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A Browser-Based 3D Scientific Visualisation of the Keros Excavations

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Abstract

During 2007-2008 and again in 2016-2018 the McDonald Institute of the University of Cambridge, and in collaboration with The Cyprus Institute during the later campaign, has been conducting excavation on the small islet of Dhaskalio, just off the west coast of the Cycladic island of Keros in Greece. Today inhabited, the island was the site of the world's earliest maritime sanctuary (ca. 2750-2300 BC). Recent excavations are highlighting the remarkable monumentality of the proto-urban settlement adjacent to the sanctuary, which shows precocious evidence for metalworking and agricultural intensification. The comprehensive paper-free digital recording strategy (to be described in full elsewhere) includes an iPad-based recording system (iDig) used in the field and in the laboratory, producing a single excavation database. Spatially, individual contexts are recorded using photogrammetry. Additionally, each excavation trench is 3D documented by means of a terrestrial laser – scanner. The latter aspect of the work is reported in detail here.

Keywords: Web visualization, digital archaeology, Laser Scanning, Photogrammetry, Early Bronze Age, Cyclades

Introduction

Aims of the 3D Documentation Project

The archaeological site under investigation (Renfrew et al. 2007; Renfrew et al. 2009, Renfrew et al. 2012; Renfrew 2013) many various parts of the islet and presents challenges in its excavation, due to the

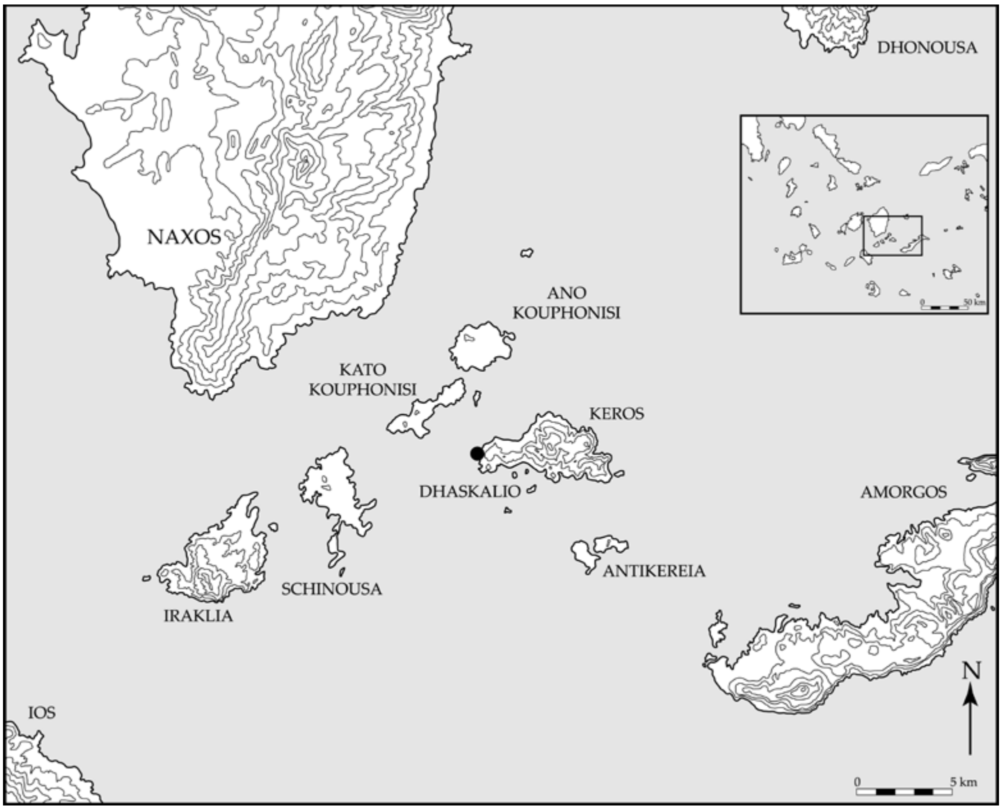

Figure 1. Location of Keros, south of Naxos, Cycladic Islands, Greece (Image credit: The Cambridge Keros Project, McDonald Institute for Archaeological Research, University of Cambridge, UK)

complexity and uniqueness of its architectural and material culture remains, as well as the challenging topography and accessibility of the islet. Consequently, an aerial photographic survey conducted in 2008 (Patias et al. 2009) by means of a remote-controlled helicopter returned a set of images that were processed in order to obtain a 3D model of the entire islet, as a first and overall platform for identification of main concentrations of archaeological remains and for the later positioning and integration of the 3D models of the various components of the excavation. In 2016 and 2017 eight new excavation trenches were opened. A series of surveyed targets were positioned along the site in order to geo-reference the excavation data: individual contexts, entire trenches or architectural complexes. Products of the photogrammetric workflow, such as orthophoto mosaics and digital elevation models, are integrated within the GIS currently being developed for the entire excavation dataset. Furthermore, these targets were used to geo-reference the two campaigns of laser-scanning documentation, carried out at the end of each of the 2016 and 2017 seasons and aiming to fully 3D document each trench at the end of the excavation seasons.

The paper reports on the integration of the whole-island aerial and terrestrial image-based 3D modelling with the terrestrial laser-scanning data, in order to: (a) create an easily accessible platform for the browser-based visualisation and investigation of 3D data and (b) integrate all 3D data produced at the site within a single system, and thus virtually re-creating the excavation process in an inverse diachronic sequence. Each of the 3D single entities were integrated within the browser-based visualisation system, where users can visualise the entire island, select trenches and perform various measurements, such as distances, depth, area, volume, extraction and comparison of cross-sections. Moreover, they can select single excavation units for further similar investigations. It further envisaged that as the GIS platform develops, 3D models will be integrated within it.

Related Works

The 3D documentation of structures and excavation is today a standard practice in archaeology. A multi-resolution approach and the integration of different modelling technologies and methodologies can provide the best results for integrating landscape, structures, stratigraphic excavation and

Figure 2. Dhaskalio promontory, aerial view

finds (Ramos and Remondino 2015). Indeed, different projects have highlighted the potential of image- and range-based modelling in the heritage sector. In Gruen, Remondino and Zhang, (2005), a multi-resolution approach exploiting passive sensors is presented for the documentation of the valley of Bamiyan where the giant statues of Buddhas existed before they were destroyed by the Taliban in 2001. A GIS database has been realized for the UNESCO area. A 3D multi- resolution approach was applied at the Rucellai's chapel in Florence (Bonora, Tucci, and Vaccaro, 2005). The authors present a new complete survey aimed to support restoration tasks. El-Hakim, Remondino and Voltolini (2008) integrated drawings, images and range data for the modelling of castles and their landscapes. Starting from the extrusion of massive models from 2D plans, the architecture could be studied and areas requiring more accurate modelling could be defined.

A multi-resolution and multi-sensor approach has been developed by Guidi et al. (2008; 2009) for the accurate and detailed 3D modelling of the entire Roman Forum in Pompei in Italy, by 3D scanning of a XIXth century plaster model of Imperial Rome. Active and passive sensors were used for the digital documentation of the archaeological site trying to fulfil all the surveying and archaeological needs and exploit all the intrinsic potentialities of the actual 3D modelling techniques.

Remondino et al. (2009) presented a reality-based project, exploiting multi-resolution and multi-source documentation for the digital reconstruction of part of the Maya archaeological site of Copán, Honduras. The final goals were to provide digital 3D models for research and public education purposes.

In Cantoro (2017), a 3D approach is proposed for the integration of aerial and terrestrial data accessible through a web-based platform. Hermon et al. (2017) discuss the use of 3D documentation in exploring how ancient buildings were constructed and possibly used, based on structural and architectural analyses, while in (Faka et al., 2017) a 3D based functional analysis of how ancient buildings functioned is presented.

Abate and Sturdy-Colls (2018) presented the use of digital 3D technologies and web visualization tools for the analysis of the Treblinka extermination and labour camps in Poland, providing a digital interactive platform, which can be used both by professional users and a public audience. The authors propose a pyramidal multi-level and multi-sensor approach – providing a 3D resolution spanning from a few centimetres in the landscape Digital Terrain Model to few millimetres in the layer-by-layer archaeological test trench;

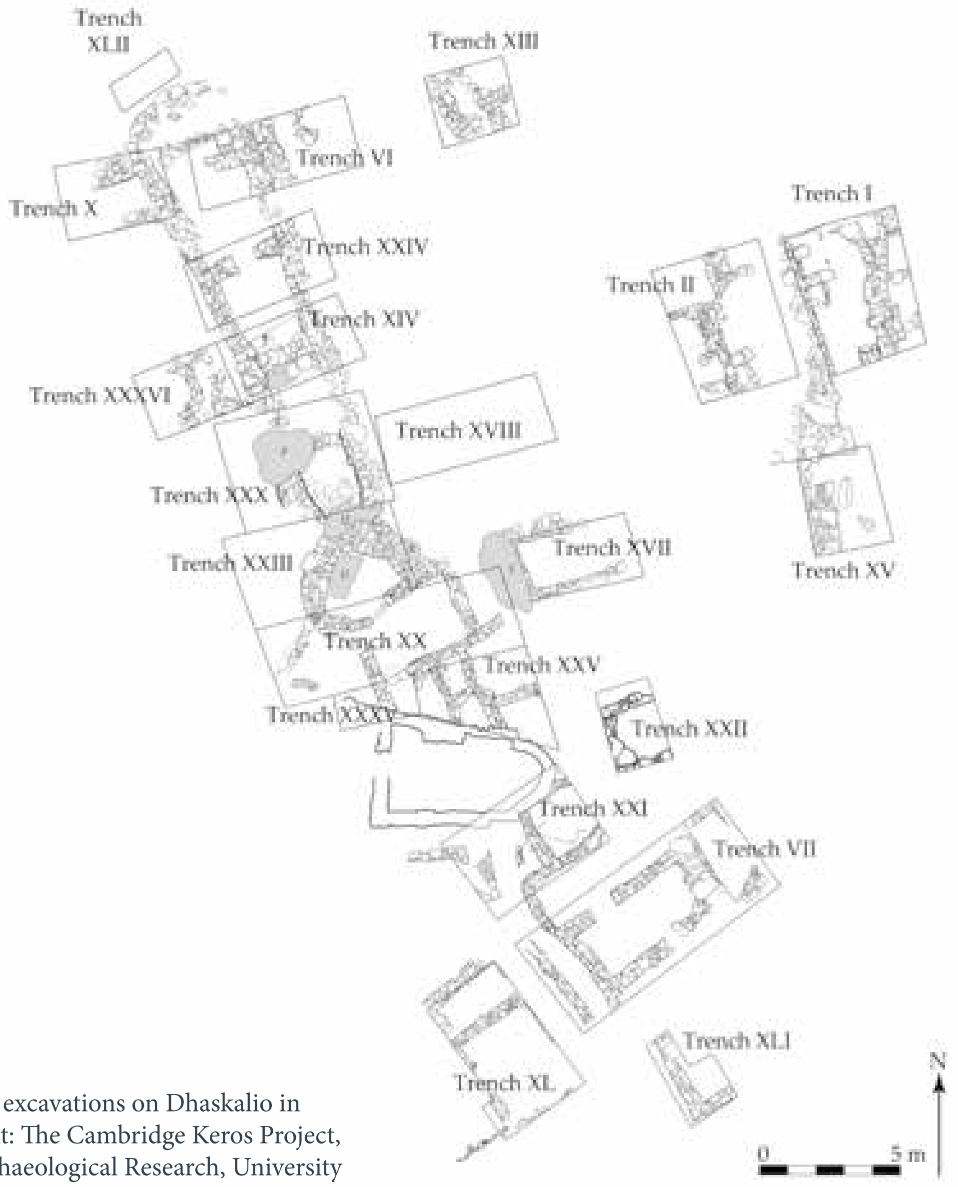

Figure 3. Plan of part of the excavations on Dhaskalio in 2007 and 2008 (Image credit: The Cambridge Keros Project, McDonald Institute for Archaeological Research, University of Cambridge, UK)

Archaeological Description of the Archaeological Site and Recent Excavation Seasons

Excavations at the site unveiled the world's earliest maritime sanctuary (2750-2250 BCE), where during the Early Bronze Age (EBA) travellers came from all over the Cyclades (and beyond) to deposit fragmented choice material (marble figurines and bowls, special ceramic items, and obsidian) in two 'special deposits', while pedestrian surveys conducted between 2012-3 revealed the existence of a dozen or so other small settlements from the same period (Figure 1).

One of them, and once connected to the main island of Keros through an isthmus nowadays underwater, is the pyramid-shaped rocky islet of Dhaskalio, rising at 35m ASL (Figure 2).

The site was excavated in two seasons, during 2007-2008 and 2016-2018 respectively. The first excavation season focused on the remains located on the summit area, where an elongated building was identified. During 2016-2018 campaigns the excavations focused on the lower levels of the islet. These have shown that there were constructions all over the promontory, using a system of massive terraces on which house walls were built. A survey of the rest of Dhaskalio identified remnants of walls located all over the islet. Domestic and non-domestic architec-

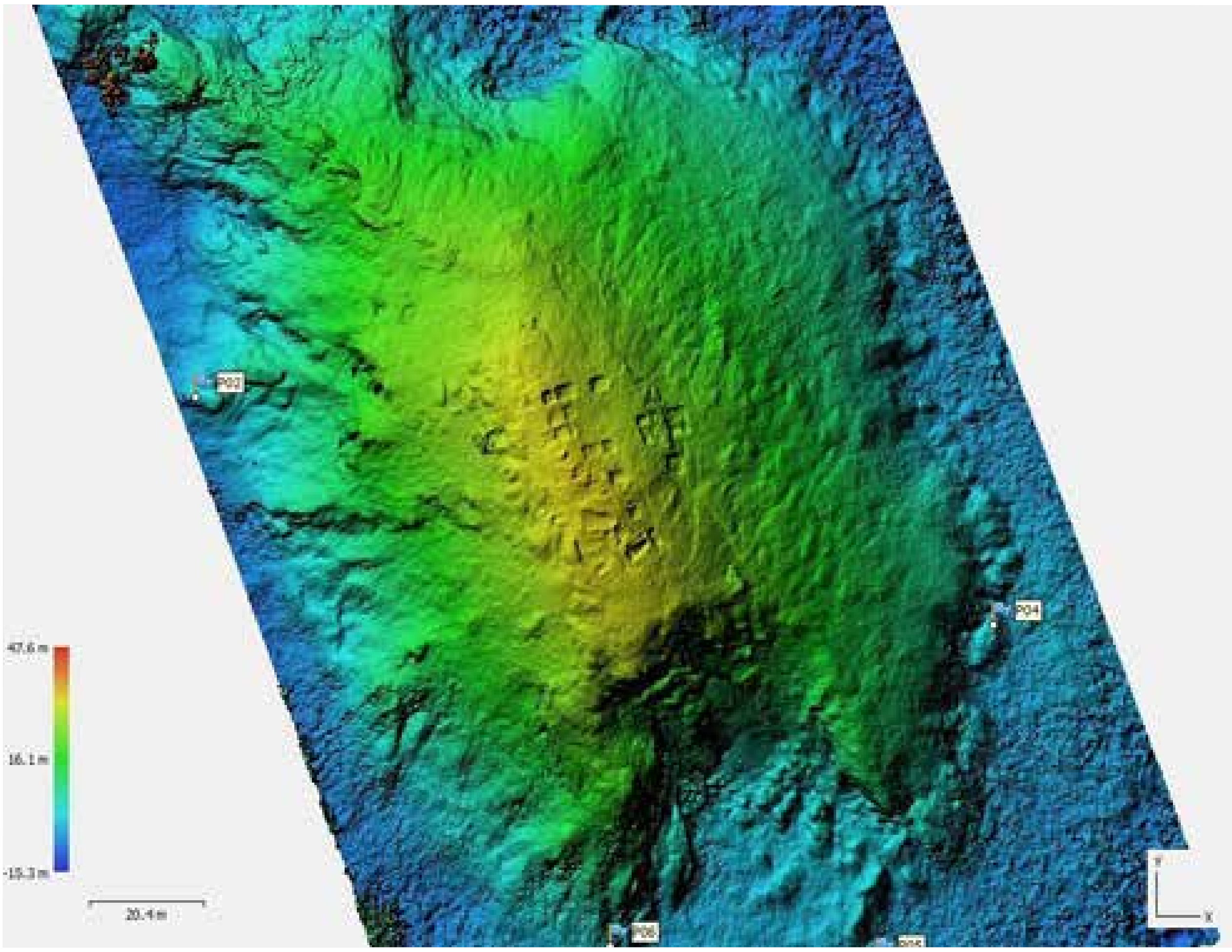

Figure 4. Dhaskalio, Digital Elevation Model

ture, the evidence of metallurgy and the complexity of remains indicate a rich and complex nature of the archaeological site, with possible antecedents to the later urbanism of major centres such as Knossos (Figure 3).

3D Data Capturing Methodology

The study described in this paper focuses on the 3D modelling and visualisation work, consisting of a top-down multi-scale image-and range-based digital documentation method developed to fulfil all the surveying and archaeological needs and exploit all the intrinsic potential of current geomatics techniques.

Image based Techniques

Since the early stages of the excavation in Keros, various kind of sensors and approaches were used for the site accurate documentation (Patias et al., 2009). Due to its portability and reliability, photogrammetry has been extensively used both from aerial and terrestrial platforms.

During 2008 an aerial survey was realised by means of an Unmanned Aerial Vehicle (UAV) with the main aim being to create a Digital Elevation Model (DEM) of the island of Dhaskalio, providing an overview of the site morphology. With the main aim to scale the model to real-world measurements natural features of the archaeological excavation were used as GCPs and CPs, bearing a RMS error of 4 cm (Figure 4).

During the 2016 and 2017 seasons UAV airborne photogrammetry continued to be used to create DEMs, orthophotos and 3D mesh models, and terrestrial photogrammetry was added to the spatial recording methods of the excavations. Terrestrial photogrammetry held the goal to create a 3D model for each excavated context so that a trench could

Figure 5. Trench L deposit, image-based 3D model

be virtually re-excavated at any time in the future. In the field, photographers use handheld 16 MP cameras take between 30 and 300 image captures, according with the trench dimensions (Figure 5). The camera parameters have been set as following: Focal Length 22mm; ISO 100, f/8. A number of coded targets are captured in the scene as well with a twofold final goal: georeference each deposit in the same reference system and apply a metric scale to each three-dimensional reconstruction. The typical photogrammetric workflow has been applied, consisting of three main steps, namely: image correspondences detection, bundle adjustment and dense image matching (Remondino et al., 2014).

At the end of the photogrammetric documentation process, each of the individual excavation units are separately documented as a single 3D model,subsequently to be re-composed and merged within a single diachronic 3D model, while maintaining their geometric shape, which corresponds to the excavation process itself. Thus, the entire excavation volume with its features, material culture remains as they were found, and architectonic remains has been 3D documented and aligned within a single 3D volume.

Trench	2016 Excavation	2017 Excavation
A	√	√
B	X	√
C	√	√
E	X	√
F	**X**	√
H	√	√
L	√	√
N	**X**	√
SB	√	X
Wall A	√	X
North Wall	√	X

Table I: Terrestrial Laser Scanning Surveys, documented trenches

Range Based Technique

Two range-based surveys were performed at the end of each archaeological campaign (2016 and 2017) with the main aim being to document the trenches and the whole progress of the excavation during a one-year period (Δt). Moreover, during 2017, new

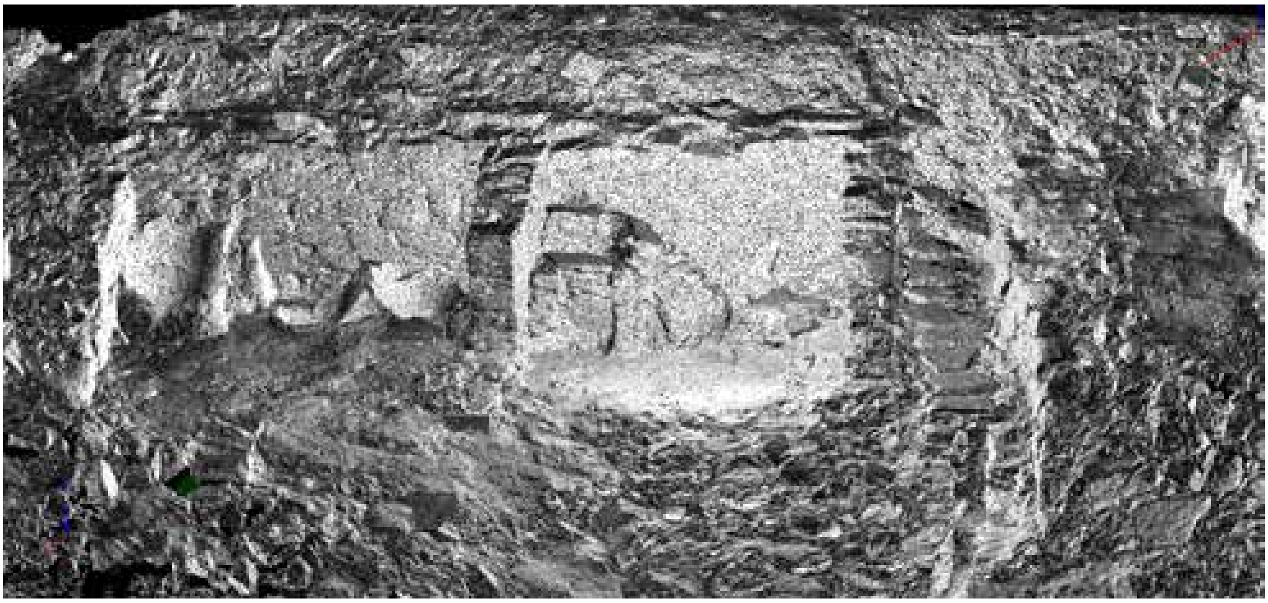

Figure 6. Trench H, Terrestrial Laser Scan 3D model

trenches were opened and documented for the first time (Table I). Thus, trenches that were excavated two years in a row were documented twice, while trenches opened in 2017 were documented once (Further TLS survey also took place in 2018, not further discussed here).

The range-based survey was realized using two Terrestrial Laser Scanners (TLSs) yielding an average distance scanner-object of 5 meters with a mean resolution of 3.5 mm per scan. A standard post processing pipeline, using JRC Reconstructor software, was then applied (Mills and Andrews, 2011). After the range maps registration, which resulted in a mean RMS error of ~5mm, each trench was manually cleaned and filtered in order to remove external noise and unwanted data. A merged model for each single trench was finally created with an average spacing of ~1 cm (Figure 6). The number of scans per trench was a-priori planned to capture all the archaeological attributes visible at the end of each excavation campaign (Table II). Since the extent of each area was slightly expanded between the two seasons, in 2017 the number of scans was increased to capture newly unearthed archaeological features in depth.

Exploiting the photogrammetric GCPs network, collected by means of a DGPS, each point cloud was finally georeferenced in the local reference system, so to meet the requirements for the integration in the web-based visualization system described below.

Trench	Number of Scans 2016	Number of Scans 2017
A	19	58
B	X	25
C	12	36
E	X	19
F	**16**	32
H	**21**	37
L	**13**	30
N	**X**	19
SB	**7**	X
Wall A	**21**	X
North Wall	**11**	X

Table II: Number of stations per single trench

Digital Preservation - Browser-Based System

With the main aim of creating an easy-to-use interactive platform for the Keros archaeological site, open both for professional and general use, all the models and 3D information have been organised in a single web-based interactive application. In accord with the initial pyramidal approach, the user is able to browse the virtual objects from a landscape to a layer-by-layer scale in the same virtual environment. The web-based system, which can be exploited using

Figure 7. Web visualization system

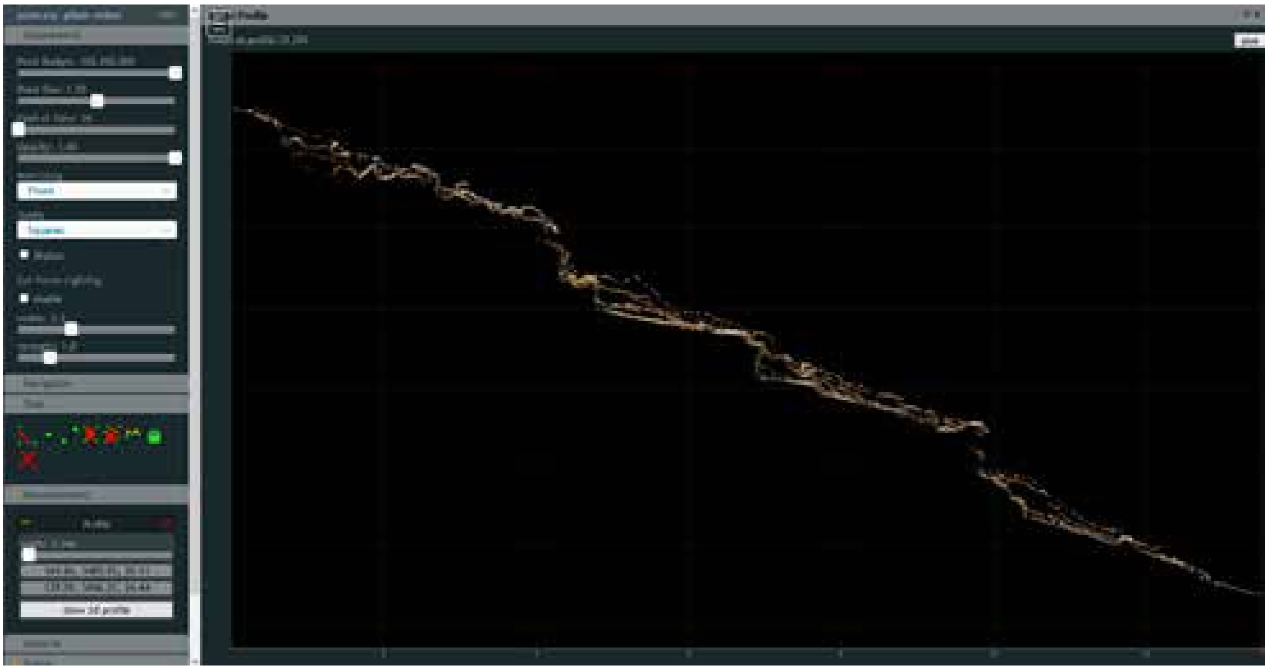

Figure 8. Trench L, deposits sequence

traditional WebGL enabled browsers, is built over an open-source viewer, allowing for the interactive streaming of point cloud. The digital platform is based on the objective of creating an open and scalable system which is able to display different kinds of 3D objects in the same web environment (Figure 7). Through the proposed database architecture, high-resolution 3D models consisting of millions of points and RGB values are available online via the open source WebGL based Potree viewer (Schutz and Wimmer, 2015). Potree is a point-based rendering solution specifically developed for visualizing large point clouds using standard web-based technologies. It is capable of easily providing a responsible interactive viewer that only requires a traditional web browser (WebGL enabled), freeing the user

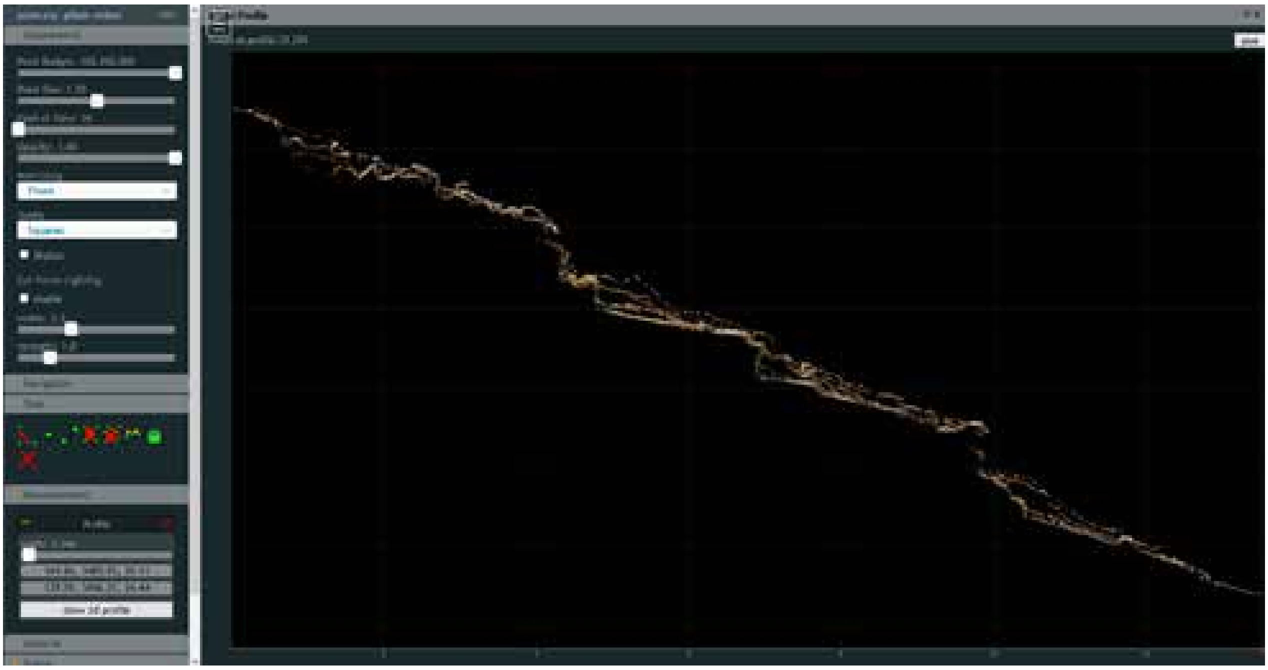

Figure 9. Web visualization system

from any configuration issues or specific software. Potree point cloud files are encoded in an octree data structure using a dedicated converter (Schutz, 2018) guaranteeing a high level of content protection and security.

The selected viewer features the ability to:

- visualize 3D point clouds online; measure distance, compute volumes and areas;
- extract, visualize and download sections;
- link with external resources (metadata) through dedicated hotspots located on the 3D interactive point cloud.

A virtual excavation diary is available according with the following multi-scale data structure:

the first level of information is represented by the Digital Elevation Model (DEM) acquired from an aerial platform covering the entire island of Daskhalio; at ground level, each trench is visible as a layer-to-layer 3D documentation, allowing to switch among deposits and analyse their morphological features and relationships (figure 8);

finally, a 3D multi-temporal (yearly) laser scanning model of each trench is available (Figure 9).

All the different levels of information are available through interactive hot-posts located in the 3D virtual environment.

Conclusion

This work proposed a comprehensive and interactive tool for the visualization of the excavation of the rocky islet of Dhaskalio, exploiting an open-source web-based platform composed of different level of details (LODs). First of all, a pyramidal multi-level and multi-sensor 3D modelling strategy through the use of different kind of active and passive sensors has been illustrated.

Thereafter, the paper focused on the visualization platform which was built to allow the final users, belonging either to the scientific community or a public audience, to analyse the 3D environment from a landscape to a layer-by layer perspective. The proposed technologies have shown the reliability of data streaming of high-resolution three-dimensional models, providing smooth online interaction and visualization.

Since the island of Keros and Daskhalio have been deemed inaccessible due to conservation and scientific issues, the proposed web system could allow users to access and virtually experience sites otherwise impossible to visit in the near future.

Future Works

Future work will integrate this output with the photogrammetry models, allowing a user to virtually re-excavate the site by visualising contexts in 3D, the stratigraphic relationships, and the sequence of context deposition (and removal). It further envisaged that as the GIS platform develops 3D models may ultimately be integrated within it.

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