Advanced Digitization Methods for the 3D Visualization and Interpretation of Cultural Heritage: The Sphinx of the Naxians at Delphi

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Abstract. Creating a 3D model for a Cultural Heritage (CH) asset is a rather time-consuming and complicated process. Latest-generation sensors in the field of cultural heritage and new photogrammetry algorithms have simplified the 3D modelling process reducing the cost of 3D scanning. In this work, the 3D model of the Sphinx of the Naxians, located in the Archeological Museum of Delphi, Greece, was created using UaV Photogrammetry. A Delphi Augmented Reality (AR) application was developed in order to allow users to virtually explore and learn about the Delphi's monuments in a way that is interactive and engaging, while walking around the archeological site viewing 3D models superimposed on real-world surroundings via a mobile phone. The AR visualization employs the 3D model of the Sphinx introducing the concept of archeological uncertainty regarding the initial orientation of the monument.

Keywords: Sphinx of the Naxians, Delphi, 3D Modeling, AR, Archaeological Uncertainty

1 Introduction

3D modeling for Cultural Heritage (CH) is widely used in archaeological museums, often in interactive exhibits. 3D models for CH can be employed for documentation, protection, reconstruction, conservation, dissemination and promotion of CH exhibits and monuments [1,2]. Latest generation sensors in the field of cultural heritage and new photogrammetry algorithms have simplified the 3D modelling process and reduced the cost of 3D scanning [3]. User requirements in relation to the documentation

and exploitation of the 3D model as well as environmental conditions should be considered, in order to define the optimal 3D scanning strategy for the creation of the final 3D model [4].

An archaeologist's level of confidence in an interpretation derived from archaeological data is defined as uncertainty [5]. Multiple levels of uncertainty, related to how an archaeological structure may have existed in the past, can be visualized through Augmented Reality (AR) bringing the uncertainty element of the archaeological expert into the visualization. Augmented Reality is a technology that allows users to superimpose digital content onto the real world, creating a layer of information that enhances and expands upon the physical world. AR has the potential to revolutionize the way we interact with and experience the world around us, by providing a new level of digital augmentation of our surroundings and engagement with digital experiences. In a single 3D archaeological reconstruction, we can now differentiate through varying visualization the reconstructed parts for which there is strong evidence that they existed as visualized, as opposed to those for which there is less evidence and knowledge in relation to their former form [6].

In this work, the 3D model of the Sphinx of the Naxians was created using UaV Photogrammetry. We aim to employ this model to visualize the different options regarding the initial orientation of the monument, by providing varied interpretations based in historical evidence viewed by the visitor on-site.

We also put forward the Delphi AR application, through which we can visualize digitized monuments superimposed onto real-world surroundings via a mobile phone (Mobile Augmented Reality – MAR). Such monuments are often deployed in museums, sometimes being the integral part of interactive exhibits in the museum environment. The proposed AR visualization, for the first time, introduces the concept of archeological uncertainty to the user, while navigating the real-world surroundings of a historical site. Delphi AR is set up by a host or a museum curator and used by a visitor. The host of the AR application can walk through the historical site and place anchors at the potential locations of various monuments in the past, ensuring their correct placement, size and orientation on-site. A description of the monuments can also be provided, explaining their history and significance. Visitors of the Delphi archeological site can then use the AR application while walking around the site, selecting 3d monuments' reconstruction and viewing these in 3D through their phone camera simply by pointing their camera at the desired location. The AR application utilizes markerless tracking, e.g., it does not require any special markers or targets to function, allowing users to experience the 3D digitized monument from any angle, as superimposed on the real-world.

2 Description of the monument

One of the most renowned monuments of Delphi, dominating Apollo's sanctuary, is the colossal marble statue of a Sphinx placed on the top of a 9.9-meter-high Ionic column. It was discovered in 1861 by the French archaeologist Paul Foucart at a two meters distance from the Temple of Apollo, along with the initial carved rock used as

the surface for its base. The statue stood on a large marble base near the terrace of the temple of Apollo and it was erected around 560 BC, as a votive offering of the island of Naxos. It constitutes the earliest Ionic architectural element found in the sanctuary of Delphi and its colossal dimensions and commanding position express the political and artistic supremacy of Naxos during the Archaic period [7]. The Sphinx is a hybrid creature with the head of a woman, the body of a lion and its majestic wings form an eastern influence assimilated by ancient Greek art forming a particularly popular motif in Archaic Greece [8]. The Sphinx is associated with the Delphic sanctuary on account of the story of king Oedipus, who encountered the creature upon his return from the oracle in his effort to avoid his god-ordained destiny. His tragic end is associated with the central ordain of the Delphic theology, “Know thyself”, that commands that a person must lead a virtuous life irrespective of the knowledge of his predetermined by the Gods fate. On the political aspect the votive offering as testified by a decree inscription on the base of the statue da-ting in 328-327 BC bestowed the Naxians with the right to Promanteia, that is priority to the Delphic oracle [9].

3 The 3D modelling process

The "Sphinx of Naxians" has a height of 2.22 meters and it is placed in the Archeological Museum of Delphi. 3D modelling with laser or structured-light 3D scanners was not applicable due to museum restrictions for placing a ladder or a scaffold near the statue. For this reason, 3D scanning with UaV photogrammetry was selected. This technique uses multiple overlapping photographs and advanced algorithms for producing an accurate 3D model of the CH asset [10,11].

A Mavic Air 2s drone was selected due to its small size and maneuverability. This drone uses a 1-inch camera sensor and has the ability to capture 4K video. Five different flights were conducted in a low speed around and on top the statue, capturing video with 4K resolution at 30fps (**Fig. 1**). Using this video and with a ratio of 1 frame per second, 1812 oblique and top-down photographs were extracted (**Fig. 2**). The Reality Capture software was then utilised in order to produce the final 3D model of the Sphinx of Naxians, consisting of 1.2M triangles and 587K vertices (**Fig. 3**). The scketcfab platform was used for publishing on-line the 3D model (https://skfb.ly/oxrzB). The 3D model of the Sphinx was 3D printed and painted and now it is exhibited in the exhibition hall reserved for the project (hall XIV of the Archaeological Museum of Delphi) (**Fig. 4**).

Fig. 1. The use of UaV for 4K video capture in the Museum

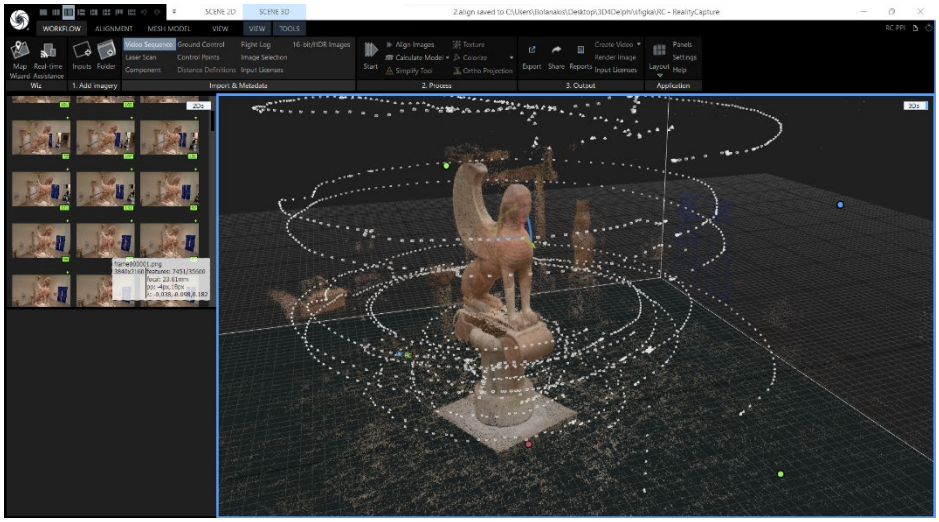

Fig. 2. Extracted photographs for photogrammetry.

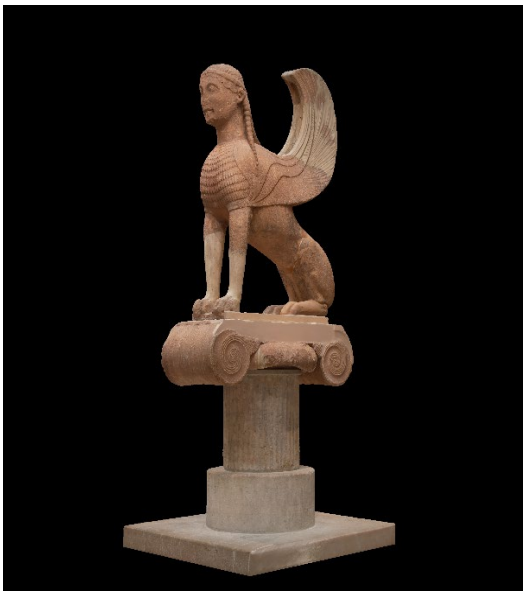

Fig. 3. The 3D model of the Sphinx

Fig. 4. 3D print of the Sphinx of the Naxians exhibited in the exhibition hall reserved for the project (hall XIV of the Archaeological Museum of Delphi)

4 Case Study Analysis

Although the position of the Naxian votive is certain, the orientation of the statue of the Sphinx remains unknown. Literary sources and the archaeological data indicate the following two most likely versions:

a) The sphinx was oriented towards the temple of Apollo (NW). Since its discovery during la the Great excavation at the end of the 19th century and according to the literary sources, the Sphinx was associated with Dionysos, whose tomb was in the main part (Sekos) of the temple of Apollo and for this reason the Sphinx was facing the temple. In this case, the mythical creature formed a chthonic divinity with ferocious strength, which would assume the role of the guardian of the tomb [12]. Known from Aegean art of the Bronze Age, as well as Egypt and the Near East, this fabulous creature, relating to the death demons Keres, assumes a funerary and votive form and function. It was often present in funerary steles or formed a central decorative motif on sarcophagi from the later Mycenaean period, or as votive statues, mounted on Ionic columns, flanking the entrances to temples in an apotropaic sense, during the archaic period [13]. The first archaeologist to have supported this orientation associating the Sphinx with early funerary monuments in the Cyclades was Bernard Holtzmann [14].

b) The sphinx was oriented towards the Sacred Way (NE).

However, the French archaeologist Pierre Amandry, who thoroughly examined the statue in the early 1950s, claimed that the Sphinx of Naxians was oriented NE, observing a mild deterioration at the left part of the statue, probably caused by its constant exposure to rain and wind, while the right part suffered from more severe weather conditions (**Fig. 5**). However, in the axonometric plan representing the votive he sets it in the E-SE axis, as this direction is orientated in alignment with the Sacred Way. Furthermore, he describes this orientation as plausible and expressed the need for a more detailed observation on the surface of the statue. Moreover, the actual base of the votive still preserved in situ presents a slight deviation from the axis of the polygonal wall of the Temple of Apollo diverging towards the Sacred Way.

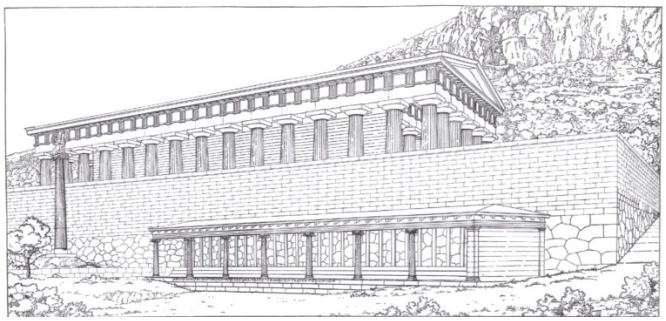

Fig. 5. The Sphinx of Naxians in front of the Apollo Temple diverging towards the Sacred Way [7]

The Sphinx's face presents a different pattern of damages (dotted) on the right side of its face and on the hair, while the surface is clearly better preserved on the left part [**Fig. 6**]. Respectively, the wings and the rear part of the statue in general are more corroded on the right, than on the left. Furthermore, the front left part of the capital's spiral seemed to have a mild homogeneous deterioration, while the front right has been severely damaged. This conclusion could be verified by a study of the damage caused to marble by the winter rains, reinforced by the SW wind, and the summer storms precipitated into tempest by the North wind [9]. This theory also explains the observation of the archeologist Pierre de la Coste Messelière who found a slight asymmetry between the two sides of the face of the Sphinx. Recently, also Jean-Luc Martinez in his review of the Statue supports the aspect of damage due to climatic changes [14].

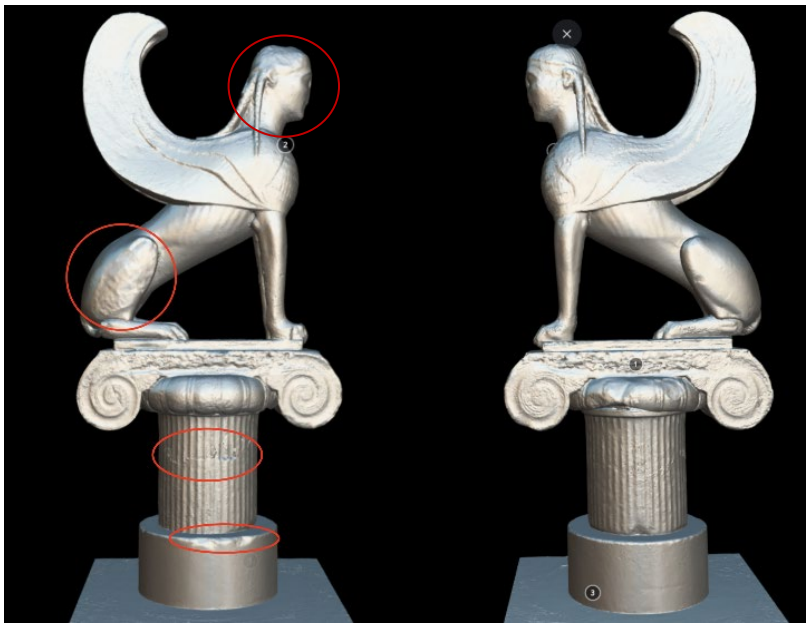

Fig. 6. Right and left part (respectively) comparison

5 Augmented Reality Visualization

The main use case for the Delphi AR application is to allow users to virtually explore and learn about the Delphi's monuments in a way that is interactive and engaging. Most importantly, the AR visualization aims to introduce the concept of archeological uncertainty, in relation to monuments and their past form, often neglected in 3D reconstructions which often communicate only one version of the past. The MAR Delphi application can be used by visitors or students as an educational tool, or simply by those interested in experiencing the monument in a new and innovative way while walking around the archeological site. It allows them to see the monuments in their

true size and scale on-site, superimposed onto the real-world and to learn more about their history, cultural significance based on varied interpretations of their past as well as position and form. It also allows for a more personalized and flexible experience, as guests can select which monuments they would like to view and explore at their own pace [**Fig. 7**].

Historical sites and monuments often have incomplete or conflicting information about monuments' original appearance and layout. Therefore, the notion of archeological uncertainty is introduced, for the first time, embedded in the AR visualization. Regarding the Sphinx monument, the user can select and preview in real-time the different possible orientations of the monument and thus, better understand and consider varied historical hypotheses or theories. Overall, the markerless visualization of the monuments is a prime example of the potential of AR to enrich and enhance our understanding and appreciation of the world around us. By providing a new level of immersion and engagement, AR has the power to change the way we see and experience the world, and to enhance our appreciation of the world's history and cultural heritage.

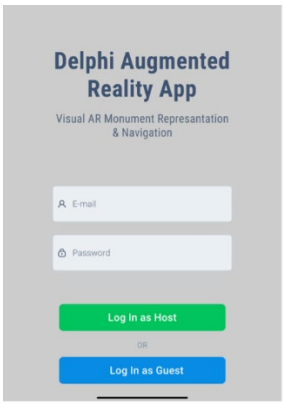

Fig. 7. Login Initial Screen (Host/Guest)

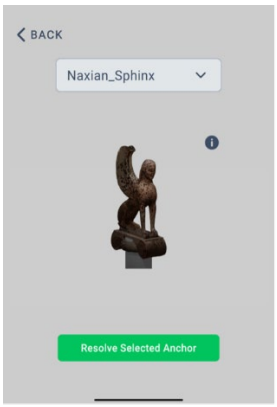

Fig. 8. Guest Model Selection to view onsite

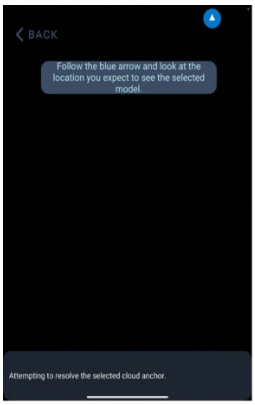

Fig. 9. Guest's AR View (Camera disabled)

The Delphi MAR application is based around cloud anchors and a shared real-time database that can be accessed by the users. Cloud Anchors are virtual points that enable us to map real world locations and have them identified by the application, in order to superimpose the monuments on them. A real-time database holds the positional information in relation to the placement of the monument, as well as any relevant info that will be displayed to the user. The host of the guided tour has to, beforehand, scan the surrounding environment of the Sphinx using the device's built-in camera and correctly place a cloud anchor point that will then be used as a reference to spawn the Sphynx's 3D model.

After successfully mapping the environment and defining the anchor point, the host is asked to accurately rotate as well as scale the Sphynx's 3D model so that it can be seamlessly superimposed onto the Delphi Archeological site and confirm the changes.

This information is then automatically synched onto the database and can be accessed by the visitors' companion app (**Fig. 8**, **9**). During the placement of monument, geo-location coordinates are also saved during this process and will then be used to guide the visitors around the archeological site and assist them in accurately pointing their device towards the desired location to view the AR experience. They will have the chance to view the Sphynx's possible orientations, thus, view varied scenarios regarding the monument's archeological uncertainty.

Finally, a sandbox-like mode has also been implemented, which enables the visitor to freely move as well as scale the Sphynx's model in real-time. [**Fig. 10**].Through this, visitors can experiment with it, bringing it closer in view on the mobile phone's screen, so as to examine geometric details such as materials used, or a specific aspect of the monument and overall have an engaging and informative experience.

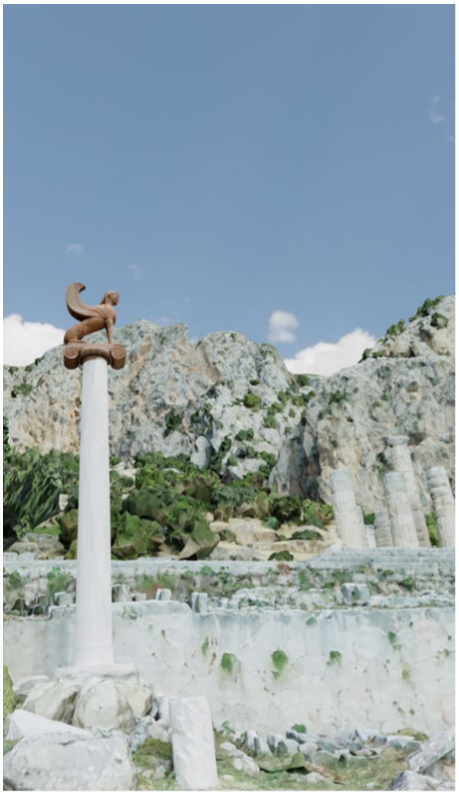

Fig. 10. Visualization of the Sphynx's AR View.

6 Conclusions

Since the great excavation of Delphi, in the late 19th century, the emblematic monuments that were brought to light never ceased to be in the centre of archaeological

research creating an ongoing debate of great interest for the scientific community. Many of them still present today several archaeological uncertainties, regarding their history, the reconstruction of their initial form, the nature of their function and the final process of deconstruction or destruction, resulting as such into different reconstruction approaches depending on the historical period assessed. The 3D4Delphi project aims at the development of alternative reconstructions of a specific chronological phase of a monument, based on the available scientific evidence, providing varied 3D reconstruction models within the frame of archaeological uncertainty, and finally assessing the degree of certainty of each alternative case by modelling uncertainty with Bayesian logic. In the case of the Sphynx, new evidence derived from the 3D scanning of the sculpture revealed its potential original orientation but also additional hypotheses, opening the discussion related to the contextual meaning of the famous Naxian votive at a new level of investigation through an interdisciplinary approach. In this sense, assessment of the archaeological data is incorporated in the scientific process integrating advanced 3D visualization as well as mathematical modelling of uncertainty with state of the art scanning technology.

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