAL REALITY FOR MUSEUM HERITAGE PRESENTATION: CONTEXTUALISATION OF SCULPTURE FROM THE TANG ERA

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ABSTRACT:

The present research concerns the contextualisation and presentation of eleven small statues from the Tang era dated from the XI and XII centuries CE today housed at the Asian Art Museum in Turin (MAO). A multidisciplinary group with expertise in Asian art, digital representation, and information processing systems, with the support of VR@POLITO and MOD Lab Arch of the Politecnico di Torino is involved in the work. The goal is to present together several Tang-era pottery models not belonging to the same funerary outfit within the spaces of a coeval, philologically compatible hypogeal tomb. With a pronounced storytelling intent, the reconstructive 3D model represents a virtual exhibition project summarizing Tang art's architectural, pictorial, and sculptural features. The pipeline was developed through photogrammetric acquisition with Structure from Motion (SfM) technology and 3D modeling of the artworks, reconstructive modeling and texturing of a Tang tomb as the ideal space of the statues, and communication through a virtual reality (VR) experience augmented with a set of information.

1. INTRODUCTION

This research has been realized in the framework of the agreement between the Politecnico di Torino and the Fondazione Torino Musei to enhance museum heritage through digital methodologies and technologies. In particular, the work concerns the digital survey, contextualisation, and presentation of eleven small statues from the Tang era dated from the XI and XII centuries CE today housed at the Asian Art Museum in Turin (MAO), affiliated with the Fondazione Torino Musei.
The work involved a multidisciplinary group of scholars with expertise in Asian art, digital representation, and information processing systems, with the support of VR@POLITO and MOD Lab Arch of the Politecnico di Torino.

2. VR FOR MUSEUM HERITAGE

Following the principles of new museology (Vergo, 1997), museums should not merely be viewed as static venues for artifact preservation. Instead, they should be perceived as evolving entities that offer captivating experiences. Their objective should be to foster visitor engagement, active participation, and knowledge acquisition, transforming from mere display areas into enriched educational environments (Vergo, 1997; Weil, 1990). As they prioritize visitor-centric engagement, museums are progressively integrating innovative digital tools. This integration provides audiences with immersive, interactive, and multi-dimensional experiences beyond the scope of conventional exhibits. In this evolving landscape, Virtual Reality (VR) is gaining prominence (Bekele et al., 2018).
To date, museums have employed VR to offer alternative ways for their visitors to engage (Bekele et al., 2018). This approach provides captivating, interactive, and immersive experiences within museum education (Carrozzino and Bergamasco, 2010). It also facilitates the digital reconstruction of lost or damaged historical sites (Tom Dieck et al., 2019) and artifacts (Gonizzi Barsanti et al., 2015). Notably, the ability to make lost locations accessible or to revive historical figures and objects holds significant value for museums (Tom Dieck et al., 2019).
Given the capability of VR to craft diverse virtual environments, museum experts have ventured into curating entirely virtual exhibitions that can be enjoyed independently of the museum's physical location (Bekele et al., 2018). While this strategy draws individuals to the exhibition, it is generally seen as a supplement rather than a substitute for the latter (Vergo, 1997). Many examples of VR experiences have effectively enhanced museums' experiential learning (Carrozzino and Bergamasco, 2010).
Digital reconstruction and VR have also been utilized for safeguarding and conserving heritage. They serve as tools to aid archaeologists in restoration efforts and to minimize expenses linked to on-site expeditions (Bekele et al., 2018). Indeed, VR allows researchers to revive delicate artifacts virtually, allowing them to examine these items or even entire locations (Bekele et al., 2018) in a simulated and immersive manner. In Cassidy et al., 2019, a VR platform allows users to delve into and interact with a 3D rendition of the Pleito Cave, an archaeological landmark in California, USA. This instance underscores the capability of VR to immerse users in meticulously recreated settings using techniques like 3D reconstruction, such as photogrammetry and laser scanning. Such advancements pave the way for virtual visits from afar.
As indicated by the authors (Siddiqui et al., 2022), the quality of immersive VR experiences is closely tied to the quality of the VR equipment. When combined with accessories like, e.g., Google Cardboard, smartphones can offer an initial level of immersion. This is enabled by their motion sensors, which detect shifts in the user's head position and orientation, seamlessly adjusting the viewpoint in response. For a truly immersive and interactive experience, though, dedicated Head-Mounted Displays (HMDs) are essential. These devices, equipped with positional tracking and hand controllers (collectively called VR kits), are typically more expensive or

sophisticated. Thus, frequently, there is a need to balance affordability and simplicity on one side and advanced features and a captivating experience on the other.
An example of a VR application of the first type, based on Google Cardboard, is the Virtual Museums of Caen, presented in (McCaffery et al., 2015). The experience is structured as a virtual tour, where the user is guided through a series of points of interest, each corresponding to a 360-degree video. Videos can be viewed automatically in sequence or by allowing the user to select the next point of interest. The immersive view is further complemented by an audio commentary related to the displayed content.
Instead, an instance of an application designed for commercial VR kits is presented by (Spallone et al., 2023). There, the authors showcase an interactive VR application that offers a reconstruction of the Temple of Ptah at Karnak, putting forth two theories about the original placement of the statues of the goddess Sekhmet. The application begins with a passive scene accompanied by a narrated introduction. Afterward, there is a scene in which the users can traverse the virtual space either by physically walking, provided there is enough room, or by using hand controllers, with a common navigation technique that is teleporting (Cannavo et al., 2021). Users can engage with specific virtual components as they navigate, prompting audio descriptions tied to their current location.
The blend of technology with heritage conservation underscores the groundbreaking impact of VR within the museum realm. Beyond enhancing museums' accessibility and educational offerings, VR plays a pivotal role in safeguarding and deepening the comprehension of cultural legacies. Integrating this technology into museums emerges as a resource that amplifies the conventional museum visit while broadening horizons in education, preservation, and audience engagement.

3. RESEARCH PIPELINE

3D reconstruction of archaeological sites based on digital surveys of existing remains, and supplemented with any documentary sources (photographs, survey drawings, textual descriptions) that testify to their consistencies in the past, and on philological comparison with coeval and stylistically comparable artifacts is now a widespread research activity aimed at interdisciplinary study and presentation to the public (Ferdani et al., 2020).
Creating connections between archaeological sites and art artifacts now dispersed in museums is also currently receiving attention, with artworks being relocated to their original locations (Fazio et al., 2022) when they are known or by placement in philologically compatible buildings to show museum visitors the spaces within which the artworks originally lived, the meanings and function they took on in statuary groups, as well as about the building.
Both of the activities described above have been tested by the authors in previous papers (Spallone et al., 2022; Spallone et al., 2023) and used immersive VR experiences imagined to be enjoyed in the museum for effective communication to the public.
Peculiar to the present case study is the goal of presenting together several Tang-era pottery models, not belonging to the same funerary outfit, within the spaces of a coeval, philologically compatible hypogeal tomb.
The hollows of the tomb, which has come down to us without decoration, were covered with wall paintings documented in other tombs of the same rank. With a pronounced storytelling intent, the reconstructive 3D model represents an exhibition project that summarizes the architectural, pictorial, and sculptural characters of Tang art.

Figure 1. The pottery figures into the MAO showcases. (Photo: F. Ronco)

The pipeline was developed through photogrammetric acquisition with Structure from Motion (SfM) technology and 3D modeling of the artworks, reconstructive modeling and texturing of a Tang tomb as the ideal space of the statues, and communication through a VR experience augmented with a set of information.
The work aims to respond to the problem of the enjoyment of small artworks, often separated into different display cases, along with numerous other artifacts (Fig. 1). For the visitor, it is often difficult to make connections between these and imagine their context. The selected pottery figurines belong to different Tang tomb funerary sets from the Shaanxi and Henan regions. They are painted terracotta works of various sizes (between 12 and 66 cm) depicting other characters and animals: actors, dancers, court ladies, officials, palafreniers and horses, as well as figures of protective creatures of the tomb.
They were surveyed using the well-known SfM technique, and the acquisitions were processed with Agisoft Metashape®. The textured meshes were then imported into Blender® for further digital sculpting processing.
The tomb of Chinese general Zhang Shigui in Shaanxi, documented by survey drawings, was found to be philologically compatible with the artifacts housed at the MAO. However, the wall decorations and some stone elements have disappeared or significantly deteriorated. Therefore, in compliance with the London Charter (2009) and the Seville Principles (2017), wall decorations taken from the documentation of other related tombs, such as those in the tomb of Prince Yide and the tomb of Princess Yongtai, were applied to the reconstructive 3D model. A stone portal found in the tomb of Prince Li Shou was also included.
The outcome of such reconstruction consists of a true palimpsest of Tang funerary architecture inclusive of its decorative apparatus that becomes, in turn, the ideal exhibition space of a repertoire of the sculpture coeval and present in the same area, in a kind of compendium between architecture and funerary sculpture of the period.
The VR experience allows visitors to explore the reconstructed space, view the statues placed in the architecture, and obtain additional written and spoken information regarding the funerary area, decorations, and artworks. The latter are animated by a 360-degree rotation that ultimately allows them to be seen, overcoming the actual exhibition's static nature.
The 3D models were imported into Unity and re-topologized. Open XR programming interfaces and Google's SDK package were used for the prototype development of the application, which was imagined to be usable in the Android environment via stand-alone visors and Google cardboard, respectively. Due to the considerable length of the path inside the tomb, the technique of movement through teleportation was chosen, using hot spots to which the user lands. Balloons signal additional information. Hot spots and balloons are activated by prolonged observation of them.

4. BRINGING DEATH INTO CONTEXT

In the galleries dedicated to China at the Museum of Asian Arts in Turin (MAO), objects datable to the Tang Dynasty (618-907) come almost exclusively from burials. This interest in Chinese funerary objects is common in Western museums, where tomb fittings and relics are muted of their ritual significance and are appreciated for their presumed artistic merit, with no traces of the original context of use.

Chinese connoisseurs have never been interested in Tang pottery models: conceived specifically for the tomb, they have always been perceived as inauspicious. It was only in the West that Chinese burial objects became collectables, starting from the second decade of the 20th century, when China was going through a period of unprecedented social upheaval, paying little attention to questions of heritage preservation. Tang pottery models of horses, grooms, ladies-in-waiting, camels, and tomb guardians flooded the international art market, finding their way into Western interiors, but their context of origin was lost forever.

China has a long tradition of mortuary practices centered on large underground tombs with external mounds and a rich and diversified assemblage. Since the 1st millennium BCE, tombs were adorned not only with objects used by the deceased during their lifetime (*shenqi*) but also with earthenware models made especially for the tomb (*mingqi*), easily identifiable by their inferior quality. These tropes satisfied the need of the dead and complied with the ritual and ethical codes of the living. Once in the tomb, they played their part in a fantastic recreation of life in the otherworld. During the Tang Dynasty (618-907), *mingqi* like those displayed at MAO and used in the immersive experience project, were part of this ritual reenactment (Wu Hung. 1995).

The tomb's architectural layout and its furnishing also served as a platform for social aggrandizement. Funerary processions, with several carts of funerary models, were a way to strengthen ties in society and solidify loyalty within and beyond it. Rarely a tomb depicted the former life of its occupant. In fact, its scale, epitaph, and art reflected the status that the tomb builders and the family wished for the deceased, as well as the politics and beliefs in death and the afterlife that were deemed appropriate at the time (Chao-Hui Jenny Liu (2005). Tang burials were therefore complex, time-consuming and resource-depleting endeavors that had a major impact in society and whose preparation could take months if not years.

Murals, pottery figurines and stone sculptures in larger aristocratic and imperial tombs conjured up a personalized paradise mirroring the best aspects of the earthly world, embellished overground by a spirit road with stone statues and ritual structures (Tonia Eckfield (2011). Beneath, the tomb contained extensive frescoes with painted figures similar to those made in pottery. The layout evoked a royal architecture: the entrance ramp mimicked the approach to the palace; frescos and recessed niches evoked its enclosures and courtyards. Ceramic horses and grooms were placed closer to the entrance, while figures of musicians and court ladies were often closer to the coffin chamber. The space was furnished in such a way as to allow the spirit of the deceased to roam in and out and continue their daily routine for eternity with no amenities spared, including saddled pottery horses standing at the door.

The burial models in the MAO collection were moulded, fired in the kilns and either cold-painted or covered in three-colours lead-glaze (*sancai*). They were all mass-produced between 618 and 755, when An Lushan and his rebellion brought this period of creative effervescence to a halt. They reflect Tang cosmopolitan society of the 7th and 8th centuries, whose prosperity came from its Central Asian network. Funerary sculptures thus shared conventions with Indian and central Asian Buddhist monumental sculpture, especially in their plasticity, dynamism and muscular hyper-realism.

Economic prosperity fostered a great interest in the West: foreign ideas and products trickled into the funerary assemblages of the period. Sogdians and Persians became exotic commodities- inhabiting the tomb as servants, dancers, musicians and grooms for horses and camels. Stereotyped, they all shared common features for their faces and dress, with large beards and big noses, fierce expressions and vigorous postures, almost caricatured.

Military officers in armour, civil officials, and sometimes foreign ambassadors completed the setting. The statues of the officials were to present the case of the deceased to the fierce judge of the afterlife, while fantastic animals would guard the occupant forever. Each one of these models played an essential part in the reenactment of life in death, which was strictly organized according to the laws of the living.

MAO funerary models' display raises questions that can hardly be answered within the four walls of the museum: how did they move from the tomb to the museum? How were they originally intended to be seen and function for the afterlife? What was their relation to the tomb layout and its mural scheme? Alternative ways of looking are needed, and this immersive experience project may help to investigate further the interaction of these pottery models with the other elements - coffin, architectural fittings and murals- in the space for which they were created, thus shedding light on the mortuary practices and spiritual beliefs of the Tang period.

5. DIGITAL SURVEY

Photogrammetry can be a valuable, fast, and low-cost tool for obtaining metric three-dimensional models of small and medium archaeological artifacts. It allows the creation of digital 3D models faster and more reliably from a metric point of view than other techniques (Condorelli & Bonetto, 2022). It maintains the shapes, colors, and materials even in the case of small objects, as in this case.

The pipeline of the digital reconstruction process within the museum's sculptural heritage is already consolidated. The presented case study is part of a larger project, utilizing hand-held digital photogrammetry aimed to obtain models that can be used for visualization purposes on web platforms and the creation of virtual tours and the realization of tactile models through FDM 3D printing. This method was chosen by the standards laid out in the already mentioned London Charter and Seville Principles and Bordeaux White Paper (Alliez et al., 2017), which proposes best practices for digitization and visualization in cultural heritage and the humanities.

The eleven statues selected, thanks to the contribution of conservator Laura Vigo, are of such dimensions that it was possible to move them to a room specially equipped for photogrammetric surveying, enabling more controlled image capture. The works were placed on a square table to facilitate shooting and light positioning around the statue in an equidistant way. The lighting system consisted of two soft boxes alternating with two lamps and reflective umbrellas.

The camera was a 61.0 MP Sony full-frame Alpha 7R IV with two lenses: Sony FE 2/28 mm and Sony FE 2.8/50 mm macro lens for the smallest artwork and details.

In addition, some arrangements were made to optimize the result of the photogrammetric survey: the support surface was covered with newsprint to guarantee good photo-matching; a color checker was used to making the textures' color rendering reliable, and a marker equipped with a metric scale was used to help scale the resulting virtual models.

Artwork	Set of photos	Altezza obiettivo [m]	Distanza obiettivo (orizz) [m]	Shooting height [m]	GSD
Actor 1 (h= 12,4 cm)	1	0,1	0,42	0,42	0,06
	2	0,04	0,18	0,18	0,02
	3	0,09	0,18	0,18	0,02
Actor 2(sin) (h= 25,1 cm)	1	0,09	0,25	0,25	0,03
	2	0,17	0,25	0,25	0,03
	3	0,11	0,55	0,55	0,07
	4	0,35	0,2	0,22	0,03
Actor 3(center) (h= 24,5 cm)	1	0,2	0,45	0,45	0,06
	2	0,04	0,25	0,25	0,03
	3	0,14	0,2	0,2	0,03
	4	0,2	0,2	0,2	0,03
	5	0,1	0,35	0,15	0,02
Actor 4 (dx) (h= 24,1 cm)	1	0,2	0,4	0,4	0,05
	2	0,04	0,25	0,25	0,03
	3	0,14	0.3	0,3	0,04
	4	0,2	0,2	0,2	0,03
	5	0,1	0,35	0,23	0,03
Kunlun dancer (h=34,9 cm)	1	0,17	0,54	0,54	0,07
	2	0,04	0,3	0,3	0,04
	3	0,15	0,3	0,3	0,04
	4	0,3	0,25	0,25	0,03
	5	0,5	0,2	0,27	0,04
Court Lady (h=33,7 cm)	1	0,16	0,45	0,45	0,06
	2	0,04	0,25	0,25	0,03
	3	0,16	0,25	0,25	0,03
	4	0,22	0,25	0,25	0,03
	5	0,3	0,1	0,1	0,01
	6	0,39	0,1	0,11	0,02
Antropomorphic Zhenmushou (h=38,1 cm)	1	0,19	0,45	0,45	0,06
	2	0,14	0,4	0,4	0,05
	3	0,04	0,25	0,26	0,04
	4	0,135	0,3	0,3	0,04
	5	0,3	0,25	0,25	0,03
	6	0,35	0,15	0,15	0,02
	7	0,35	0,15	0,16	0,02
	8	0,4	0,15	0,16	0,02
Zoomorphic Zhenmushou (h=38,2 cm)	1	0,16	0,45	0,45	0,06
	2	0,16	0,4	0,4	0,05
	3	0,04	0,25	0,25	0,04
	4	0,14	0,25	0,25	0,04
	5	0,14	0,2	0,22	0,03
	6	0,1	0,2	0,2	0,03
	7	0,26	0,25	0,25	0,04
	8	0,38	0,2	0,22	0,03
Horse (h= 53,4 cm)	1	0,18	0,66	0,66	0,09
	2	0,04	0,3	0,3	0,04
	3	0,04	0,3	0,33	0,04
	4	0,2	0,3	0,25	0,03
	5	0,6	0,5	0,58	0,08
Palafrenier (h=40,1 cm)	1	0,17	0,55	0,55	0,07
	2	0,04	0,2	0,25	0,03
	3	0,17	0,15	0,15	0,02
	4	0,34	0,15	0,15	0,02
	5	0,5	0,15	0,18	0,02
Minister (h=66,9 cm)	1	0,42	1,1	1,1	0,15
	2	0,54	1,1	1,1	0,15
	3	0,34	0,45	0,45	0,06
	4	0,75	0,45	0,46	0,06

Table 1. Shooting parameters for different surveyed artworks (Editing: F. Ronco)

Before proceeding with the survey, the shooting mode, the camera's distance, the number of turns to be made around the artworks, and the approximate number of shots for each turn have been established.

There were a few challenges encountered during the capturing of the data:

- Environmental factors: it was only possible to move the statues out of the display cases, but remaining inside an exhibition room with some warm artificial lights;
- Size of objects: some artworks were relatively small or rich in fine details that have been necessary to use a macro lens;
- Supports: the smallest artworks (three actors) cannot stand on their own, so it was necessary for a technician to hold the statues in place, avoiding the use of PMMA supports that would have caused reflection problems.

To optimize the resolution of the 3D models, following the guidance of the scientific literature (Morita & Bilmes, 2018) (Farella, Morelli, Rigon, Grilli, & Remondino, 2022), we used different criteria in the photo shooting.

In general, the first set of pictures was made for the camera frame to include the whole object. Then, we determined a minimum of 80% overlap between adjacent images.

Another critical factor was to ensure a sufficient depth of field (DoF) to return an acceptable image sharpness, as required by image-based modeling (IBM) applications. In the selected artworks, it is especially relevant when small artefacts were acquired with macro lenses. Therefore, high aperture settings (f/16) have been used to limit the DoF problem, achieving more accurate and less noisy reconstructions.

To prevent unsharp areas and considering the lighting conditions, the material, and the dimensions of the artefacts, it was decided to set the shots with 250 ISO and the exposure time that varies between 1/5 of a second to 2.5 seconds.

The number of shooting sets (heights) varies from 3 for the smallest artwork to 8 for the highest and more complex artworks (Fig. 2).

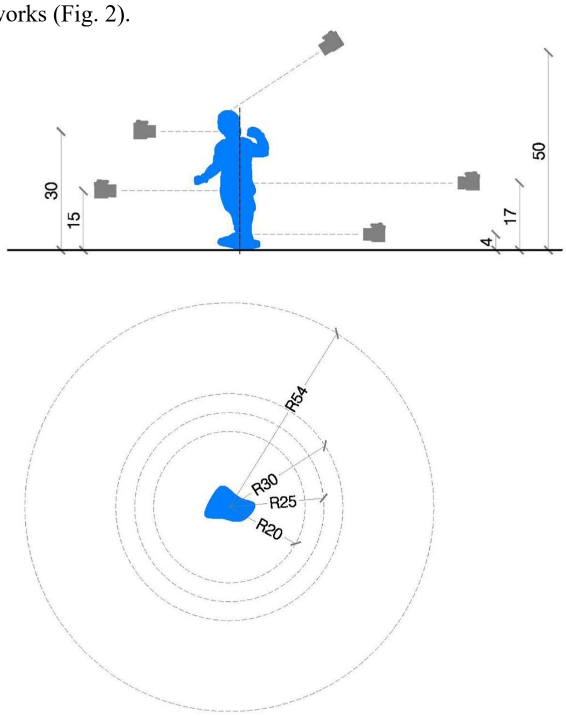

Figure 2. Kunlun Dancer: photogrammetric shooting scheme. (Scheme: F. Ronco)

Depending on dimensions and the level of detail, several shots between 90 and 130 were taken around the statues at distances between 20 and 110 cm to achieve a GSD between 0.03 and 0.103.

Table 1 shows the data for each statue and the GSD. The acquired data were then processed using Agisoft Metashape® through the image alignment, the creation of the sparse and dense point clouds, the cleaning operation, and the surface/mesh and texture generation. The meshes have been simplified to minimize models' size by reducing the number of faces while preserving the shape, volume, and boundaries. The resulting reconstruction was of high quality with a consistent point cloud density, capturing sub-millimeter details such as clay cracks and paint flakes (Fig. 3). The mesh model was finally exported in .obj for the implementation within the Blender® environment.

Figure 3. Actor 1: zoom on the textured mesh. (Editing: F. Ronco)

6. REALITY-BASED 3D MODELLING AND 3D RECONSTRUCTIVE MODELLING

A search within the MAO archives was conducted to contextualize the three-dimensional models of the museum's works. From that analysis, the tomb of Zhang Shigui, a military functionary who served in the early phase of the Tang Dynasty, was identified. The tomb was opened in 1972 and is located in Taizong Mausoleum, Zhaoling, in Jiuzong Mountain, Shaanxi, China (Pirazzoli, 2002).
A sloping access route leads to the burial chamber at a depth of more than 14 meters. Along this path are encountered five arched passages, five vertical air channels, and two pairs of small square side niches that contain many statues from the grave goods. The stone bed and funerary epitaph were also found in this burial. In addition, there are signs of wall paintings that have been lost (Pirazzoli, 2002).
The digital reconstruction was made possible by excavation surveys. These were complemented by appropriate photographic evidence of other similar Tang burials that allowed clear visualization of the context.
The open-source 3D modeling software Blender 3.1 was used for three-dimensional reconstruction.
The first step involved 3D modeling of the primary environment, divided into the abovementioned spaces. Subsequently, we moved on to realizing the additional elements, such as the stone bed and the funeral epitaph. In addition, a similar portal was chosen to make up for the lack of the original portal of Zhang Shigui's tomb, which was destroyed.
The portal selected belongs to the tomb of Prince Li Shou, dating to the same period, and is contextually compatible (Fong, 1987) (Fig. 4).
The structure of Zhang Shigui's tomb has simple geometric surfaces, and it was possible to work for the most part directly on the program's default polygons through Edit Mode.
Also, Boolean modifiers were used for the more complex parts, for example, the pavilion vault of the burial chamber.
For the outdoor, photographs of the landscape context in which the burial is located were again evaluated. This environment was reproduced using digital sculpting tools with which polygons could be freely deformed to obtain natural 3D elements such as trees and rocks. An essential aspect of the representation is the mound of earth protruding above the burial chamber.

Figure 4: Reconstructive 3D model of the Zhang Shigui tomb entrance with the Li Shou tomb portal. (Modelling: M. Ferraro)

This type of recurring conformations indicated the presence of the tomb below. Furthermore, the whole site is surrounded by a brick wall, revealing that the area was protected. Once all the three-dimensional models were refined, an additional step of cleaning up the visual noise present on the Tang statues was also performed. At this point, the final composition was created by placing the statues inside the side niches. The only three exceptions for placement are the grave keepers set to guard the portal and the statue of the military officer placed inside the burial chamber. Moreover, the interior of the side niches was also filled with "clone" statues of the originals, without any textures, to represent the abundance of items that were once part of the funerary equipment (Fig. 5).
To finalize the 3D models and give them realism, 3D materials were created and attached to them. In Blender, it is possible to create basic materials and modify them by imputing physical properties via Principled BSDF parameters. Because of the type of construction of these tombs, which were grouted and painted, a high-roughness, opaque material was applied to most of the surfaces.
Regarding the stone elements, i.e., the portal, epitaph, tomb bed, and statues, they were attached to a low roughness material that highlights the different polishes. The environmental elements were left with default materials.
This last step was replicated within Unity, the software used to produce the VR experience, using the dedicated materials editor in the program.
To add textures to the objects, a UV Unwrapping process was performed through Blender's dedicated tools for creating UV maps. Images of the wall paintings chosen to replace the originals were placed on the tomb's walls through photographic editing in Photoshop.
In the initial part of the tomb, some famous paintings from the grave of Prince Yide were placed (Fig. 6). The theme portrayed here is that of the honour guard parading toward the pavilions of the imperial family (Shang, 2018).

Figure 5: Composition of tomb niches. (Editing: M. Ferraro)

Figure 6: Textures of Prince Yide at the beginning of the tomb descent. (Editing: M. Ferraro)

The central part of the access ramp to the burial chamber echoes the wall paintings of Princess Yongtai's tomb, famous for the excellent state of preservation of the frescoes; these mainly depict court scenes and floral motifs (Lui, 2022). In the last stage, normal maps were generated from scratch, using wall texture images as the basis. These relief mappings allow graphics engines to simulate the details of a surface more accurately. This process aims to have realistic light refraction without acting directly on the polygon meshes, thus optimizing the computational speed of the applications.

7. VR EXPERIENCE

For the prototyping phase of the VR experience, Unity version 2021.3 served as the foundational platform. The project was specifically engineered for compatibility with standalone Meta VR HMDs (e.g., Meta Quest 2) and Google Cardboard. The OpenXR (The Khronos Group Inc - OpenXR: https://www.khronos.org/openxr/) application API was utilized for the standalone headsets, facilitating seamless integration of graphic engines across diverse VR devices. Conversely, for the Google Cardboard integration, the official Google Software Development Kit (SDK) (Google Cardboard XR Plugin for Unity: https://github.com/googlevr/cardboard-xr-plugin package) for Unity was employed. For both versions, the decision was made to maintain real-time 3D rendering, avoiding 360 videos, and to ensure a consistent interaction paradigm (based on gaze) across the various supported devices.
Firstly, the integration of the models related to tomb reconstruction required a pre-processing step to reduce their complexity and enable integration into real-time simulations on mobile devices. Specifically, a retopology tool for Blender (Exoside Quad Remesher: https://exoside.com/) was executed to optimize the mesh (Lu et al., 2023), reducing the polygon count to 1500 polygons per model, aligning with the recommended specifications for Unity mobile applications (Figure 1). Simultaneously, the textures were optimized, decreasing their resolution from 8K to 2K and converting them to a lossy format (JPEG). The User eXperience (UX) has been designed to focus on intuitiveness and simplicity. Once started and the VR device is worn, users find themselves in the primary scene exterior of the archaeological site. An initial User Interface (UI) element provides a persistent introduction to the simulation, explaining the navigation technique within the virtual space and instructing on interactions with the artworks and the hotspots. Navigation within the virtual environment employs a teleportation technique triggered by focusing one's gaze on designated Points-Of-Interest (POIs) demarcated by yellow floor platforms. Specific platforms are augmented with contextual balloons, signaling supplementary informational layers. These contents are activated by prolonged observation of the hotspot, delivering content through audio streams, textual elements, and, in some cases, videos. From a design perspective, the user interface incorporates "look at" logic, dynamically aligning UI elements to the user's line of sight. The textual narrative employs a conversational yet descriptive tone, optimized for broad and diverse user demographics, typical of museum visitor profiles.
The architectural layout of the virtual tomb experience is subdivided into three distinct segments underpinned by structural considerations. The initial segment delineates the elongated descent ramp, devoid of intricate structural nuances, hosting informative hotspots elucidating architectural methodologies. The subsequent segment encompasses arched passages and air intakes and houses the niches of the funerary statues (now preserved at the MAO). Informational balloons are present on the tomb frescoes (Fig. 7), providing insights into Princess Yongtai's legacy and expounding on the cultural facets of the Tang dynasty. Within the niches, statues are curated thematically: the foremost niches showcase performing arts personas (e.g., dancers, actors), followed by court life characters (e.g., the lady), culminating in urban life scenes (e.g., equestrian scenes). The concluding segment is demarcated by a meticulously crafted stone portal, safeguarding the inner funerary sanctum. Visitors can interact with the portal and the statues of the Zhenmushou, which form its base, to discover their function and details (Fig. 8).
Passing through this portal leads to the central funerary chamber, distinguished by Zhang Shigui's epitaph, ornate murals, and a commemorative statue of a distinguished military officer (Fig. 9). Positioning this artifact in the concluding segment of the experience amplifies its significance, especially considering its probable connection to a burial similar to that of Zhang Shigui, as it represents an individual of equivalent social rank. Upon the culmination of this immersive journey, users can freely continue to explore the structure or conclude their tour.

Figure 7: Example of a POI in a funerary niche, including the statue, the informational balloon, and the interface element containing textual information, paired with a video showing a high-resolution rendering of the artifacts. (Editing: M. Ferraro)

Figure 8: POI at the stone portal, with the statues of the Zhenmushou. The yellow platform used to indicate POIs is also visible. (Editing: M. Ferraro)

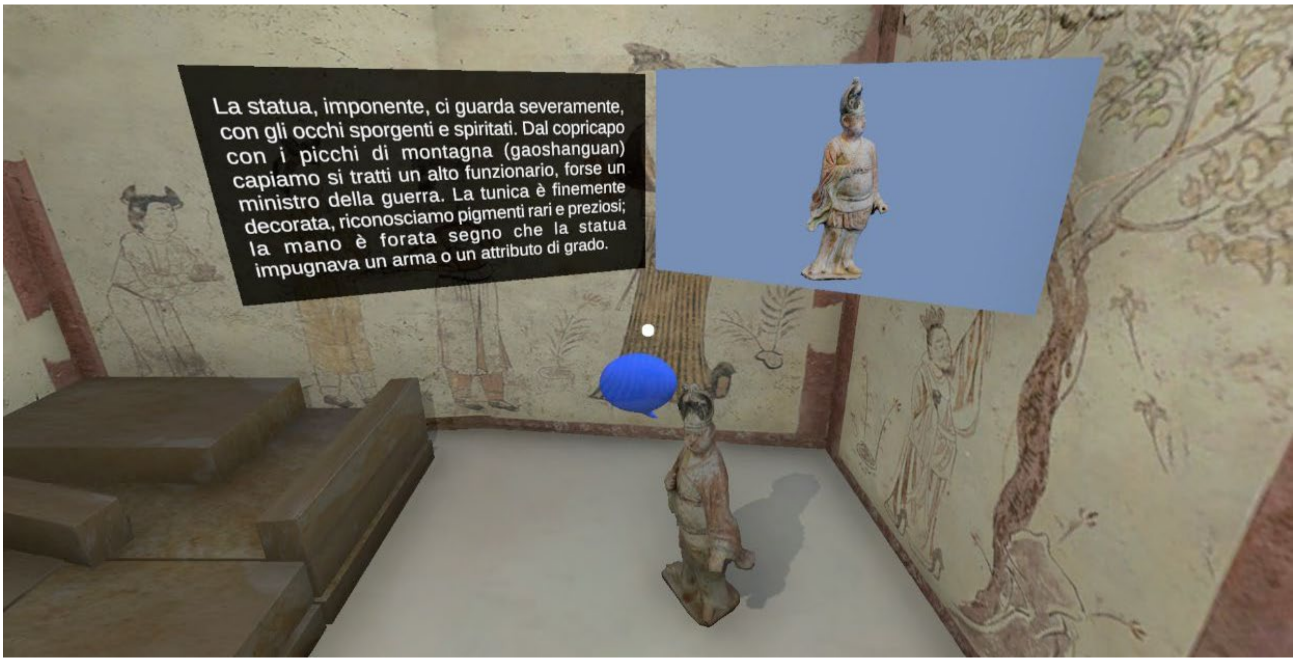

Figure 9: POI of the distinguished military officer statue inside the central funeral chamber. (Editing: M. Ferraro)

8. CONCLUSIONS

The multidisciplinary experience presented in this paper demonstrates how digital convergence can be usefully employed in a pipeline that traverses the phases of analysis, interpretation, modeling, and presentation of museum heritage. This last is interweaved with archeological heritage and is part of a meaningful storytelling that aims to communicate the mortuary practices and spiritual beliefs of the Tang period through the construction of a context that summarizes the figurative culture of the period.

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