For:

Matthew Vincent, Victor Manuel Lopez-Menchero Bendicho, Marinos Ioannides and Thomas E. Levy (editors) *Acquisition, Curation, and Dissemination of Spatial Cultural Heritage Data.* Publisher: Springer

Delphi4Delphi - Data Acquisition of Spatial Cultural Heritage Data for Ancient Delphi, Greece

Ioannis Liritzis[1]*, George Pavlidis[2], Spyros Vosinakis[3], Anestis Koutsoudis[2], Pantelis Volonakis[1], Nikos Petrochilos[4], Matthew D. Howland[5], Brady Liss[5], Thomas E. Levy[5]

*Corresponding author

Abstract

For Digital Cultural Heritage, 3D modeling is an essential practice for the identification, monitoring, conservation, restoration and enhancement of archaeological objects from artifacts to monuments. In this context 3D computer graphics can support archaeology and heritage policy, offering scholars a "sixth sense" for the understanding of the past, as it allows them to almost relive it. In addition, current trends for 3D video gaming (serious games) and scientific storytelling provide a variety of new approaches towards new, enhanced and realistic experiences of the past. The research project 'Digital Enterprise for Learning Practice of Heritage Initiative FOR Delphi (Delphi4Delphi) targets most of these issues. In particular, it focuses on educational, research and social implications of digital heritage, through the use of modern technologies such as digital optical documentation, geographical information systems and georeferencing, big data, video and interactive content production for education, virtual and augmented reality, cyber archaeometry and Cyber-Archaeology. This paper presents an overview of Delphi4Delphi in relation to the issues of acquisition, curation, and dissemination of spatial cultural heritage data.

Research Framework

Digital archaeology has rapidly grown over the past fifteen years to an asset for research, education and the society, showing a magnificent emergence during the 1990s (Reilly, 1990). The digital media and learning initiatives on virtual collaborative environments for cultural heritage define new (sub-) disciplines in archaeological, or in general, heritage sciences. New nomenclature emerges such as cyber archaeology, virtual worlds, augmented and immersive realities; and all are related to museums and cultural heritage - tangible, intangible or natural (Anderson, et al., 2009; Bell, 2008; Forte, 2010). The interaction between real entities, the empirical perception of material culture (objects), and their virtual replicas (the digital representations), creates new perspectives in the domain of data processing, data analysis, data sharing, data contextualization and cultural transmission. The wide spectrum of digital archaeology deals with such themes on a variety of transdisciplinary and interdisciplinary topics from archaeological informatics or computational archaeology.

New approaches have been added using various interactive practices. Thus, 3D modeling is a very useful practice for the identification, monitoring, conservation, restoration and enhancement of archaeological objects. In this context 3D computer graphics can support archaeology and heritage policy, offering scholars a "sixth sense" for the understanding of the past, as it allows them to almost relive it. In addition, current trends for 3D video gaming (serious games) and scientific storytelling provide a variety of new approaches towards new, enhanced and realistic experiences of the past.

The research project 'Digital Enterprise for Learning Practice of Heritage Initiative FOR Delphi, Delphi4Delphi) targets most of these issues. In particular, it focuses on research, social and educational implications of digital heritage, through the use of modern technologies such as digital optical documentation (Pavlidis et al., 2007), like laser scanning and aerial and terrestrial computational and stereo photography, geographical information systems and georeferencing, big data, video and interactive content production for education, virtual and augmented reality, cyber archaeometry (Liritzis et al., 2015) and Cyber-Archaeology (Levy, 2015).

The Delphi4Delphi project applies a variety of new approaches using interactive practice. Accordingly, the 3D modeling enhances the identification, monitoring, conservation, restoration and enhancement of archaeological objects and viewer experience. In this context, 3D computer graphics can support archaeological research and heritage policy, offering scholars a "sixth sense" for the understanding of the past, as it allows them almost to live it. This has been successfully deployed in the Middle East in Jordan, Saudi Arabia, Israel and other areas (Smith et al., 2014).

The work described here presents the first large-scale interdisciplinary project results including Structure from Motion (SfM) and CAVEcam-based measurements of significant heritage objects and monuments and helium balloon aerial images of the sanctuary and Tholos, in Delphi, Greece.

Delphi – UNESCO World Heritage Site

The historical significance of Delphi centers on the ancient political decisions taken after consultation of the Oracle, especially during the colonization movement in the Archaic period (ca. 8th century BC – 480 BC), when established cities asked for the consent and guidance of the Oracle. The sanctuary was also the seat of the Amphictyonic League, an association of political and tribal communities settled in the region that were linked together, with the intention to protect and manage the Temple of Demeter in Thermopylae and that of Apollo in Delphi. The League was ruled by a council that consisted of two representatives from each member but later this composition underwent several modifications. The Council's jurisdiction to impose punishment on offenders triggered some of the major political and military conflicts of antiquity. After the First Sacred War, in the beginning of the 6th c. BC, the importance of the sanctuary grew even more. At that time, the Pythian Games were organized, a Panhellenic athletic event that was held every four years.

Figure 1. Part of the Delphi site photographed from the theatre, showing the rectangular-shaped Temple of Apollo (middle)

Here we present a brief overview of the monuments the Delphi4Delphi project recorded in 2015 and 2016. Among the most imposing monuments at Delphi is the temple of Apollo (4th c. BC) that was established after the destruction of the previous temple with the financial contribution of cities, rulers and war reparations of the impious Phocians (Figure 1). A short distance from the temple is the theatre that was built in the 4th c. BC, but remodeled in the 2nd c. BC with funds from the kings of Pergamon. Further down the hill is the Gymnasium of Delphi, a complex block of buildings dated to the 4th century B.C.E., which underwent several modifications and additions in the following centuries. Next to the Gymnasium is the Sanctuary of Athena Pronaea (and the Tholos), where two temples were erected, one at the eastern end of the precinct dated in the Archaic period, and one at the western end, dated to approximately the middle of the 4th c. BC, when the former building collapsed due to rock falling.

The most precious art works, made of valuable materials such as bronze statues, were recovered in the early excavations at Delphi. They provide a vague impression of the sumptuous gifts that were once erected at the site. Some of these are exhibited in the Delphi Museum and are considered as masterpieces of ancient Greek art. Most famous is the bronze charioteer, part of the victorious chariot complex dedicated by the tyrant Polyzalos of Gela during the Pythian Games of 478 or 474 BC. Other masterpieces include the marble sphinx that was set on a tall Ionic column that was an offering of the citizens of Naxos from the period 570-560 BC, as well as decorative architectural elements of monuments, such as those from the Treasury of the Siphnians (Bommelaer, 2015).

The dataset obtained during our first season represents about 300 GigaBytes – truly a ‘big data’ set for cultural heritage research considering it was collected over a period of seven days. Moreover, high-definition balloon photographs of Delphi’s sanctuary were obtained in order to generate 3D models and high-quality GIS datasets to monitor site conservation, facilitate research around the world and offer effective educational learning outcomes.

Methods and Measurements

Three types of digital photography-based optical documentation methods were used in the 2015 and 2016 Delphi4Delphi seasons, *Structure from Motion*, *CAVEcam photography and balloon photography*. In the following paragraphs, we present the application of those techniques and summarize some of the obtained results.

Structure from motion reconstruction

The first method is based on Structure from Motion (SfM). This is a technique of spectral imaging (in the visible spectrum) and refers to the process of reconstructing 3D structures from 2D image sequences. It is a technique of computational photography and refers to the process of deducing the 3D structure of a scene from 2D image sequences of the scene. In its original form SfM was developed within the computer vision domain as a method for the reconstruction of the geometry of a scene captured by multiple camera shots (videos) using characteristic (key) points in the image set. In that form, SfM could only produce a sparse 3D point cloud for a scene, which was not useful for cultural heritage digitization projects that have high resolution and accuracy requirements. SfM, algorithmically, targets the minimization of error in detecting key point correspondences in successive images; these key points are certain visually important features, such as corner points (edges with slopes in multiple directions). Nowadays, 3D reconstruction with SfM is coupled with Multiple View Stereo photography (MVS) and is capable of creating a dense set of 3D points, virtually extracting and exploiting information from all image pixels in all dataset images. Practically, SfM is performed with digital cameras (aided by photographic equipment and robotic systems) and special algorithms and software implementations. In its current form, the technique is able to provide impressive 3D reconstruction results and is of particular importance in cultural heritage applications. Figure 2 shows an example of SfM 3D reconstruction in the context of the DELPHI4DELPHI project.

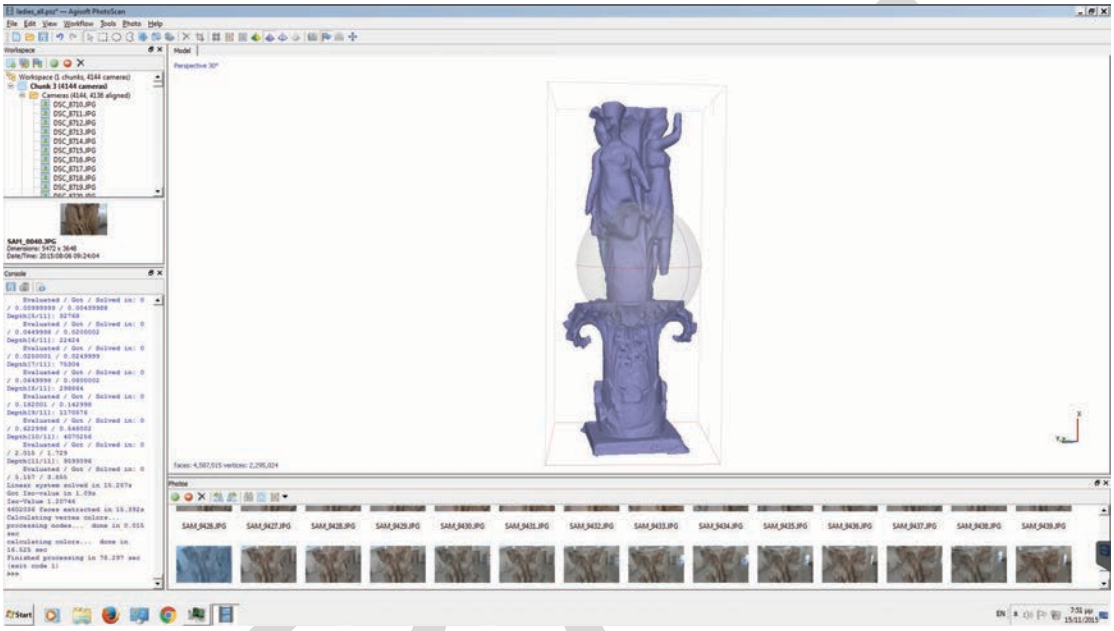

Figure 2. Structure from Motion (SfM) reconstruction process for the “Column with the dancers” from the Delphi archaeological museum

Researchers assessed the quality of the SfM in relation to issues such as data collection and processing times, human resources and required background knowledge and budgetary requirements as well. Numerous works focus on the evaluation of SfM reconstructions for the generation of digital elevation models (Neitzel et al., 2011; Ouédraogo et al. 2014; Javernick et al., 2014). Opitz et al. (2012) compared the pipelines of generating 3D models using close-range photogrammetry and scanning. DeReu et al. (2012) and Doneus et al. (2011) evaluated SfM for the archaeological excavation documentation. Additionally, SfM has been examined as a practical digitization tool (McCarthy, 2014). Researchers have also compared the data produced by different SfM implementations (Nguyen et al., 2012; Kersten et al., 2012). Koutsoudis et al. (2013) evaluated the performance of an SfM implementation on movable objects and monuments. The data evaluation phase indicated that for monuments with feature-rich surfaces under appropriate lighting conditions and with the appropriate hardware and software solutions, high quality results can be achieved by a large set of images using SfM.

The following Figures (Figure 3-Figure 6) of this section present some of the results from the SfM sessions on various subjects from the Delphi archaeological museum. Specifically, Figure 3 presents virtual views from the 3D model of the “Omphalos”; this model has a count of 6.7 million vertices and 13.5 million faces, and is shown as a graylevel geometry representation and a textured model. Figure 4 shows graylevel geometry and textured model views of the 3D model for the “Column with the dancers”, which amounts to 5.3 million vertices and about 11 million faces. Figure 5 presents views from the 3D model of the “Naxian Sphinx” with a count of 10 million vertices and 20 million faces, similarly using a graylevel geometry and a textured model representation from various viewpoints. Finally, Figure 6 shows graylevel geometry and textured model representations for the 3D model of the statue of the “Charioteer”, which amounts to 6 million vertices and 12 million faces.

Figure 3. 3D model from the Delphi archaeological museum: the high-resolution and accuracy geometry (graylevel) and the textured model of the *Omphalos* (navel)

Figure 4. 3D model from the Delphi archaeological museum: the high-resolution and accuracy geometry (graylevel) and the textured model of the *column with the dancers*

Figure 5. 3D model from the Delphi archaeological museum: the high-resolution and accuracy geometry (graylevel) and the textured model of the *Naxian Sphinx*

Figure 6. 3D model from the Delphi archaeological museum: the high-resolution and accuracy geometry (graylevel and mesh) and the textured model of *the Charioteer*

CAVEcam photography

CAVEcam photography for the Delphi4Delphi project involves the 3D CAVEcam stereo photography system developed by Tom DeFanti's research team at UC San Diego (Ainsworth et al., 2011; Smith et al., 2013). This system includes two cameras mounted on a robotic GigaPan® Epic Pro platform; Panasonic LUMIX® GF-1 cameras provide 12.1 megapixel resolution despite being relatively small for mounting side-by-side in the controller. By bracketing the cameras next to each other, they collect two sets of images with slightly differing perspectives to provide stereoscopic vision (much like human eyes). The robotic mount affords automated movement for the cameras in 360 degrees horizontally and up to 180 degrees vertically; this is outfitted with an Ainsworth CC-1 Dual-Camera Controller[1] to automatically capture images from both cameras simultaneously. Together, the dual-cameras and robotic platform create two grids of images from distinct perspectives (gigapans) which are individually stitched (using the PTGui® Pro software) and displayed to create a single, high-resolution 3D image. The CAVEcam system used in Delphi4Delphi is shown in action in Figure 7. Application of the CAVEcam for Cultural Heritage presents unique challenges when seeking to archive, analyze and visualize the acquired stereo gigapixel panoramas. Several of these include overcoming limited accessibility to hard-to-reach or inaccessible areas, poor lighting conditions, graffiti, congested tourist areas, occlusion, and the sheer physical expanse of many cultural heritage sites. (DeFanti et al., 2009).

The main goal of the application of this method in Delphi4Delphi was to capture CAVEcam imagery of major archaeological objects in the Delphi Archaeological Museum and the significant monuments of the archaeological site. Obstacles, like intrusions (i.e. curious tourists intrigued by the automatically rotating cameras) and drastic changes in lighting during the capture time needed to be avoided as much as possible; thus, the best time to collect imagery was near dusk around the closing of visitation to the site. Within the museum, it was more difficult to prevent visitors from walking through CAVEcam's line of sight, but post-processing can correct for this. At each location on site and in the museum, the cameras were manually set for the specific circumstances (ISO, Aperture, Shutter Speed, Focus, and White Balance). The GigaPan robotic mount is also set based on the shutter speed of the cameras to ensure they are not moved while taking a photograph. As the settings were typically well lit, the CAVEcam took slightly under 6 minutes to complete a full image capture. The mount rotated a full 360 degrees horizontally and 150 degrees vertically (+75 degrees, -75 degrees) for collection. In each instance, both cameras collected a grid of 72 images in 6 rows of 12 photographs (144 total photographs per CAVEcam image). After each day in the field, all the images were

[1] Ainsworth CC-1 Dual-Camera Controller, Ainsworth & Partners.

downloaded from the cameras onto a field computer; however, most of the stitching was completed in the lab after the expedition.

Figure 7. The CAVEcam instrument in action (left) capturing of the Apollo Temple in the Delphi site; (b) capturing the famous bronze charioteer in the Delphi Archaeological Museum

At the end of the project, 28 sets of CAVEcam imagery were captured in 15 different positions throughout the Delphi museum and site. Some of the stitched panoramas are shown in the following Figures (Figure 8-Figure 11). On-site locations included the Temple of Apollo, the Sanctuary of Athena Pronaia (and the Tholos), the stadium, the gymnasium, the theater, the Roman house complex, and the Roman portico. The theater was photographed from 10 unique locations for an experimental SfM reconstruction based on the CAVEcam images. In the archaeological museum, the famous bronze charioteer and the Sphinx of Naxos were also captured with the CAVEcam. In total, the CAVEcam data included 4032 individual photographs, approximately 56 gigabytes of data. Over the course of only 5 days (including just 4 visits to the archaeological site and 2 visits to the museum), the project successfully created a digital 3D record of the major cultural heritage artifacts and features of Delphi. Despite both the museum and site being major tourist attractions, we were able to successfully capture clean images in almost all cases. Part of this success can be attributed to the rapid capture time of the CAVEcam (less than 6 minutes); however, when needed, the public was often cooperative in waiting for the instrument to finish. These 360-degree 3D gigapans can now be viewed and shared by scholars and the public alike in immersive visualization CAVEs – bringing the field back to the lab (Figure 8-Figure 11). Based on this case study, it is abundantly evident that the CAVEcam is an invaluable tool for creating a digital heritage for culture and archaeological sites in a quick, non-invasive, and affordable manner (DeFanti et al., 2009). Figure 12 shows a design plan of CAVEkiosk, a VR installation with six panels used for the stereo display of 3D models from Delphi4Delphi and other projects.

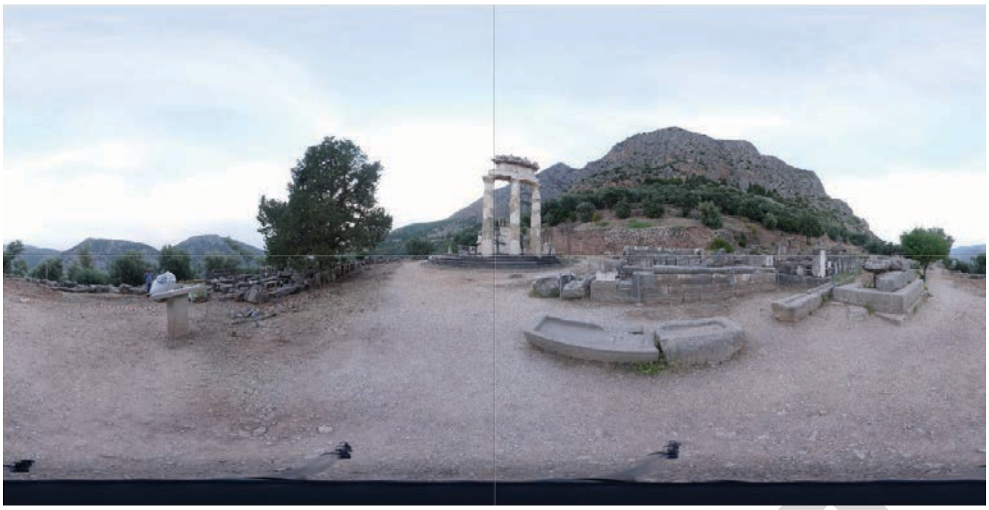

Figure 8. Stitched CAVEcam imagery from one camera of the Sanctuary of Athena Pronaia and Tholos at the Delphi archaeological site

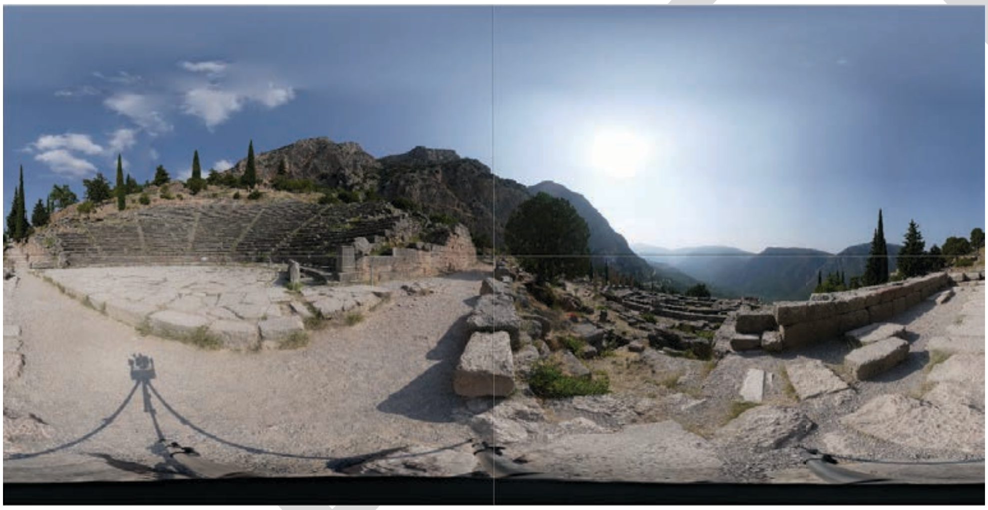

Figure 9. Stitched CAVEcam imagery from one camera of the theater and Temple of Apollo at the Delphi archaeological site

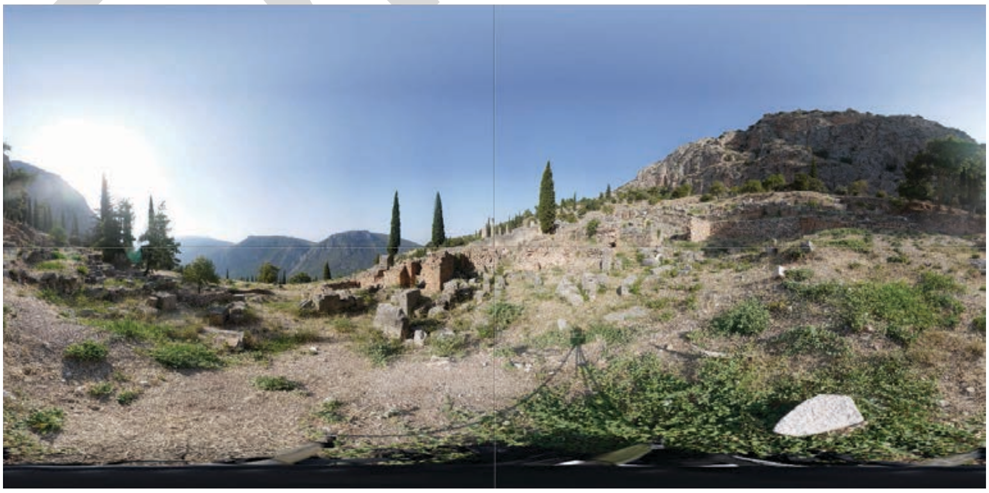

Figure 10. Stitched CAVEcam imagery from one camera of the Roman house complex at the Delphi archaeological site

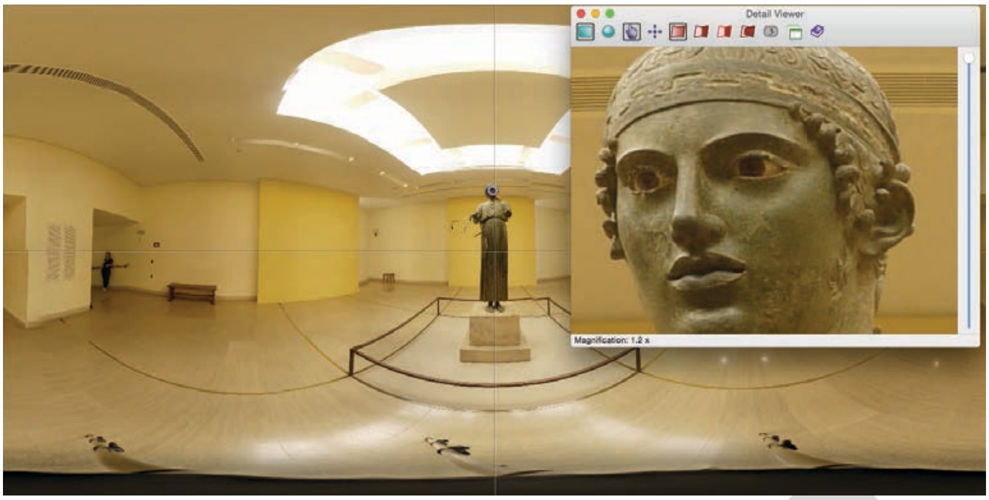

Figure 11. Stitched CAVEcam imagery from one camera of the bronze charioteer with zoom inset emphasizing the high resolution in the Delphi archaeological museum

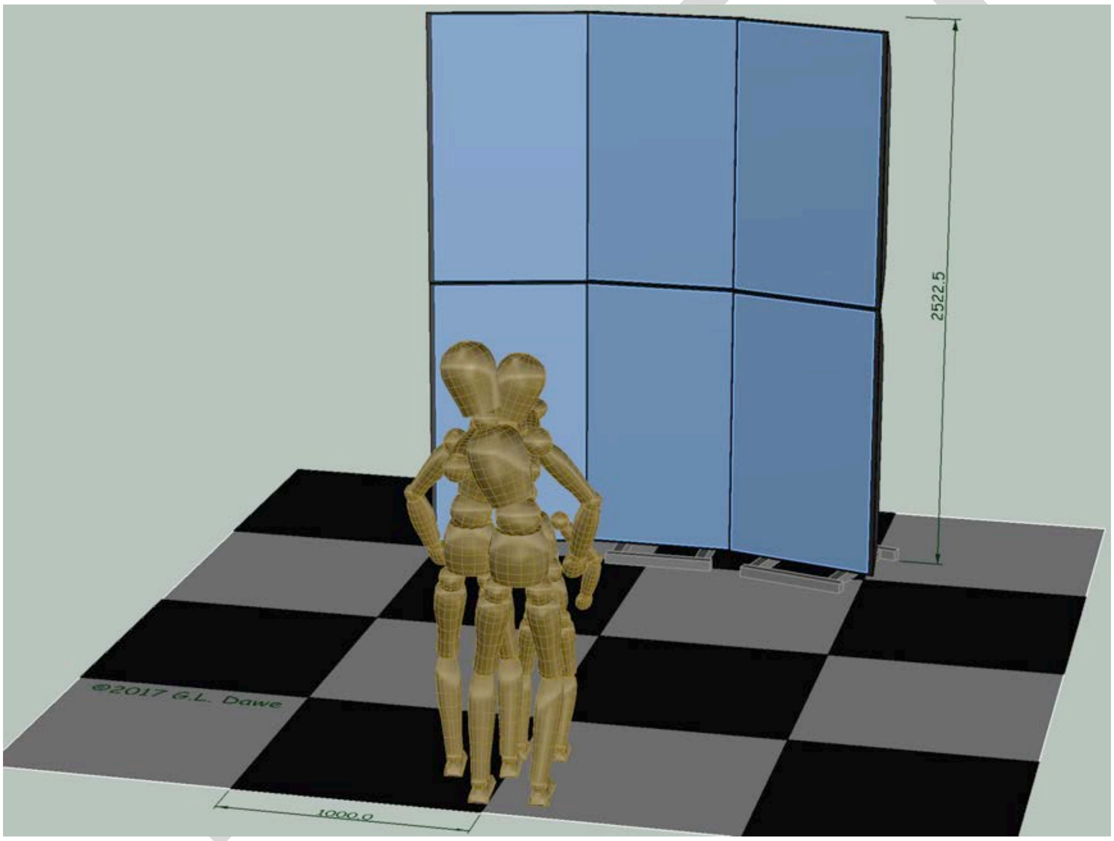

Figure 12. Design plan of CAVEkiosk with six panels used for Delphi4Delphi and other projects (courtesy Greg Dawe, Qualcomm Institute)

Balloon aerial photography

Low-altitude aerial photography was applied at Delphi in order to acquire SfM-oriented photographic datasets and to obtain publication-quality single images. The balloon platform consisted of a Kingfisher™ Aerostat balloon, filled with helium, and an attached wind sail that serves to stabilize the platform in windy conditions.

The balloon was kept inflated throughout the 1-week long expedition season. It was tethered down each night in a wind-sheltered Delphi Museum open air compartment, resulting in minimal helium loss on a daily basis. During photography, a Picavet suspension camera platform was hung from the balloon, ensuring that the camera would remain pointed vertically (when desired) at all times. A Canon EOS 50D digital SLR camera with either an 18mm or a 50mm lens and equipped with an interval timer to trigger the camera shutter was used for all aerial photography at the site. The balloon was also tethered to a ground-based operator who manipulated the balloon and camera's location via the tether in patterns appropriate for SfM- and single-image-oriented photography. SfM-based image capture required that the balloon be flown in custom transect patterns, with transect width varying depending on wind conditions and site size, and the objective of attaining 75%+ overlap between adjacent images. Images were taken at varying elevations of between 10 and 100 meters above the ground, again depending on target size. This approach is an ideal approach to balloon-based SfM photography, refined through trial-and-error at other sites (Howland, et al., 2014). The balloon photography system was also used to capture publication-quality single images, taken at both oblique and vertical angles. SfM-oriented data capture serves a tripartite goal: generation of 3D models, generation of orthophotographs, and generation of digital elevation models (DEMs). The latter two objectives, involving creating GIS data, ultimately facilitate the creation of detailed architectural plans through digitization/vectorization of architectural features visible in generated orthophotographs. Ultimately, over 7,000 images were successfully captured with the balloon system, amounting to over 300 Gigabytes of data during the 1-week season.

Figure 13. Photos from the balloon camera system

Figure 13 shows two photos taken by the balloon camera system during the 2016 photo sessions. The photo on the left shows a part of the theatre whereas the right photo shows part of the Apollo temple. Figure 14 shows a screenshot of the 3D model of the main part of the archaeological site created using the balloon photos. Figure 15 shows the orthophotograph that was created from the 3D reconstruction of the site.

Figure 14. 3D model of the main archaeological site

Figure 15. Orthophotograph of the main archaeological site

Conclusions

European researchers are at the cutting edge of digital cultural heritage. However, until now, there have been no large-scale projects of this nature in Greece. Delphi4Delphi is the first such international Cyber-Archaeology project in Greece. The main aim of the research is the 3D optical documentation of the Delphi sanctuary and its unique museum objects, which will enhance conservation, archaeological research and local tourism. The large dataset will allow a detailed analysis of the virtual ancient city of Delphi in a combined way using various imaging techniques applied on the rich set of cultural heritage features and objects, as well as making use of archaeoastronomical results related to the time for delivering oracles (Liritzis and Castro, 2013) to enhance the visitor experience.

Acknowledgements

We thank the Ministry of Culture & Sports, Greece for granting permit and Mrs. A. Psalti for facilitating our daily plan in Delphi. Funding for the UC San Diego team was generously provided to Thomas E. Levy by Andrew Viterbi and the Viterbi Family Foundation (San Diego) and Norma Kershaw and the Kershaw Family Foundation (Orange County). Thanks also to Alina Levy for helping with the logistics of the Delphi4Delphi expedition.

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Authors

* Author for correspondence.

- [1]**Ioannis Liritzis***
  Department of Mediterranean Studies, Lab of Archaeometry, University of the Aegean, Rhodes, 85100, Greece (Email: liritzis@rhodes.aegean.gr)
- [2]**Spyros Vosinakis**
  Department of Product and Systems Design Engineering, University of the Aegean, Konstantinoupoleos 2, Hermoupolis, Syros, 84100, Greece (Email: spyrosv@aegean.gr)
- [3]**George Pavlidis**
  ATHENA - Research and Innovation Centre in Information, Communication and Knowledge Technologies, Panepistimioupoli Kimmerion, P.O. Box 159, 67100, Xanthi, Greece (Email: gpavlid@ipet.gr)
- [1]**Pantelis Volonakis**
  Department of Mediterranean Studies, Lab of Archaeometry, University of the Aegean, Rhodes, 85100, Greece (Email: p.volonakis@aegean.gr)

- [4]**Nikos Petrochilos**
  Ephoria of Antiquities in Phokis, Museum of Delphi, Delphi, Greece (Email: npetrochilos@hotmail.com)
- [3]**Anestis Koutsoudis**
  ATHENA - Research and Innovation Centre in Information, Communication and Knowledge Technologies, Panepistimioupoli Kimmerion, P.O. Box 159, 67100, Xanthi, Greece (Email: akoutsou@ipet.gr)
- [5]**Matthew D. Howland**
  Department of Anthropology and Center for Cyber-Archaeology and Sustainability –Qualcomm Institute, University of California, San Diego, Social Sciences Building Room 210 9500 Gilman Drive La Jolla, CA, 92093-0532, USA (Email: mdhowlan@ucsd.edu)
- [5]**Brady Liss**
  Department of Anthropology and Center for Cyber-Archaeology and Sustainability –Qualcomm Institute, University of California, San Diego, Social Sciences Building Room 210 9500 Gilman Drive La Jolla, CA, 92093-0532, USA (Email: bliss@ucsd.edu)
- [5]**Thomas E. Levy**
  Department of Anthropology and Center for Cyber-Archaeology and Sustainability –Qualcomm Institute, University of California, San Diego, Social Sciences Building Room 210 9500 Gilman Drive La Jolla, CA, 92093-0532, USA (Email: tlevy@ucsd.edu)