Combining 3D Surveying with Archaeological Uncertainty: The Metopes of the Athenian Treasury at Delphi

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***Abstract*—At the archaeological site of Delphi, significant monuments inherently communicate uncertainty regarding the reconstruction of their initial form. An innovative, preliminary, theoretical formulation of a 3D visualization system is proposed, combining 3D surveying based on terrestrial laser scanning and archaeological uncertainty which, unlike past work, will offer multiple hypotheses to be visualized. The system, when implemented, will take as input the archaeologists' assessment regarding various evidence and offers probabilistic reasoning in relation to the monuments' past form, which is finally reconstructed and visualized in 3D. The positioning of the metopes of the Athenian Treasury at Delphi is presented as a case study.**

***Index Terms*—visualization, uncertainty, 3D reconstructions, cultural heritage, Delphi**

I. Introduction

The significance of visualizing the uncertainty in a body of data has been acknowledged in different fields such as visualizing uncertainty in flow data [1], in astrophysical data [2], in protein data [3] as well as in seismic data processing [4]. A recent systematic evaluation of uncertainty visualization techniques puts forward the evaluation practice concerning the interpretation and semantics of uncertainty and confidence reporting [5], [6]. Modeling as well as visualizing uncertainty in data can substantially improve our understanding and interpretation and facilitate better decision making.

By uncertainty in this case, we define an archaeology expert's level of trust in an interpretation deriving from material, literary and comparative evidence. Archaeologists piece together information based on the excavation finds forming a probable version of the past. This version becomes more certain as the evidence increases from various other sources. Uncertainty, therefore, should be incorporated in the visualization process when attempting to visually reconstruct an ancient ruin. During the last decade, the heritage community has witnessed an increase in 3D photorealistic reconstructions of archaeological structures focused more on pleasing visuals, overriding the question of scientific accuracy. Experts have urged caution in the abundant use of 3D reconstructions because of the possibility of misleading the public [7]. The archaeological community has stressed the need to acknowledge other possible hypotheses as well as the difference between what has been found and how it is interpreted.

The aim of this paper is to bring attention to the significance of visualizing the uncertainty over 3D reconstructions of cultural heritage monuments and to analyze how this would be possible in the presentation of 3D cultural reconstructions of ancient buildings at the archaeological site of Delphi, Greece. The archaeologists interpret a site based on a limited amount of material remains and use literaty sources and comparative evidence from other sites, literary sources, as well as specific hypotheses in order to create a reconstruction. Different levels of certainty on some areas of the reconstruction may appear. If we are able to model such uncertainties and incorporate them with the visualization of a 3D reconstruction, we would promote learning about archaeological hypotheses, comparing uncertainties across different models and highlighting cases where further archaeological research is required. In this paper, the preliminary theoretical description of a complete 3D visualization system of archaeological uncertainty is described based on mathematical modelling, which will use as input the archaeologists' assessment of the extent evidence and will calculate, when implemented, the relative probability in

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relation to how these parts existed in the past, reconstructed and visualized in 3D. Therefore, it will be possible for different parts of a building to be associated with varied probabilities in relation to whether the actual reconstruction is accurate and at which degree, thus, offering multiple reconstructed options regarding the form of an architectural structure in the past.

Fig. 1. The 3D model of the Athenian Treasury monument

II. Background

Representing uncertainty is through the use of Bayesian probability, reflecting traditional logic and subjective beliefs [8]. Earlier work on the visualization of uncertainty for archaeological reconstructions showcased 3D reconstructions of a Romano-British building consisting of hypothetical and recovered parts based on opacity levels; the more opaque a section of the 3D reconstruction, the more certain it was that its past form was as visualized [9]. A visualization framework supporting the mathematical modeling of uncertainty was implemented using networked interactive graphics to display the reconstructions [10]. In this work, archaeologists could not update their belief related to new evidence uncovered in excavations, because neither of the employed Bayesian or Possibility theory could handle such updates.

More recently, a fuzzy logic model was proposed for calculating the archaeological uncertainty of the ancient Roman temple of Diana in Nemi, Italy [11]. The visualization was based on transparency and colour visualization. 3D reconstructions of this site were presented quantifying uncertainty by a fuzzy logic approach. The resulting reliability value signified how reliable the 3D reconstructed part was in relation to evidence [12]. This scale ranged from zero (0) to one (1), where value 0 means that something is totally unreliable, while value 1 means that something is absolutely reliable. There was strong dependence of the reliability metric on the order in which the building's historical evidence of the reconstruction and objects were added to the fuzzy logic model, therefore, the model did not produce accurate reliability results.

Recent work tried to resolve such issues [13]. Concentrating on the Palace of Zakros in Crete, Greece, three potential reconstructions for every spatial location in the Palace of Zakros were visualized in 3D. The distribution did not give 0 probability values in any of the reconstructed options. After archaeologists communicated their assessment in relation to whether a reconstructed option was accurate, the distribution changed and it was clear which is the preferable option based on combined opinions by experts. This mathematical rationale is much closer to how archaeologists think in relation to different hypotheses compared to previous work [11], [9].

Fig. 2. 3D shaded model of a metope in greyscale

III. The Athenian Treasury at Delphi: Case Study

The archaeological site of Delphi lies on the slopes of Mount Parnassus in central Greece and it was one of the most prominent religious centres of ancient Greece, which gained power and fame because of the sanctuary and oracle of Apollo Pythios. The extended excavations at the site have brought to light the sanctuary of Apollo and monuments such as the sanctuary of Athena Pronaia, the Gymnasium, the Castalian Spring, the Stadium. Delphi is considered as a relatively well-known site of the ancient Greek civilisation, because of the quantity of the extant evidence: archaeological findings, architectural remains and philological texts have allowed a reconstruction of the buildings, as well as of the activities that took place there. Nevertheless, several details of the ancient site still constitute issues of scientific dispute among archaeologists, architects and historians.

One of these points of archaeological uncertainty is the exact positioning of the metopes of the Athenian Treasury, the building which housed the votive offerings of the city of Athens and its citizens. The treasury has been built at a time when Athens was reaching its economic and political peak, around the beginning of the 5th c. B.C., a little before or after the battle of Marathon and the victory of the Athenians against the Persians. It was a small doric building, shaped like a temple in antis, however, its construction completely by Parian white marble and its vast sculptural program made it as one of the most luxurious treasuries of the sanctuary.

The metopes of the Athenian Treasury are widely considered as masterpieces of ancient Greek sculpture, as well as testimonies of the transition from the archaic to the classical art. Despite several evidence for the metopes preserved, they do not suffice to determine their exact positioning and order on the building. In the framework of this project, three different proposals will be thoroughly examined: the first is the proposal by Pierre De la Coste Messelière [14], who was the first to publish the metopes in detail in 1957, the second is the proposal by Klaus Hoffelner [15] and the third the proposal by Clemente Marconi [16]. These proposals have a common basis, namely they take into account a series of evidence that is mainly undisputed. First of all, the vast majority of the fragments under examination is attributed with certainty to the metopes of the Athenian Treasury, because of their material, dimensions and technique. Secondly, there is no doubt on the total number of the metopes: 30 metopes in total, 9 on each long side (north and south) and 6 on each narrow side (east and west). Furthermore, the mythological themes of the metopes are also certain: the metopes depict the labours of Theseus, the mythical king and founder of Athens; the labours of Herakles, a panhellenic hero, with extra importance being given to a specific labour, the cattle of Geryon; and an Amazonomachy, the mythical battle between the Greeks and the female warriors named Amazons, in which both Herakles and Theseus took part. What is, however, disputed is which cycle would be depicted on which side. Comparative research has shown that the metopes of one side would be attributed to the same mythololgical cycle, but one mythological cycle could be expanded to more than one side.

Out of the 30 metopes, only metope no 5 can be placed with undisputed certainty on the building: it depicts the mythical meeting of Theseus with the goddess Athena and it was located in the middle of the south side of the Treasury, where it could be seen by the visitors walking on the Sacred Way, from the main entrance of the sanctuary to the Temple of Apollo. The goddess had a bonze helmet on her head, which expanded above the top border of the metopes. Therefore, a small cutting had to be made to the cornice above, a cutting which has been located and identified with certainty. Furthermore, scholars accept that all the metopes of the south side would depict the labours of Theseus. Besides that, the rest of the evidence (i.e. the philological texts, the exact founding location of each fragment or the exact dimensions of the metopes) does not provide information on the exact positioning of the metopes. Therefore, each theory is mainly based on slightly different proposals on the identification of certain metopes and on the ambiguity of the attribution of others to a mythological cycle. For example, De la Coste Messelière believes that metope no 5, depicting Theseus with the Amazon Penthesileia should be attributed to the mythological cycle of Theseus [14], whereas Hoffelner and Marconi believe that it should be attributed to the mythological cycle of the Amazonomachy [15], [16].

De la Coste Messelière has concluded that the south side would be occupied by the labours of Theseus, the east by the Amazonomachy, the north by the labours of Herakles and the west by the cattle of Geryon. Hoffelner suggested that the Amazonomachy would occupy the north side and the labours of Herakles the east side. Finally, Marconi has claimed that the Amazonomachy would occupy the east and west sides, whereas the labours of Herakles, including the cattle of Geryon, should be positioned on the north side. Therefore, the exact positioning of the metopes of the Athenian Treasury remains uncertain, and it probably will remain so, unless new and more defining evidence come to light.

Fig. 3. Textured 3D model of an amazon statue formerly located at an acroterion of the temple

IV. Geometrical Information

The first item of archaeological evidence to be used, when the system is implemented, as input to the formulation of archaeological uncertainty visualization is the geometry derived from the 3D model of the Athenian Treasury Monument and parts of its architectural sculpture. User requirements from archaeologists and surveying engineers, including level of detail, type of 3D products, colorization requirements and selection of a co-ordinate system of reference, were set at an early stage of the project [17]. Terrestrial 3D laser scanning and aerial photogrammetry were combined in order to obtain a geometrically accurate 3D model with realistic textures from RGB images. A Faro X130 scanner was used for the 3D scanning, while a total number of 823 high resolution images, were captured with a Phantom 4 RTK UAV in a photogrammetric flight procedure. Combined point cloud and imagery data were processed in Reality Capture software and a complete textured 3D model of the Athenian Treasury Monument was produced (Figure 1). Moreover, the extant metopes of the Athenian Treasury, as well as other pieces belonging to the building's architectural sculpture, all exhibited at the Archaeological Museum of Delphi, where also scanned, using an Artec Eva 3D optical handheld scanner, to provide high-detail 3D textured models (Figures 2, 3). 3D scanning of the archaeological site as well as relevant objects will be combined with 3D reconstructions of missing parts when the system is completed, offering multiple hypotheses of the past.

V. Methodology

The aim of this research is to ultimately develop a visualization system incorporating 3D reconstructions of focal points at Delphi incorporating uncertainty for each reconstructed option visualized in 3D using Bayesian logic and taking as input archaeologists' evaluation of the existing evidence. We are focusing on the Athenian Treasury monument (Figure 1). The uncertainty in this case study regards the exact positioning of each of the 30 metopes of the building. As mentioned above, three hypotheses are examined, each one proposed and analysed by a different scholar: the first by De La Coste-Messelière in 1957 [14], the second by Hoffelner in 1988 [15] and the third by Marconi in 2006 [16]. The methodology proposed consists of the following steps:

Step 1: Discussions conducted with expert archaeologists put forward three types of evidence defining the arrangement of metopes in the Athenian treasury: Firstly, the identification of fragments belonging to the metopes; the archaeologists may find a fragment within an archaeological site, but it is not always certain to which monument it belongs. Specific fragments may be considered as part of the metopes in some reconstructions and in others not. Secondly, the mythological themes depicted on the metopes: the archaeologists arrange the metopes taking into consideration the mythological cycles. In the case of the metopes of the Athenian Treasury, this is not always clear, since some of the mythological episodes are intertwined, e.g both Herakles and Theseus took part in the Amazonomachy, which leads to other potential reconstructions. The last evidence is the comparison with existing monuments of the same historical period, e.g. the temple of Hephaestus in Athens. These comparisons will help archaeologists develop hypotheses based on evidence.

Step 2: After identifying the evidence types, an order of significance will be quantified. The archaeologists offer a judgment on a 7-point scale ranging from Never to Always for each statement of the questionnaire. The goal is to identify the order of significance of the evidence types, according to archaeologists' opinion. This information changes in real time after an additional archaeologist completes the questionnaire, keeping the system always updated.

Step 3: Multiple reconstructed options are going to be proposed for each point of interest in the Athenian treasury in relation to the metopes' location. The archaeologists are asked to offer their assessment for each hypothesis discussed above, e.g is the reconstruction of La Coste-Messelierer feasible based on evidence, through a user interface (UI) slider which takes values from zero to one, with one being fully possible and zero not possible. For each point of interest, they select which types of evidence shaped their opinion, e.g for the first point of interest their belief was based on one type of evidence. This input is used in order to calculate the uncertainty of each reconstructed option (hypothesis) based on dynamic, probabilistic calculations. The output of our system will be the probability density function (PDF) of this distribution as it is formed after the input of archaeologists. Using the PDF, the samples of distribution will be offered from our system, as points of a triangle where the three vertices represent the proposed reconstructions. If the points are close to a vertex signifying a specific hypothesis, then this reconstruction (hypothesis) is the most possible. It is significant to note that this does not make the other hypotheses impossible. Visualization paradigms, for instance, using the colour red to green signifying a lot to high probability may be used for each reconstructed option viewed by archaeologists.

VI. Conclusion

The theoretical preliminary formulation of an innovative system was presented putting forward the combination of 3D surveying methods with the visualization of archaeological uncertainty as applied to the archaeological site of Delphi in Greece. The system is theoretically designed to take as input the archaeologists' assessments in relation to the evidence and will calculate the relative probability in relation to how specific spatial locations existed in the past, offering multiple hypotheses reconstructed and visualized in 3D. New and continuous update of the system with new archaeological evidence uncovered or new beliefs formed will be possible. We will now proceed with system implementation and formal mathematical formulation of probability.

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