Re-contextualizing the standing Sekhmet statues in the Temple of Ptah at Karnak through digital reconstruction and VR experience

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Roberta Spallone
Full Professor at Politecnico di Torino, Dept. of Architecture and Design. President of REAACH (Representation Advances And Challenges Association and Chair of REAACH Symposiums (with A. Giordano and M. Russo). Her investigation focuses on representation history and digital technologies for enhancing CH. Author of 230 publications and lecturer at many international conferences.

Fabrizio Lamberti
He received the M.Sc. and the Ph.D. degrees in computer engineering from Politecnico di Torino university, Italy, in 2000 and 2005, respectively. Currently, he is a Full Professor at the Dipartimento di Automatica e Informatica at Politecnico di Torino, where he leads the VR@POLITO lab. His interests pertain computer graphics, human-machine interaction and intelligent systems.

Davide Calandra
He received the B.Sc., M.Sc., and Ph.D. degrees in computer engineering from Politecnico di Torino, in 2014, 2017, and 2023. He is a research fellow at the Dipartimento di Automatica e Informatica at Politecnico di Torino, with interests in interactive graphics applications, eXtended Reality and human-machine interaction.

Davide Mezzino
Architect, Ph.D., currently, Research Fellow at the International Telematic University UniNettuno. From 2018 to 2022 Digital Expert at Fondazione Museo delle Antichità Egizie di Torino. Within the Digital Humanities field, his research focuses on survey and representation of cultural built heritage, as well as on digitization of museum environments.

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Recent trends in the Digital Humanities – conceived as new modalities of collaborative, transdisciplinary and computational research and presentation – also strongly influence research approaches and presentation practices in museums. Indeed, ongoing projects in museums have considerably expanded digital access to data and information, documentation and visualization of ancient ruins and objects. In addition, 3D modelling and eXtended Reality opened up new avenues of interacting with a wider public through digital reconstructions that allow both objects and sites to be presented through visual narratives based on multidisciplinary scholarly research. The article illustrates the use of 3D digital reconstruction and virtual reality to re-contextualise standing statues of Sekhmet in the Temple of Ptah at Karnak, where they were found in 1818. Today, they are on display at Museo Egizio, Turin. The theoretical framework of the research and the operational workflow – based on the study of the available archaeological, textual, and pictorial data – is presented here.

Keywords:
Virtual Reality; Digital Reconstruction; 3D Modelling; Digital Humanities; Museo Egizio, Turin; Statues of Sekhmet; Ptah Temple at Karnak.

Johannes Auenmüller
Curator at the Museo Egizio di Torino since January 2020. He holds a PhD in Egyptology from Free University Berlin and was research associate at the universities of Bonn, Münster and Munich. His main areas of interest include the sociology and regional prosopography of pharaonic Egypt, technology of metal production and bronze casting, and rock inscriptions and epigraphy in ancient Nubia.

Martina Rinascimento
Student of the master degree "Digital and Interaction Design" at Politecnico di Milano. Graduated in Product Design in 2022 at Politecnico di Torino with a final project focused on cultural heritage and virtual reality. Mastering soft and hard skills, such as teamwork, UX/UI methodologies and XR technologies.

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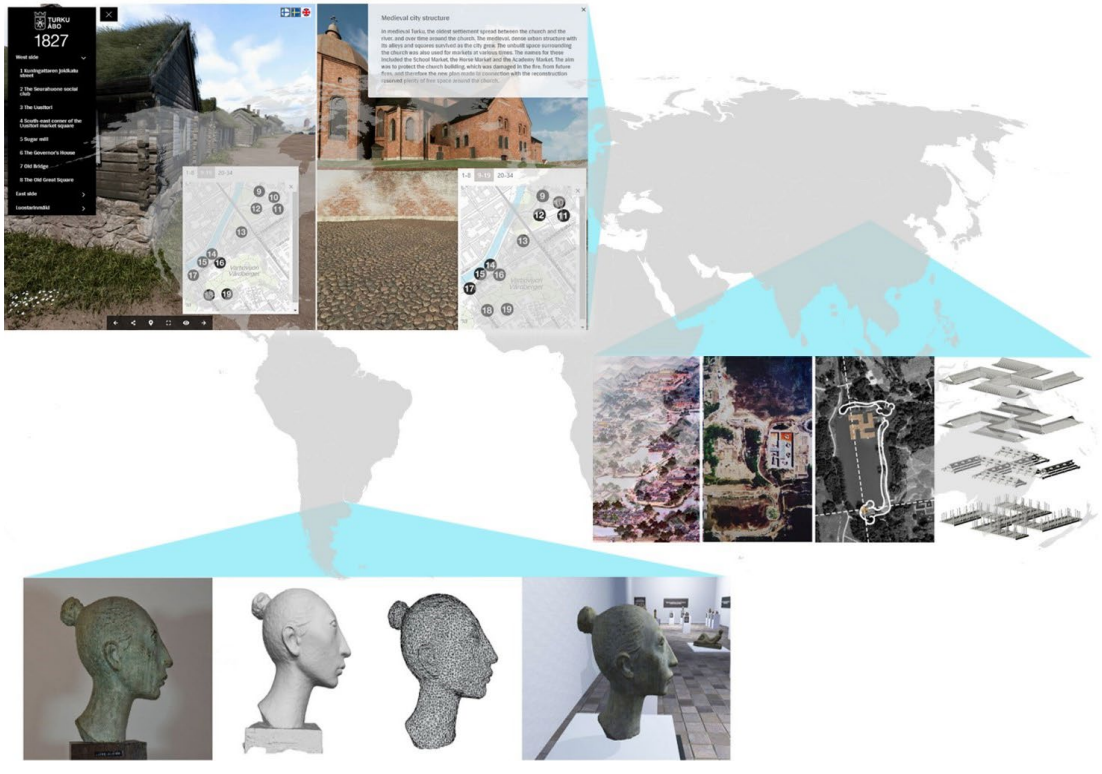
1. INTRODUCTION

This article, a result of the collaboration between Museo Egizio, Turin and the Politecnico di Torino, presents interdisciplinary research aimed at re-contextualising the standing statues of the goddess Sekhmet via digital reconstructions and VR experiences. The "Galleria dei Re" (King's Gallery) at Museo Egizio exhibits numerous seated and standing Sekhmet statues, which originally, it seems, were all installed in the mortuary temple of King Amenhotep III in Western Thebes. However, the standing Sekhmets in the Turin collection were all found in front of the temple of Ptah at Karnak in 1818. Since no archaeological record exists, their former disposition in this temple is one of the main challenges of this research.

2. DIGITAL HUMANITIES FOR ARCHAEOLOGICAL AND MUSEUM HERITAGE: AN OVERVIEW

The methods of the Digital Humanities have profoundly changed approaches to the study of cultural heritage and, more importantly, the methods of gaining knowledge and understanding (Burdick et al., 2012). The generated outputs, including digital visualizations, render knowledge and information more accessible by linking data in spatiotemporal frameworks (Münster et al., 2019). In addition, the digital approach also adds to a holistic exploitation by activating user participation. In archaeology, the use of digital images and 3D models has introduced new forms of information (re-)presentation. Within this field, digital workflows have profoundly transformed the methods of gaining scholarly knowledge. They facilitate the analysis of ancient documents or monuments through visual reconstructions and allow for the creation of virtual environments for disseminating data to, and sharing interpretations with, scholars and non-specialists.
In this context, the distinction between Digital Cultural Heritage and Digital Humanities, which previously addressed archaeological and historical data from different methodological perspectives, is becoming less relevant. Indeed, the overarching interest "to initiate a fruitful discussion on the commonalities and differences" between Digital Humanities and Digital Cultural Heritage is becoming a growing and consolidated trend (Münster et al., 2019, p. 813). Several successful projects illustrate how skills traditionally used in the fields of museums and archaeology can be reshaped by digital means, including digital reconstruction and VR. The digital 3D reconstruction of the "Wanfanganhe" Pavilion in Beijing, China (Chen & Del Blanco Garcia, 2022), the Argentinian project "Digitalización de bienes culturales mediante imágenes 3D" (Morita and Bilmes, 2018) or the exhibition "Krause. Vestigios disponibles" (Loaiza Carvajal et al., 2020) can be mentioned (Fig. 1). Common features of projects in this realm are their interdisciplinary approach and teamwork character, involving collaborators with complementary skills and knowledge, which is useful in defining the research questions as well as the strategy and workflows to be adopted. Many such projects also demonstrate the role of digital methods in restoring the cultural identity of historical places through the dissemination of new narratives based on new research of architecture

Fig. 1 - Worldwide examples of virtual environments created through computer-generated 3D modelling. Sources: Museum of History and the Future, 2023; Chen & Del Blanco Garcia, 2022; Morita & Bilmes, 2018. Editing: D. Mezzino.



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and objects. These research approaches are linked by two main objectives: 1) to promote the study of archaeological sites and objects by proposing a visual interpretation approach based on 3D modelling and VR environments; 2) to improve public awareness of archaeological sites and museum collections by proposing re-contextualizations of museum objects and scientific reconstructions of archaeological sites through 3D modelling and digital visualization methods.

3. VIRTUAL REALITY AND MUSEUM HERITAGE – THEORY

Museums are open, accessible, and inclusive institutions, aiming to preserve cultural and natural-historical heritage. They carry out a polyvalent mission that includes researching, collecting, preserving, interpreting, and displaying both tangible and intangible aspects of nature and culture (ICOM, 2022). This mission is intrinsically linked to the concept of 'New Museology', introduced by Stephen E. Weil (Weil, 1990) and further elaborated by Peter Vergo in 1997 (Vergo, 1997).
According to the principles of 'New Museology', museums are not static repositories of things, but dynamic entities that shall evolve into engaging experiences. They should aim to promote visitor involvement, participation and learning by transforming from static exhibition spaces into immersive educational environments (Vergo, 1997). In this effort to focus on visitor-centred engagement, museums have started to use cutting-edge technologies to enhance their offerings. In particular, eXtended reality (XR) has transformed visitor interaction by expanding the museum experience through Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR)-based exhibitions that transcend physical facilities (Silva and Teixeira, 2022). Although all XR technologies have the potential to enrich the understanding of cultural heritage objects, AR and MR are usually applied in location-based roles to augment physical exhibitions with supplementary content, whereas VR applications are employed to complement and extend the existing exhibitions through Virtual Environments (VEs).
Traditionally, museums have employed VR to provide alternative forms of interaction with their visitors (Bekele et al., 2018). VR offers the possibility to provide captivating, interactive and immersive experiences in the context of museum learning (Carrozzino and Bergamasco, 2010). It allows visitors to overcome the boundaries of time and space by providing them access to lost or damaged historical spaces (Tom Dieck et al., 2019) or artifacts (Gonizzi Barsanti et al., 2015). For museums, this aspect of accessibility is particularly significant, as it renders the exploration of lost sites or the presentation of historical figures possible (Tom Dieck et al., 2019).
In the world of VR, museum professionals have embraced the power of creating completely virtual exhibits, separating them from the physical limitations of the museum (Bekele et al., 2018). Although this approach serves as a compelling way to attract people to visit physical exhibits, it is viewed more as a complementary rather than a substitute strategy (Vergo, 1997). The successful integration of VR experiences which support experiential learning, a key point of museum engagement, is well evidenced (Carrozzino and Bergamasco, 2010).
In addition to enriching the visitor's experience, digital reconstruction and VR have also proven valuable in the field of heritage protection and conservation. They have emerged as tools for both archaeologists and conservators, contributing to restoration efforts and reducing costs associated with field campaigns. In fact, VR offers scholars the possibility of virtually restoring and exploring fragile finds, or even entire historical sites, in a surrogate and immersive way (Bekele et al. 2018). This intersection of technology and heritage preservation exemplifies the transformative potential of VR in the museum landscape. Beyond enhancing museum accessibility and educational value, VR can contribute to the preservation and understanding of cultural heritage. In the evolving digital age, the use of this technology in museums is being embraced as a tool that not only has the potential to enhance the traditional experience but can also extend the horizons of what can be accomplished in the contexts of education, preservation, and engagement.

4. VIRTUAL REALITY AND MUSEUM HERITAGE – CASE STUDIES

Many museums, libraries, and similar institutions holding cultural heritage objects have undertaken digitization efforts aimed at facilitating research, restoration, and preservation. The resulting digitised artifacts are ready to be incorporated and employed in various XR applications to convey their meaning and create new narratives (Tsita et al., 2023).
Focusing on VR applications, their objectives include the reconstruction of archaeological sites, the promotion of new methods of knowledge sharing, and increasing the engagement with the audience, which can all be achieved through the creation of captivating, interactive, and immersive museum experiences.
Some years ago, Carrozzino and Bergamasco (2010) proposed a classification of VR-based museum installations based on interaction and immersion attributes. On the interaction scale, the classification ranged from the lowest level, including the use of more traditional devices such as mouse, keyboard, and joysticks, via the intermediate level, represented by handheld or wearable devices, to the highest level, encompassing the use of external sensors tracking, and responding to, the user. As regards the aspect of immersion, several sub-scales were employed (visual, acoustic, haptic, and motion), representing three out of the five senses currently stimulated by consumer VR devices, plus the fundamental component related to locomotion within the VE. Each subscale ranged from traditional desktop devices, via wearables, up to the external devices. Regarding the visual dimension, traditional monitors were stated to provide a good level of immersion, followed by Head-Mounted Displays (HMDs), and Cave

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Automatic Virtual Environments (CAVEs) which were indicated as the most immersive solutions. It should be considered, however, that this classification needs to be revised today to account for recent advancements of VR HMDs and related accessories, which could make some systems such as CAVE become outdated (Vasconcelos et al., 2019).
Even through hand-tracking can be considered as the most transparent technology in terms of interaction, it is not necessarily the most suitable choice due to numerous limitations. For example, the complete lack of haptic feedback can worsen the tactile perception compared to the use of a physical device delivering a form of passive haptic feedback (Pratticò et al., 2023). For this reason, the standard interaction method is still the use of 'six-degrees-of-freedom' (6DOF) hand controllers with physical buttons, usually bundled with common commercial VR systems. For instance, Restivo et al. (2023) present a VR experience in which the user is given the opportunity to interact first hand with museum artifacts. The user, immersed in a VE resembling a historical space, is seated in front of a virtual museum curator. Virtual museum artifacts are placed on a table in front of the user, who can use hand controllers to grasp and manipulate them for a closer examination. Furthermore, the ability to provide detailed explanations on demand, for example, through dedicated audio clips combined with natural gestures of the virtual curator, plays a fundamental role. In this case, this functionality is managed through interaction with objects and with buttons on the controllers, which serve as triggers to initiate an explanation by the curator's avatar.
In addition to the possibility of simulating interaction with virtual objects, the significant advantage of VR lies in the ability to allow the user to enjoy entire locations. Cassidy et al. (2019), for example, present a VR platform for visualizing, and interacting with, a 3D reconstruction of an archaeological site. The user gets immersed in environments faithfully reproduced through photogrammetric and laser scanning techniques, enabling the possibility of conducting remote visits. In order to allow the user to experience the entire VE regardless of the available physical space (Cannavò et al., 2021), a stationary joystick-based locomotion technique has been integrated. As outlined from the examples presented above, VR holds multifaceted potentials as a technology communicating cultural heritage, since it can play a versatile role in enhancing communication, preservation, and the way museums engage with their audience.

5. CONNECTING OBJECTS, TIMES, AND PLACES: STUDYING THE ORIGINAL CONTEXTS OF THE SEKHMET STATUES

The research presented here is a multidisciplinary undertaking by Museo Egizio, Turin, the Architecture and Design and the Control and Computer Engineering departments of Politecnico di Torino as well as the VR@POLITO Laboratories. The research group formed around themes such as Egyptian archaeology, digital representation, and computer graphics.
The overall goal of the project is the re-contextualization of the statues of Sekhmet currently kept at Museo Egizio by means of digital reconstructions of the architectural spaces in which they were originally – and also secondarily – installed: the temple of Amenhotep III at Kom el-Hettan, the temple of Mut and the temple of Ptah at Karnak. The creation of immersive environments by VR complements this objective, as it allows to virtually place the statues in their various locations. The paper presents the digital modelling of the Ptah temple including the placement of 3D models of the standing Sekhmet statues.
The reconstruction of the Ptah temple and its immediate surroundings made only use of the publications of the French-Egyptian archaeological mission at Karnak (see esp. http://www.cfeetk.cnrs.fr/?s=ptah and http://sith.huma-num.fr/karnak/246) and the reconstruction hypotheses of scholars. The principles of transparency expressed in the London Charter (2009) and the Principles of Seville (2017) informed the visualization criteria for the model, which is ready to be augmented with future findings and hypotheses.
The unknown original placement of the Sekhmet statues in front of the Ptah temple gave rise to different hypotheses which the digital temple model allowed to visualize and scrutinize. Therefore, two levels of research interest emerged. On the one hand, the geometric and metric reconstruction of the temple offers a dynamically modifiable assembly box for checking the statue placement hypotheses by scholars. On the other hand, the availability of the model to the public by means of an immersive VR experience allows to propose new narratives and connect the museum to the archaeological site of origin of the Sekhmet statues.
The work, currently at prototype stage, has been tested and exhibited at two events: the Biennale Tecnologia 2022 at Politecnico di Torino, and during the European Researchers' Night (UNIGHT) 2023 at Museo Egizio in the 'Galleria dei Re' (King's Gallery) directly next to the statues in question (Fig. 2). The visitors could enjoy an immersive tour of the temple of Ptah, exploring its various features and appreciating the relationship between the actual statues in the galleries

Fig. 2 - VR experiences in the 'Galleria dei Re' at Museo Egizio, Turin, during the European Researchers' Night (UNIGHT) 2023. Photo: F. Lamberti.

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and their reconstructed placement in a kind of travel through time. Further considerations in regard to the application of such an approach allow one to imagine making a connection with other archaeological sites in Egypt, offering new possibilities for visitors to enjoy the experience, not only in VR, but also through AR.

6. THE TEMPLE OF PTAH AT KARNAK AND THE STANDING SEKHMET STATUES AT MUSEO EGIZIO

The temple of Ptah at Karnak (Thiers & Zignani 2011; Thiers & Zignani 2013; Biston-Moulin & Thiers, 2016; Charloux et al., 2017) is one of the smaller sacred buildings surrounding the core of the Karnak complex. The main Ptah temple structure was built and decorated during the reign of Thutmose III (1479–1425 BCE) (Fig. 3). The origins of the Ptah temple can, however, be traced back to the late 17th and early 18th Dynasty, as mudbrick foundations of an earlier temple could be verified under the sandstone building of Thutmose III. The stone temple consisted of a courtyard with a two-columned portico in front of a tripartite structure housing three sanctuaries. The central one, dedicated to Amun-Ra, provided access to the sanctuaries of Hathor in the south and Ptah in the north. The temple was built as a way-station for the processional festivals that were celebrated at Thebes and during which the barques of the gods were ritually carried from one temple to the other. The character as way-station within its own precinct is emphasised by the gate F of Thutmose III west of the courtyard.
In the following periods, the Ptah temple was embellished with several additions, both in terms of its decoration as well as its architecture. The most noteworthy among them are the Kushite and Ptolemaic gates along the main processional axis, each associated with a mud-brick enclosure wall: The construction works undertaken under Shabako (25th Dynasty, 705–690 BCE) extended the approach to the temple towards the west with the two gates B and D. During the 30th Dynasty, the main precinct of Amun was enlarged and enclosed by a massive mudbrick wall, running directly north

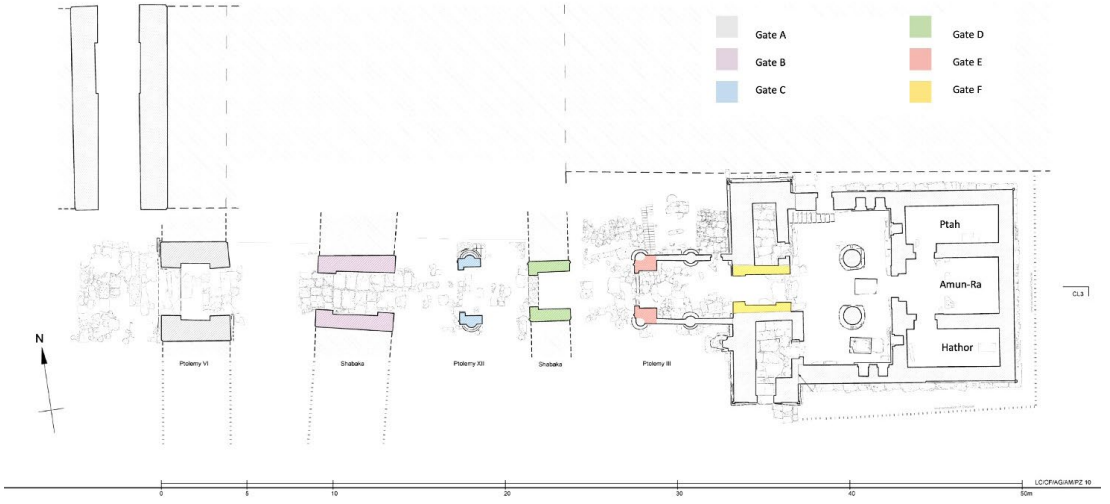

Fig. 3 - Plan of the Ptah temple with its gateways highlighted. Modified by M. Rinascimento and J. Auenmüller after Thiers & Zignani 2011, 21, lower.

of the Ptah temple, and thus triggering several architectural changes that were implemented in the following times. Under Ptolemy III (246–222 BCE), the area in front of the original 18th Dynasty temple court was reorganised, including the two pylon towers flanking the gate F of Thutmose III, the covering of the courtyard and a kiosk-like structure in front of the pylon on the west. Ptolemy VI (180–145 BCE) erected the westernmost portal A, while Ptolemy XII (80–51 BCE) had the smaller doorway C built between the 25th Dynasty gates B and D. The latest monumental evidence for the temple's use dates to the reign of Tiberius (14–37 AD). After its abandonment, the temple area was occupied by a Coptic settlement (5th–6th centuries AD).
During 1817 and 1818, Jean-Jacques Rifaud, a sculptor, adventurer, and agent of Bernardino Drovetti tasked with finding antiquities, undertook extensive pre-scientific excavations in the Ptah temple area (Cincotti 2013). A drawing of Rifaud of the temple (University of Geneva Library, Fonds Rifaud, Ms. Fr. 1602/I, f. 82: Thiers & Zignani, 2013, 497, fig. 3) seen from a bit higher up, likely from a vantage point in the area of the gates C and D shows the extent of his excavations. According to a list of Rifaud's excavations at Karnak from 1829, he also uncovered the other gateways of the temple to the west. The Ptah temple and Rifaud's findings are described in this list as follows: "a temple preceded by seven portals, with a peristyle of four columns with various capitals, nineteen statues in black granite and one in lime-stone" (translated from the French original cited in Cincotti, 2013, p. 282).
The identity of at least 16 of the 19 hardstone statues can be determined thanks to a text penned by Rifaud himself (University of Geneva Library, Fonds Rifaud, Ms. fr. 112, f. 197), in which he refers to the statues in the collection of Drovetti found by him at Karnak and now in Turin: "(...) he [=Drovetti], reserved for himself 13 statues with a human body and lion's head in an upright position in black and grey granite out of the 16 which were found at the front of the temple which I excavated in the northern part of the palace of Carnak" (translated from the French original cited in Cincotti, 2013, p. 284). Of these 13 standing

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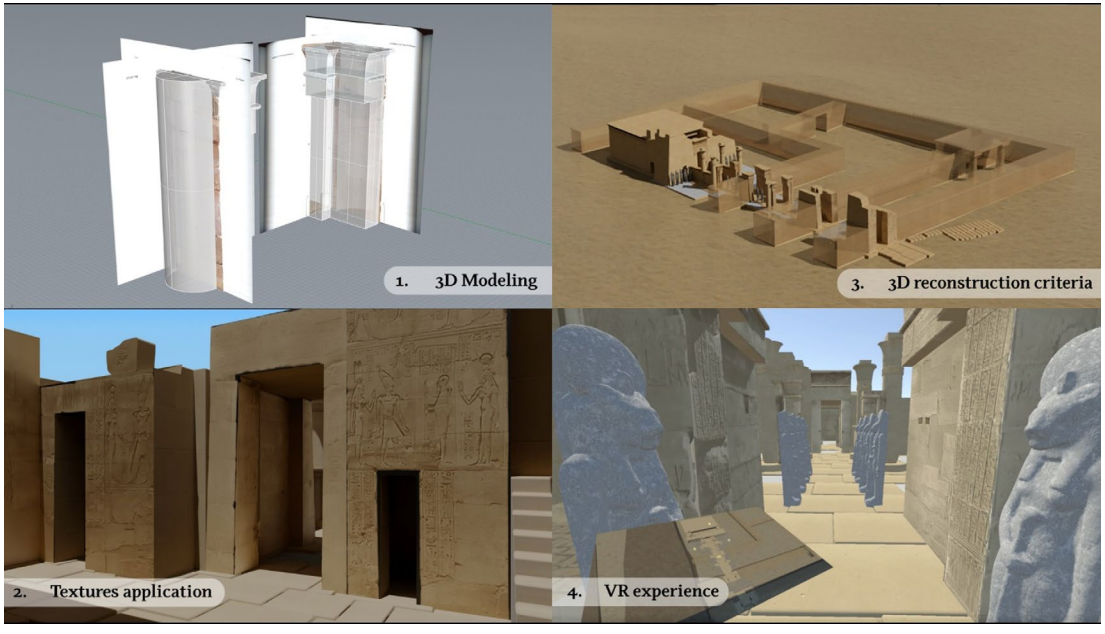

Fig. 4 - Pipeline of the reconstruction and VR visualization of the temple of Ptah with the placement of the standing Sekhmet statues. Editing: M: Rinascimento.

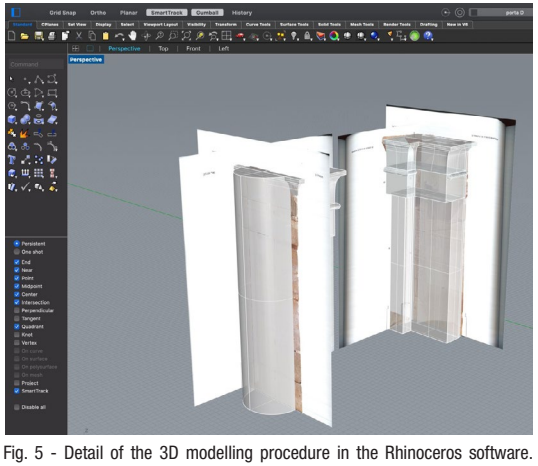

Fig. 5 - Detail of the 3D modelling procedure in the Rhinoceros software. Modelling and rendering: M. Rinascimento.

Sekhmet statues, 11 are currently in the Museo Egizio, Turin: Cat. 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, and 265.
Summing up, at least 16 standing Sekhmet statues were found by Rifaud in front of the Ptah temple. Their findspots or other details of their discovery were not recorded, so that their original arrangement in the temple remains unclear, triggering the question how these statues might have been positioned. The architectural layout of the Ptah temple complex offers some hints as to imagine the disposition of the Sekhmets. Three main scenarios can be discussed: the statues might have been a) standing in front of the temple pylon towers, b) in and/or around the Ptolemaic porch, or c) placed side by side along the processional axis (cf. Connor, 2017, p. 20). The question of when the Sekhmet statues, which all date to the reign of Amenhotep III (18th Dynasty, 1390–1353 BCE), were erected at this place remains unsettled. It seems likely that their installation was related to one of the various post-18th Dynasty building phases of the temple and its processional way. Since Rifaud found the Sekhmet statues in an architectural setting including the Ptolemaic porch, they might have been erected here in Ptolemaic times. However, it cannot be ruled out that the Sekhmets had already been at this place since the 25th or 30th Dynasty.

7. RECONSTRUCTIVE MODELLING AND VR EXPERIENCE

The VR experience has been designed for the use within a museum context but does not require open and navigable spaces. As will be explained later, the users can navigate through the digital reconstruction by means of a teleportation mechanism, allowing them to remain in a fixed position in actual space. The choice was made to employ a wearable device for the immersive VR experience, because it projects the user in a reconstructed environment and directs their cognitive and sensory attention solely to the digital world. Furthermore, through the digital reconstruction process, full control over the creation phases can be maintained, ensuring that the final 3D model is as faithful as possible to the real world as new discoveries come to light and new hypotheses are formulated.
The design process started with the collection and analysis of documents pertaining to the history of the archaeological site, the temple of Ptah at Karnak (see section above). In this research phase, information about the dimensional proportions of the building, the history of archaeological excavations at the site, and some hypotheses regarding the placement of the statues of the goddess Sekhmet in relation to the dating of the temple's elements were gathered (Fig. 4).
Plan drawings and photos of the temple (esp. Biston-Moulin & Thiers, 2016) were used as base material of the 3D digital reconstruction (Fig. 5). While the temple's modelling was accomplished using Rhinoceros software, the creation of the

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Fig. 6 - Reconstruction of the temple of Ptah and texturing, from the inside. Modelling and rendering: M. Rinascimento.

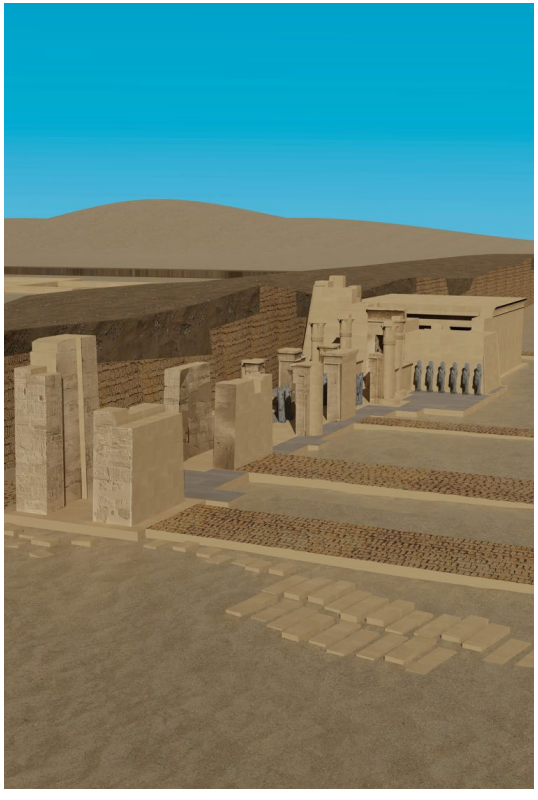

Fig. 7 - Reconstruction of the temple of Ptah and texturing, from the outside. Modelling and rendering: M. Rinascimento.

surrounding environment was carried out using Blender, chosen for its precise control over vertex, edge, and face modelling. The final step of the modelling phase was doing a retopology to facilitate the later application of textures in a smooth and accurate manner.
The following phase revolved around hypotheses regarding the placement of the 11 standing Sekhmet statues. While their arrangement was not documented, evidence from other temples was consulted. Two possibilities were then considered: either aligned along the façade of the temple pylon or placed side by side in two rows along the processional way. Both of these configurations were incorporated into the 3D model, along with the representation of another Sekhmet statue discovered in the southern chapel of the temple in 1901/2 (Cincotti, 2013). Subsequently, the colour map of the materials and the normal maps of the textures were derived from the documentation for application to the 3D model in Blender (Figs. 6–7). Then, the 3D models of the Sekhmet statues provided by Museo Egizio were integrated and positioned according to the two proposed arrangements. To visually differentiate the original structures from the reconstructed ones, a recent graphic reconstruction of the site (Rondot [ed.], 2022, pp. 256–257) was used, and two visual styles with different levels of transparency were employed: opaque elements represent the in-situ components, while transparent elements signify missing parts. The original flooring of the central axis was distinguished from the restored areas through variations in colour tones: the original portions have warmer tones, while the new sections are rendered in cooler hues.
Finally, the VR experience was designed and programmed using Unity software, doing visual scripting with Bolt, and the Oculus and SteamVR applications. This allows for the interaction between visitors and the content of the experience, as well as several expert evaluations of the prototype, to be carried out leading to the final product. Due to the immersive nature of the VR experience, the Oculus Quest Meta 2 headset must be worn.
The VR experience comprises two interactive moments. The first involves the gradual unveiling of the architectural elements of the temple in relation to their historical chronology. As the VR experience is launched, the first of the four narrating voices introduces the history of the building and provides instructions for visitor movement and navigation using a map of the structure, which also displays the locations of interactive icons of interest and the teleportation tool. This tool works through beams of light diffusing from the viewer's controller, indicating the user's destination when the designated button on the controller is pressed. This method of movement eliminates the need for a large physical space and makes it feasible for the experience to be integrated into a museum setting.
The second interactive segment occurs as visitors explore the temple and interact with pulsating icons positioned at significant points (Fig. 8), which are also displayed on the map. Upon approaching an icon, a narrating voice provides additional

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Fig. 8 - Visualization of a frame of the Virtual Reality experience, including the map and an icon of interest's visualization. Modelling and rendering: M. Rinascimento.

information about the god Ptah, the myth of Sekhmet, the events leading to the relocation of the statues from their original site to the temple, archaeological excavations, and the research supporting the two hypotheses regarding the placement of the statues (Fig. 9).

8. CONCLUSIONS

Recent trends in the Digital Humanities have strongly influenced museum research and presentation practices. XR, 3D modelling and digital archives open up new ways of visualising objects and their original contexts, as well as new ways of interacting with wider audiences.
The digital reconstruction of the Ptah temple at Karnak provides an experimental platform which not only allows to investigate the different possible locations of the standing statues of Sekhmet now at Museo Egizio, Turin, but is also open to future implementations and applications.
The immersive VR experience offers the possibility to broaden the scope of users, starting with scholars, who can explore the digital space to evaluate the coherence of their reconstruction hypotheses, to the wider public, which can learn cultural heritage objects in a stimulating and interactive way.
The research presented generates new connections between the museum and archaeological sites, opening up for an unprecedented variety of future applications as well as for stimulating methodological reflections on the agency of digital models on archaeological thought.

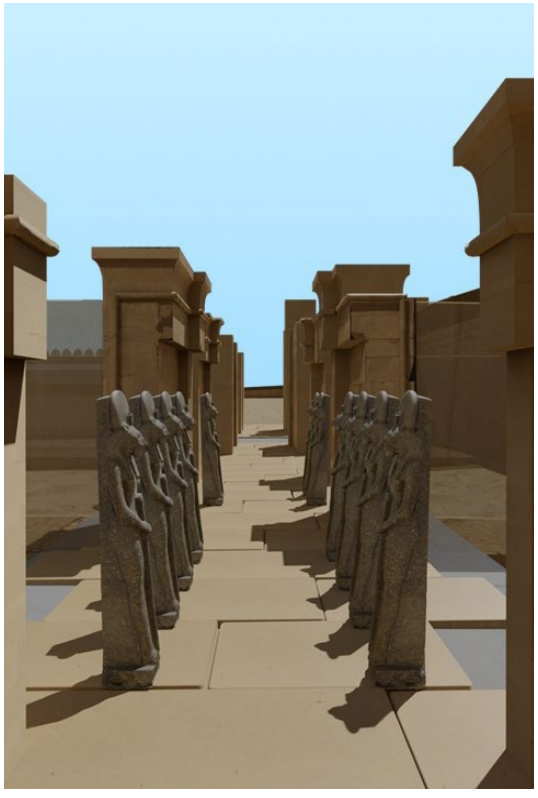

Fig. 9 - Visualization of one hypothesis for the placement of the Sekhmet statues side by side in two rows along the main outer temple axis. Modelling and rendering: M. Rinascimento.

CREDITS

Despite this publication being the result of collaborative research, D. Mezzino wrote paragraph 2; F. Lamberti paragraph 3, D. Calandra paragraph 4; R. Spallone paragraph 5; J. Auenmüller paragraph 6; M. Rinascimento paragraph 7. The authors wrote together paragraphs 1 and 8. J. Auenmüller reviewed and proof-read the whole paper.

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