

# Immersive Reconstruction of the Samnite Culture through Extended Reality

ADRIANA ROSSI, SARA GONIZZI BARSANTI and SILVIA BERTACCHI  
Università degli Studi della Campania Luigi Vanvitelli, Italy

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This paper presents the survey and virtual reconstruction of 3rd-century BC “chamber-type” tombs discovered at Santa Maria Capua Vetere, on the southern slopes of Monte Massico. Photogrammetric documentation of the surviving frescoes enabled the digital restoration of their architectural and decorative elements, allowing visitors to re-experience the funerary environment as it once appeared. From the orthophotos of the interior walls, the paintings were analyzed and reconstructed to recover their original geometries and color schemes. Since the tombs are severely damaged and their wall paintings are nearly lost, the immersive virtual environment now serves as the only means to restore their ancient splendor and convey to contemporary audiences the sensory experience once evoked by the funerary rites. Through advanced visualization technologies, the project transforms archaeological data into a shared, meaningful space where users can engage with the world of the dead that ancient visitors encountered.

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## Keywords:

3D modelling, Digital Reconstruction, Photogrammetry, Panoramic Images, Documentation, Public Outreach, XR.

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## 1. INTRODUCTION

Powerless, in some cases indifferent, we record the progressive degradation of what were originally testimonies, more unique than rare, of the Samnite culture, a glorious lineage before this population of farmers was subjected to the Roman Empire (Titus Livius, 753 BC *Ab Urbe Condita*, II,17; III, 91; VII, 1). Conceived as final resting places, the burials of the 4th-3rd century BC ratify the social and political change of the local communities. A few aristocratic families (*gens*), who in the previous century had entrusted the excavated or stone-built graves with the task of reassuring the living and thus guaranteeing the perseverance of the power of the lineage, gave way to the government of a middle class, represented by brave leaders and *mater familias*. More modest but much more numerous were the funerary monuments, no longer mausoleums but ‘chamber tombs’ semi-buried in the natural environment (Fig. 1).

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Author’s address: Adriana Rossi, Sara Gonizzi Barsanti and Silvia Bertacchi, Dipartimento di Ingegneria, Università degli Studi della Campania Luigi Vanvitelli, via Roma 29, 81031 Aversa (CE), Italy; email: (adriana.rossi, sara.gonizzibarsanti, silvia.bertacchi)@unicampania.it

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Figure 1. Archaeological Area. S. Maria Capua Vetere, Caserta: state of the site in the aftermath of vandalism, where the chamber tombs are placed inside the archaeological area; top right, environmental context by type analogy. Photos by the authors.

The architecture is almost standardized. The walls are built in tuff blocks and the internal organization is repeated: the length does not exceed three meters, while the width of less than two meters expands when it hosts a second burial, positioned horizontally in the back of the room. The paintings intervene to personalize the environment: the archetypes are drawn from the classical repertoire based on the sex and age of the deceased.

During the excavation campaign undertaken in 1854 and completed in 1891 (Weege 1909), four 'chamber-type' burials were unearthed in Campania, at the foot of Mount Massico, in an area compressed between the Ager Falernus and the Fondo Vetta. These burials were classified by experts in "structural style" (Benassai 2001), so-called for the paratactic organization of the wall paintings that usually characterize the most prestigious chamber tombs (Sampaolo 2012).

The exclusive peculiarity of these burials, conceived as final resting places, are the architectural elements painted in full scale: frames of garlands are visible on the side walls; below, colored lines connect the echinus, and the columns set on a sort of base. Adjacent to the left side of the entrance is the main funeral bed (a tuff stone bench), the 'pillow' faces the back wall illuminated by the light that spreads from the entrance. The roof is generally double pitched, sometimes barrel-vaulted. Looking at the walls from the inside, the columns and trabeation painted in continuity between the walls evoke the design of a gallery that circumscribes the central space, an immediate memory of the atrium or, by symmetry, of the peristyle (*peristilium*) in which the hall (*tablinum*) opened, where the master of the house (*dominus*) used to entertain guests and thus establish social relationships. The deceased, ideally lying on the burial bed, participates in the representation. The perspective scheme obtained from the double projections in which to associate the data of the direct survey (Fig. 2) evokes its potential (Rossi 2019).

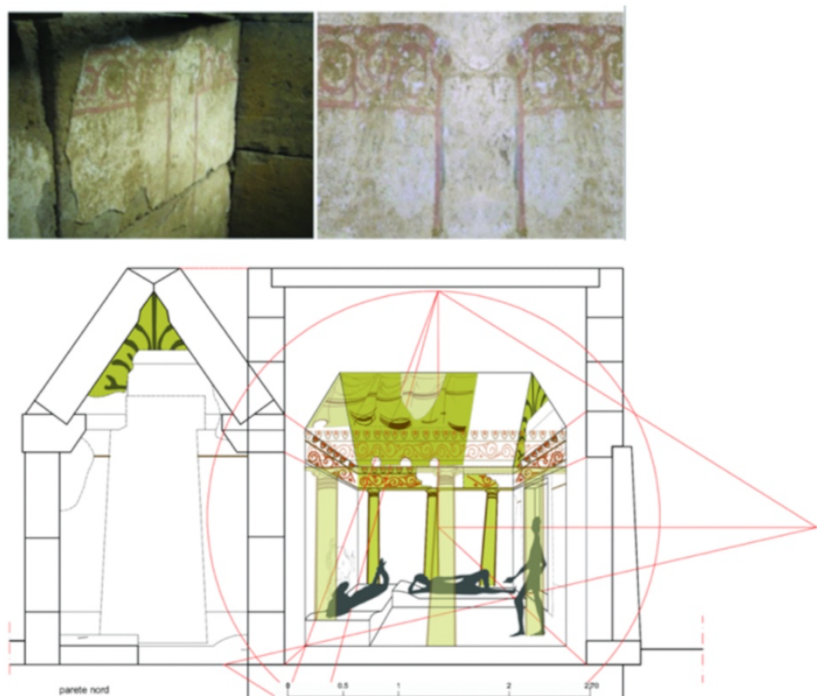


Figure 2. Double-sloping roof and two burial beds. Decorative motifs are: palmettes, Ionic columns, ovolo frieze and velarium on the slopes. Transverse and longitudinal section, in correspondence with the plan of the “chamber” restitution of the perspective scheme. Photographs and drawings 2014 by Adriana Rossi.

In the well-known tomb of the so-called Samnite Priest, ascribed to the 4th century and taken as the reference prototype, characters and objects are decorated between the painted columns on the walls and on the staircase itself. The exegesis present in literature sees in the austere character a hypothetical representation of the deceased, welcomed by the maids who accompany him to the sound of music towards Hades. The niches obtained by juxtaposing the blocks of tuff, are decorated by what art critics recognize as the ‘first’ representation of the Elysian Fields (De Caro 1998).

The article uses exegetic narratives (Minervini 1854) as intellectual levers, based on precise and accurate surveys, it digitally reconstructs the rooms, designing a space of collaboration in which the iconological interpretation of the represented space (Panofsky 1955)<sup>1</sup> traps the ‘current consumers of culture’. These visitors, induced to the knowledge of an unknown and far world to be understood, are invited to appreciate in the subjective and augmented fruition, the choices of the artists who, with the means available before Christ, were able to create a sort of ‘space capsule’ (of the type described by the director of Avatar) in which to correlate the irreconcilable worlds of the living and of the deceased.

<sup>1</sup> In the study republished as the first chapter in *Meaning in the Visual Arts, Papers in and on Art History*, Garden City, New York 1955 and 1957 (translated in Italy with the title “Il significato nelle arti visive,” Turin 1962), Panofsky seeks to establish an iconology as a science of the «supreme and essential content of the work of art», distinct from iconography, which must place itself in relation to it in the same position as ethnology in relation to ethnography.

Raising a framework of senses to make the past dialogue with current needs and expectations appears essential for the purposes of this work, aimed at attracting the interest of the community and with it the economic resources necessary to recover inherited assets, a question that has been discussed for a long time (Cerquetti 2015).

The stratagem to force the vicious cycle established between ignorance, disinterest and degradation, is offered this time by the possibility of enriching, in alignment with the international definition of "Heritage" (ICOMOS), the synesthetic perception of contemporary users. If in the past it was the suggestion of the funeral rite supported by the habitat-atmosphere designed for the purpose, today it is the applied technology that allows to merge in a concert of science, humanity and humanism, a synesthetic experience. Multimedia and multimodal fruition accompanies, with the "physicality" of a digital construct, the advanced visualization. There is no deception but integration in the mind of those who perceive two differently tangible worlds (Jenkins 2009): virtual and real participate constructively in knowledge by inspiring imaginations and actions, and the protagonists are the users (Brusaporci 2023). In this argumentative context, the article analyzes hypotheses and new paths to experiment theories and practices suitable for animating the narration (Rodriguez-Garcia et al. 2024, Bekele et al. 2018, Rossi et al. 2021). The encounter between what is physically real (or experienced as such) and what the mind conceptualizes, is guided by the flexibility of reason, but also by the contribution of memory. Leveraging digital surveys, and advanced visualization, a criterion and virtual restoration applications are identified to augment the physical experience with engaging digital content and involvement that bring history and culture to life in ways never seen before. The outcomes aim to enhance understanding of the past and bring remote rituals and myths closer to current sensibilities to ensure their preservation and accessibility for years to come. The key to the proposed narrative is used to transfer tangible and intangible cultural heritage into the present and the future, redesigning and recontextualizing it for new insights and different audiences.

For this purpose, the no-contact survey proves to be decisive, it preserves the integrity of the artifact and at the same time provides data and models to build significant and satisfying contexts. The cultural leap offered by dense and accurate cloud acquisition systems is conceptual before being practical. Compared to traditional techniques, the 3D survey, image- or range-based, is centered on the possibility of capturing thousands of points-coordinates with high information density. With the addition of textures, the photogrammetric technique returns, in true shape and size, the continuum of the surface. Digital processing, while remaining tied to the unchanged projective criteria, therefore to the correctness of the dimensions, allows to reconstruct three-dimensional spaces dual to the physical ones. Photo-modelling returns the graphic dynamics of the paintings through economic and flexibly agile technologies. The models derived through Structure from Motion (SfM), virtually restored in the missing or degraded parts, lend themselves to being deconstructed, reconfigured in creative perspectives or Extended Reality (XR) projects. Spherical panoramas prove to be advantageous for some immersive experiences. Projections on a (rectangular) plane of the surface of a sphere allows to re-map in a two-dimensional image and without any applied transformation, images acquired with a rotating head (scanning) equipped with a 180° fisheye lens and which provides a complete 360° sphere. The radius of the ideal volume corresponds to the actual distance of the main core of the photographic apparatus from the frame. The observer is projected into it and with the help of glasses or specific devices they can enjoy the full circle gigapixels mosaicked on the

spherical surface. In short, the processing based on the recording of images allows to “inhabit” what has been detected and recorded for “future reference”.

The products and services have been approached in phases. The main ones are as follows:

- complete and reliable documentation of what has been detected.
- digital restoration of the architecture and painted surfaces.
- reconstruction hypotheses of original environments and landscapes.
- programming of guided tours to read the connections that led to the iconographic interpretation.
- design of collaboration spaces suitable for interactive and inclusive use.
- organization for “future reference” of an information system in which to correlate sources and models.
- management of “objects” collected in “ontological” categories.
- online and remote management of digital information of different types and through devices (visors, glasses, tracking systems, etc.).
- cultural policies to support the tourism industry, recreational entertainment and educational projects.

The innovation of this work lies in the reading and interpretation of ancient paintings as precursors of the augmented environment, exploiting the possibilities provided using modern technologies, from three-dimensional survey to the use of augmented environments.

## 2. OBJECTIVES AND METHODS: ACTION OF *RE-LAEVO*

The first essential approach to understanding an artifact is the dimensional survey of its physical properties, a field of application of descriptive geometry, which is not limited to the definition of plans-elevations or three-dimensional views of the volumes studied. Far beyond the ‘properties’ quantifiable with appropriate tools and methods, there are in fact the ‘attributes’ that characterize the quality of the places and the designed habitats. These are identifying characteristics, less evident than the properties, but for this reason more significant and essential. The ‘attributes’ must be revealed or brought from what initially appears ‘smooth’ and indistinct (*laevo*) to what instead imposes itself to be relevant in function of the objectives (*re-laevo*).

In the case proposed in this paper, it is the wall paintings that differentiate the “rooms,” standardized in the proportionally variable properties in well-defined intervals. Although drawing on a consolidated repertoire (Dentzer 1968), the painted elements show identifying relationships of the attributes. Drawings of *echinuses*, columns and frames are recurrent in contemporary chamber tombs. These elements are generally used to separate narrative scenes (Pontrandolfo and Rouveret 1992). The Pompeiians will later use the same ones to simulate the depth of spaces: sophisticated trompe l’oeil demonstrate their intuitive ability. In both methods, it is noted that the observer is positioned outside the frame of the representation. A condition that scientific foundations guarantee

by virtue of codified rules (Migliari 1982). In the chambers studied and defined by experts as having a “structural style,” there is no hint of the three-dimensionality of the spaces. The volutes of the capitals are frontal, as are the brightly colored profiles of the columns placed to support the frame paratactically repeated on the four internal walls. A fact generally stigmatized as an “immature” drawing, typical of those who, like children, do not yet know how to portray objects as they see them (Piaget 1970). With the scientific awareness that has matured (Panofsky 1927), another interpretation emerges, opening a field of interest for our purposes.

Inspired by current culture, the hypothesis is suggested, perhaps tendentious, that the artists of the 4th-3rd century BC were far from the desire-will to “petrify” the observer outside the painting. On the other hand, the Samnite artists manifest the will to anticipate and resolve, with the means at their disposal, what computer science allows today by accompanying the physical experience with digital content (mixed and/or extended reality).

Whoever lives in the room enjoys the life of the house, of the family, of the community that flows beyond the porticoes. Nelson Goodman (1906-1998) emphasized that the recognition of the physicality of what is presented in perspective is linked to the mental experience of whoever reads and interprets the representation (Goodman 1968, Docci and De Rubertis 1986). The opposing theories of Erwin Panofsky (1892-1968) and Decio Gioseffi (1919-2007) have been overcome (Gioseffi 1986) in the operationalist perspective of Percy Williams Bridgman (1882-1961) and Hugo Dingler (1881-1954). Moreover, even recently the evidence has been discussed that the perspective constructed with the rules of geometry is not the only one possible (Migliari 2005). In this argumentative context, the potential of cloud computing is used to “inhabit” the “enlarged” rooms of the portico. Two paths were chosen to acquire the necessary data:

1. the Structure for Motion (SfM) technique to obtain the restitution of the finds and create the basis for a subsequent virtual restoration of the internal environments of the chamber tombs.
2. panoramic shots, from which to derive the navigability of an ideal but functional space for the remote approach of the mosaic gigapixels.

## 2.1 Photo modelling of structural style rooms

The construction or reconstruction of the 3D model starting from data acquired with a camera (APS-C Canon 60D) equipped with an 18 mm lens is preliminary. Given the light conditions of the day, the ISO was set to 640 and the aperture to 8. The images were acquired starting from the outside and then entering the interior of the chambers and thus covering the entire visible surface. Regarding the shooting mode, it was necessary to guarantee a minimum overlap of about 70%. For the reconstruction of the three-dimensional scenes, an “image-based 3D modelling” algorithm was tested. The estimation of the geometric parameters of the optical system was carried out directly in a digital environment (it would have been possible to also import the calibration file exported with commercial software such as PhotoModeler). The derived models composed of decimated and cleaned 3D point clouds were scaled using targets and direct measurements and then oriented according to the axes. The 2D textures were spread in true shape and size on the derived orthophotos (Fig. 3).

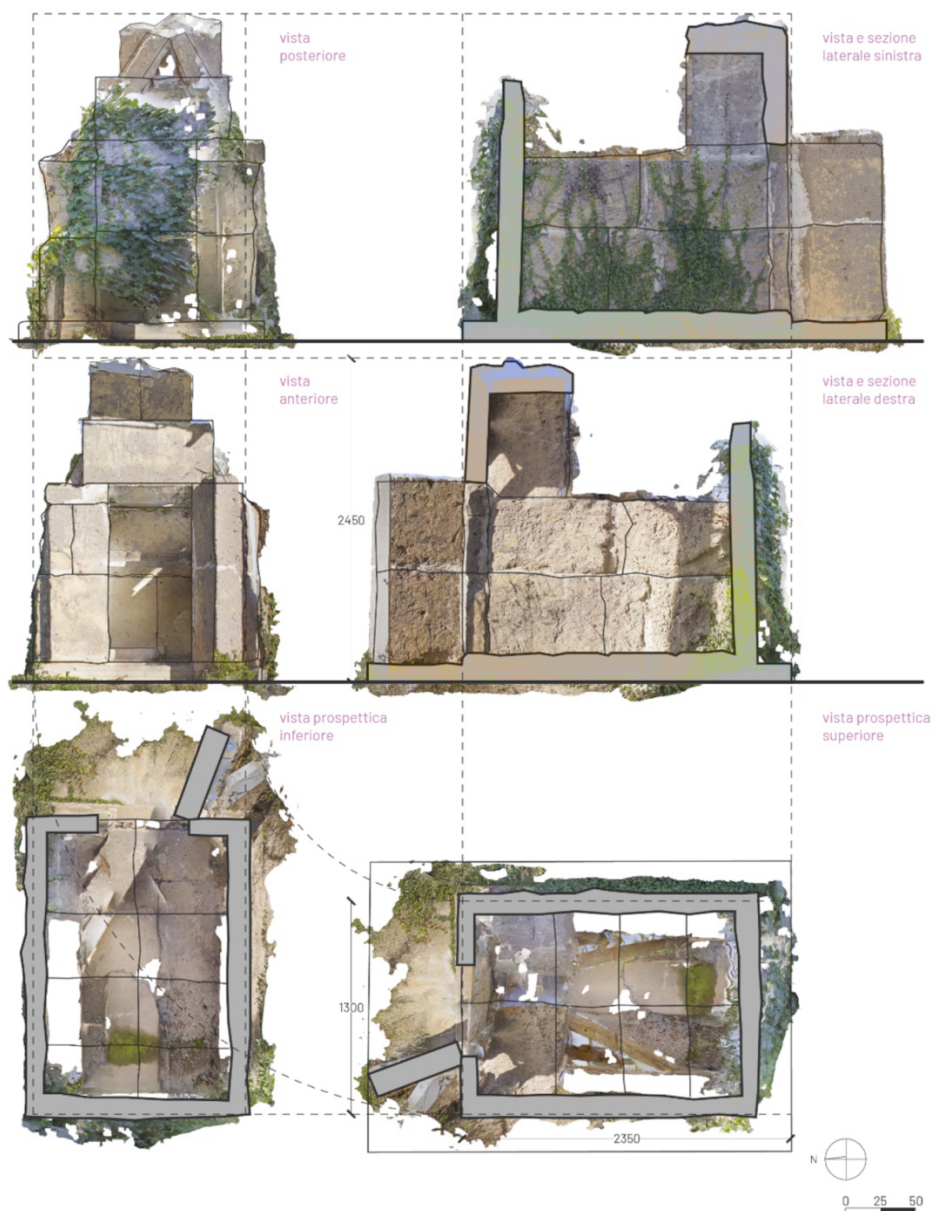


Figure 3. Operation of the reality-based model, orthophotos of the archaeological finds. TAR course A.Y. 20-21 (prof. Adriana Rossi, students A. Caianiello, A. Clemente, A. Applauso. Re-elaborations by Tutor Sara Gonizzi Barsanti).

## 2.2 Panoramic shots of the interior

Complementary to the 3D reconstructions of the models, as anticipated, are the 360° shots (Carbone 2017 and 2018, Rossi et al. 2016). The projective criteria that link the recognition of homologous points

between overlapping images are the same. The calculation processes aimed at obtaining the stitching of digital images are completely different. In the field, it is necessary to use a tripod positioned in a level and a panoramic head. Their joint use limits parallax errors, the main cause of inaccuracies in the subsequent automatic assembly process (Fig. 4). Depending on the characteristics of the place, the timing of the survey and the final resolution required, the type of optics is chosen: the greater the focal length, the higher the number of shots to be taken. The rotation interval around the nodal point, the main of the two with which a photographic device is equipped, in a reflex camera usually placed near the lens, derives from the width of the field. To obtain good results, it is necessary to properly evaluate the percentage of overlap between adjacent shots. The rotation interval of the head must ensure an overlap never less than 20-25%; higher threshold values do not lead to significant improvements while lower threshold values, although permitted by some software, do not guarantee the necessary precision and the desired chromatic uniformity of the panorama. To this end, it is necessary to plan the shooting phases. A measure that will reduce the operations in the field and with them the time required to obtain a high-quality mosaic. It remains necessary to verify the adequate lighting given the natural light and therefore the large differences in exposure between the east and the west, a careful choice of the photographic camera settings is necessary to balance the colors and make the HDR (High Dynamic Range) exposure uniform. In this case study, mediating resolution and convenience, the set detail was returned using two different lenses: a focal length of 8 mm f/22, with ISO 200, to generate internal and external spherical panoramas. By setting a rotation of 30°, twelve shots were sufficient to cover, with the necessary overlaps, a full angle along the horizontal trajectory and a flat angle along the vertical one (2 shots for sky and earth at plus and minus 90°); and a focal length of 18 mm to acquire a set of images to be processed for the photo modelling of the chamber tombs, whose surface is always less than 6 m<sup>2</sup> (on average 2x3 m).

Once the field operations were completed, the recorded data were processed with stitching software. Among the various opportunities offered, we chose to work with PTgui (Pano Tools graphical user interface), a non-open-source program but capable of performing the mathematical operations necessary to remove optical distortion and make it possible to join multiple frames. The individual frames are scaled, oriented and positioned in space, then merged and made uniform in color and brightness, to be adapted to the ideal surface of the sphere. When the series of photographs covers a 360° view on the horizontal axis and 180° on the vertical one, the system virtually projects the observer to the center of a sphere whose radii are equal to the distance of the respective shooting planes. The mosaic automatically positioned on the internal surface will allow the observer to see the panoramas surrounding the photographer/operator through the main nodal point in the photographic optics. The lines, in the reality vertical and horizontal, are transformed into what we could define as isometric lines subjected to "blender", to generate a balanced mosaic in the gradual transition of the geometric properties, color temperature and brightness. At the end of these operations, the output product will appear as a strip with deformed sections that can be saved in various formats and sizes.



Figure 4. Virtual tour a) Position of the tombs inside the archaeological area b) Interior of chamber tombs, spherical panorama or equirectangular projection of the state of the sites (from LM12 thesis, E. Carbone a.y. 16-17, supervisor A. Rossi, assistant supervisor F. Fiorillo; acquisition and processing by the author).

### 2.3 Modelling virtual spaces

As a guide to the construction of collaboration spaces, the documentation of the oldest chamber tomb excavated by Fritz Weege (1909: 111-112). Of this, only the casts of the watercolor paintings for the Archaeological Museum of Naples remain, transferred, in the recent past, to the Archaeological Museum of Ancient Capua (Santa Maria Capua Vetere) where a 1:1 scale reconstruction of the chamber tomb now lost forever is set up. On a small scale, the reliefs commented by Guido Minervini (1854: 181-184) have been handed down to us. The graphic and literary description by Minervini, taken up by Stefano De Caro and other scholars, proves to be valuable for iconographic interpretation. Illusorily “expanded” by the frescoed portico, the space encourages imagination in the most representative place of the house, where the living weave relationships, plan and schedule actions.

The deposition of the deceased therefore crystallizes a moment of the ritual shared by the community to reassure the living and ensure public order. In step with the times, the transcription of the chamber tomb into a sort of machine into which to enter to “remedy” the experience by moving in time and space (De Luca and Russo 2021).

The 3D reconstruction of the structure in a CAD environment allowed to obtain its complete geometry, avoiding loss of details. This passage was then fundamental for the AR/VR application. The derived models composed of 3D point clouds, decimated and cleaned, were scaled using targets and direct measurements and then oriented according to the axes to create orthophotos of the various views from which to draw the technical views with the textures of the 2D paintings. The virtual restoration was divided into three steps:

1. Reconstruction of the missing volumes to complete the architectural configuration of the rooms.
2. Reconstruction of the missing textures.
3. Restoration of interior paintings.

Processing on an accurate and metric model allows to obtain a result close to reality. Furthermore, having the texture of the materials with photogrammetry, it is possible to reproduce the same also on the parts virtually added. The third part of the virtual restoration process of the spaces shows how the use of photogrammetry guides the reading, orienting the interpretation of the reconstructed forms where they are missing. The expanded volumes were reconstructed in a vector environment (Rhinoceros). Processing on an accurate and metric model allows for a result close to reality that can be flexibly used for the virtual restoration of the missing parts. The virtual restoration process is functional for the modelling (Rhinoceros) of volumes dedicated to the fruition project dedicated to the individual purposes (Fig. 5).

When the photogrammetric acquisition is carried out with pronounced shadows or strong chiaroscuro, determined by the presence of direct sunlight on the surveyed object, it is possible to act in the post-processing phase for the removal of shadows from the textures of the digital model (Apollonio et al. 2023). This makes it possible to greatly improve the fruition of the model in the virtual environment, avoiding the “double shadow effect”, those appearing in the texture of the apparent color, which add up to those generated by the rendering in the virtual environment, and which can generate phenomena of unpleasant enjoyment by the user. For the case study of the tomb, the texture improvement was performed semi-automatically by detecting the light and shadow areas (shadow and light color with interactive brush tool) with the Agisoft Texture De-Lighter utility software (version 2.1.1), which allows to remove the cast shadows from the textured model (Fig. 6a). Then the model has been uploaded to Sketchfab platform, an on-line 3D viewer for visualization and interaction with AR/VR applications, allowing inspection of models, both reality-based and the virtually restored one (Fig. 6b).

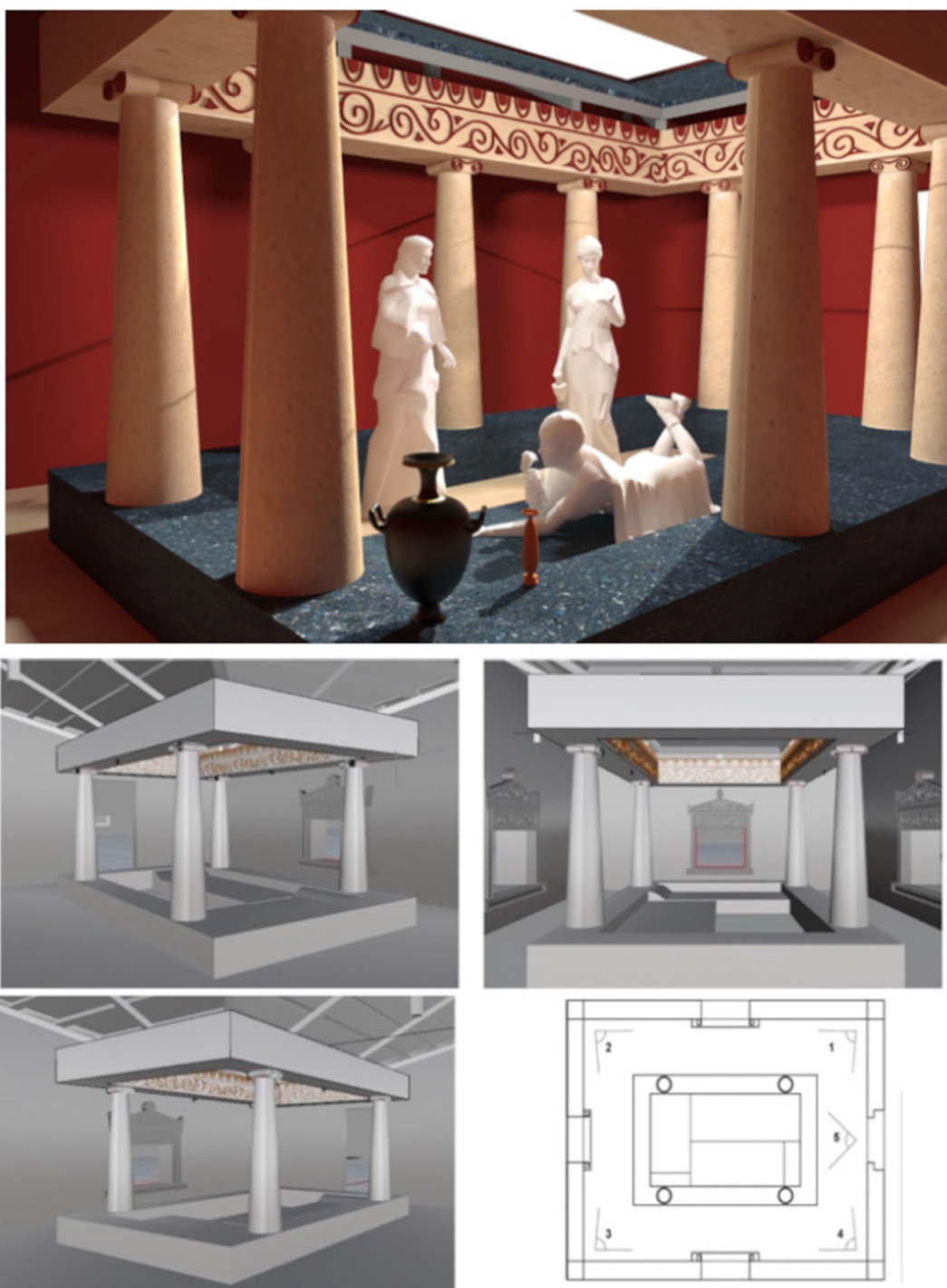


Figure 5. Operation of the reality-based model, Modelling of the "extended" portico space in a vector environment using Rhinoceros software (TAR course A.Y. 15-16 prof A Rossi, students A. Basilicata, D. Caccavale).

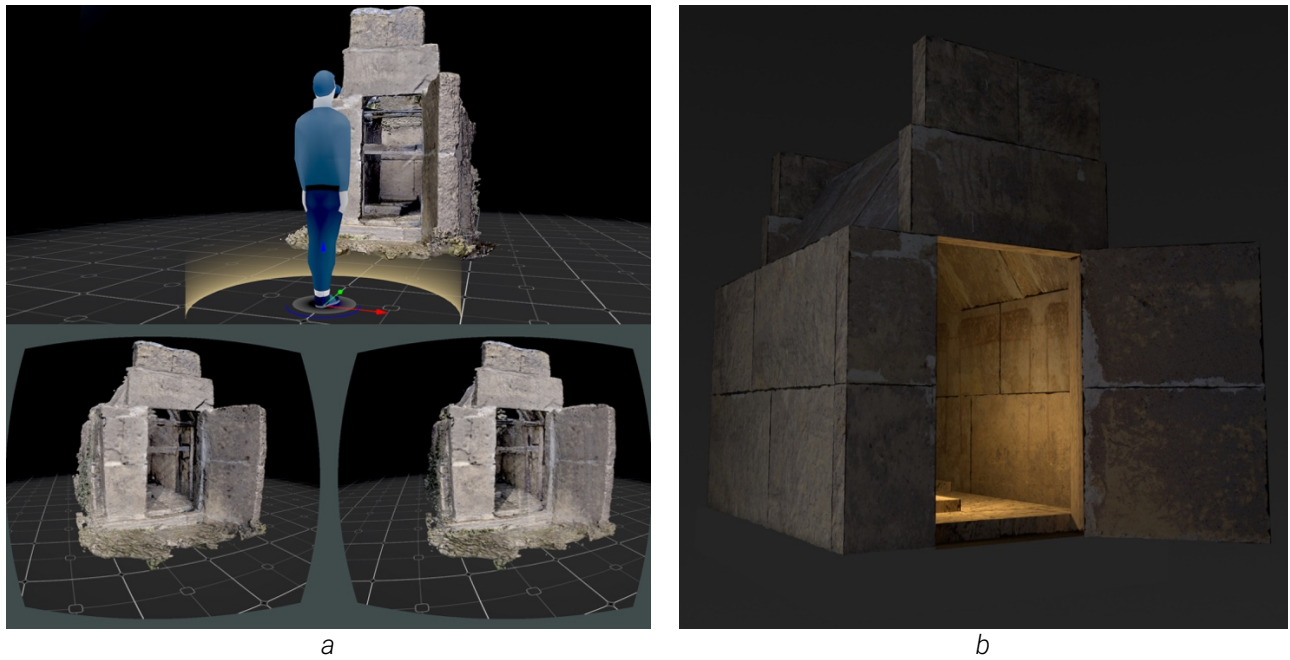


Figure 6. a) Reality-based model of a tomb in the Schetchfab virtual environment setting for VR visualisation; b) Reconstruction model of the tomb with restoration of interior paintings and simulation of lighting with appropriate color temperature. Elaborations by Silvia Bertacchi.



Figure 7. Equirectangular view of the interior of the virtually restored tomb. Elaborations by Silvia Bertacchi.

The objects of the funeral trousseau, the brick beds and the gabled windows are tangible; the living enter the chamber to deposit the deceased or to visit on other ritual occasions, we like to fantasize, to

animate the story of an encounter between two irreconcilable worlds except in the mind of the user, here old and new antinomies disintegrate: survey/project, material/immaterial, analogue/digital real/virtual (Figs. 7-8).

The emotional state of the visitors, accelerated by the atmosphere of the habitat in dim light, alters the perception well “beyond” the existing. The afterlife, feared and respected by the Samnite people who believed that existence was linked to divine will, finds in the imagination of the user the meeting point of tradition and innovation, a flywheel to connect in personal experience meaning/signifier, sky/earth, concrete/abstract, knowledge and conceptualization, artistic aspirations and technological potential, culture-education-economy-politics.

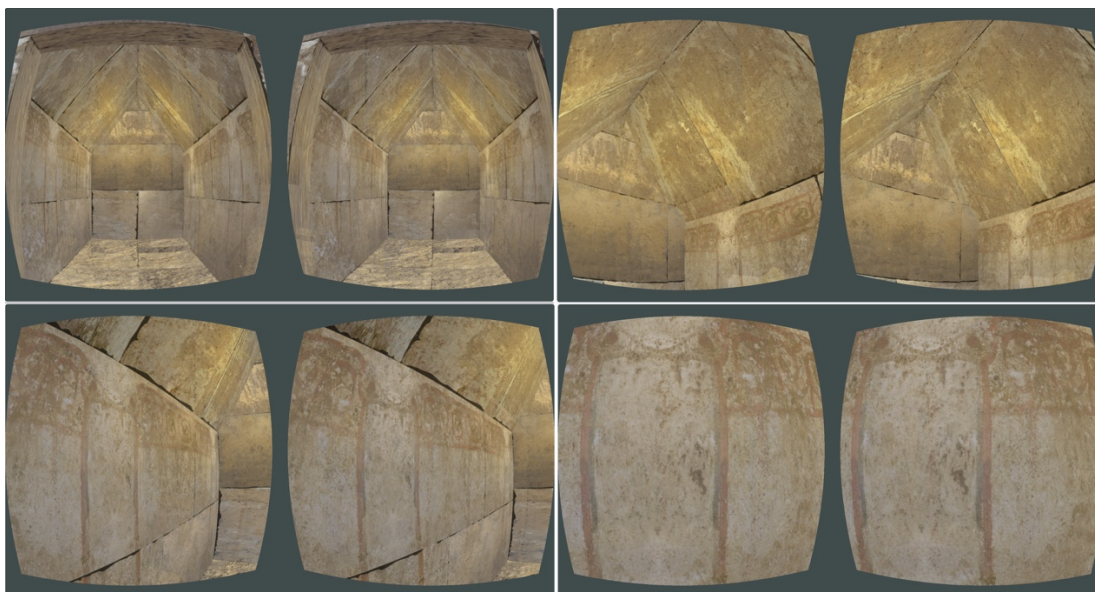


Figure 8. VR views of the interior of the tomb, from the general space to the details of the wall paintings (capital and frieze). Elaborations by Silvia Bertacchi.

### 3. CONCLUSIONS

In the interpretation that the artists of the 4th and 3rd centuries BC provide with the means at their disposal, they increase the sensorial perception of the participants in the funeral rite by using the structural style chamber. By showing that they isolate architectural elements, the Samnite painters represent a paradigmatic model for Western art. Overcoming the limits of physical perception has therefore not been an exclusive objective of the recent computer acquisition, but an ambitious artistic goal (Rossi 2016). Today's challenge is to overturn the unique relationship between cultural heritage and visitor offering new cognitive processes based mainly on flexible active experience in alignment with the international definition of “Heritage” (UNESCO). Challenges and advances enabled by the original and creative, heuristic use of the state of the art that far beyond IT research connotes the identity of our IT area in the preservation and presentation of cultural heritage in the digital and hybrid sphere. The use of state-of-the-art technology in digitization and presentation of Cultural

Heritage has enabled the collaborative effort for more inclusive and comprehensive heritage preservation. Thanks to the results obtained from the photogrammetric processing it was possible to graphically and virtually regain the ancient environment to study the perception of space when the paintings were all visible and the tombs were complete. The renderings of the 3D reconstruction on the reality-based model with the addition of the reconstructed textures of the internal walls, with not only the completion of the pictorial decoration but also the original colors, allowed the layout of the depicted structures to be highlighted correctly and accurately. In this way it was also easier to identify and understand the perception that the visitor of the 4th century BC must have had when he immersed in the internal environment of the tomb. The use of AR technologies to increase and reinforce the information provided by museum's expositions is well defined and built in different ways, related to the possibilities of space, control and funding in museums. These technologies are a powerful tool in the educative function of CH, allowing to describe and explain in an easy and engaging way concepts sometimes complicated. The combination of information, images and 3D models, interactively manipulated by the user permits the visitor to explore an ancient world without really moving and to actively participate in the virtual environment. This immersive environment, achieved with the perception of depth thanks to the paintings and the illumination of the interior of the chambers, can provide the idea of a 3D environment that goes beyond the physical dimensions. There is the intention, in the future, to continue to implement this AR environment with also texts and information, archival images, etc., and provide the museum with an application to permit the visitors to experiment the feelings of entering the world of the deceased.

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