Unmanned Aerial Vehicles and the Multi Temporal Mapping Results of the Dispilio Lakeside Prehistoric Settlement

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Abstract. In this paper the authors present the evolution of the Unmanned Aerial Vehicles (UAV) and photogrammetric processing software technology through the multi temporal mapping of the lakeside Palaeolithic settlement of Dispilio (Kastoria, Greece). The study of the settlement initiated in 2006 using a Remote Control (RC) Helicopter, which was not equipped with an automated navigation and image acquisition system. Currently a multi-copter drone is used that can demonstrate flight stability, is capable of hovering in small heights and is equipped with an automated navigation and image acquisition system. With respect to the photogrammetric processing software at the start of the study specialized single image processing software like Bentley IRAS/c® were used for the production of rectified images, followed by the use of stereo image processing software like LPS® (Erdas) that have the ability to produce B/W Digital Terrain Models (DTM) and ortho rectified images. Currently specialized multi photo processing software is used like Agisoft Photoscan® or Imagine UAV® (Erdas) that the ability to produce dense coloured point clouds and ortho rectified images.

Keywords: UAV · Photo processing software · Laser scanner
DSM · DTM · Orthophotos

1 Introduction

According to the definition which was given by the association UVS International - an international non - profit association registered with the Chamber Commercial of Hague, unmanned aerial vehicles (UAV) (or Remotely Piloted Vehicle (RPV), Remotely Operated Aircraft (ROA), Remotely Piloted Aircraft (RPA) and Unmanned Vehicle Systems (UVS) are aircrafts designed to operate without the presence of pilot [1].

The documentation of Cultural Heritage has been one of the earliest application areas of UAVs. There are several reasons for this [2–21]:

- The archaeological sites require a very detailed and a large-scale mapping (normally 1:50–1:500). This requirement cannot be met by regular aerial photography, due to high flying height, small scale and relatively low image resolution.

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- Additional, UAV overcomes difficulties of ground surveys, as terrain restrictions, country restrictions, high costs and most importantly due to limited amount of ground detail that can be mapped.
- Documentation speed and timely mapping are additional important factors of advantages of UAVs.

The first experiment was a 3 m long airplane (fixed wing UAV), with a flying height of 150 m [19], which was followed by the first model helicopter (rotary wing UAV), with a flying height up to 100 m, equipped with a medium format Rolleiflex camera in 1980.

During the course of time, UAV technology is established as a preferred solution to CH aerial documentation, since additional benefits have been proved [2–21]:

- Decrease of technology costs with the use of low cost and low weight gyroscopes, GPS, INS, etc.
- Estimation of the orientation elements of the camera, thus decrease of the time of the photogrammetric procession of data due to higher accuracy sensors.
- Potential increase of the payload which permits the use of a variety of multispectral sensors and Lidars.
- Capacity of immediate flight and friendly navigation tools, even in areas that - mainly for military reasons- the flights are prohibited.

In this paper the authors present the evolution of the Unmanned Aerial Vehicles (UAV) and photogrammetric processing software technology through the multi temporal mapping of the lakeside Palaeolithic settlement of Dispilio (Kastoria, Greece, Fig. 1).

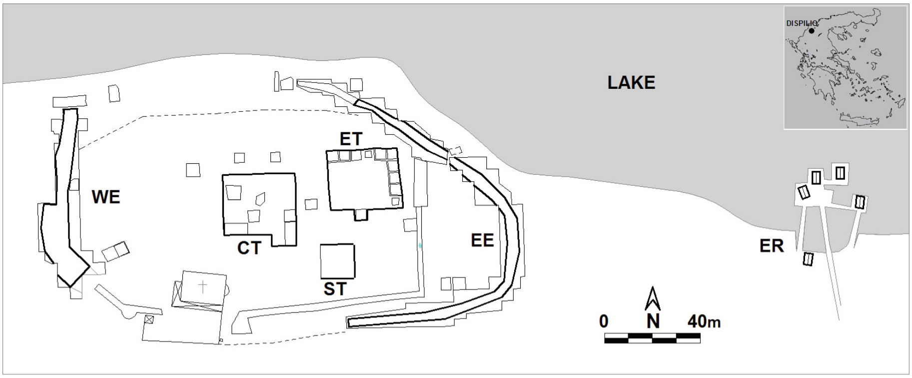

Fig. 1. The archaeological site of the prehistoric Dispilio settlement with the sites: West wall-WE, Central trench-CT, East trench-ET, East wall-EE, South trench-ST, and the modern day representation of the huts-ER.

2 Study Area

The Prehistoric settlement of Dispilio is located north of the modern Dispilio settlement at the south shore of Lake Orestiada. The settlement was discovered in 1932. It was inhabited between 5,500 and 3,500 B.C and covered an area of approximately 20,000 m^2. The pitched roof huts were constructed using wooden structural elements (coniferous trees). They were seated in platforms located above the lake's water surface. The stone wall which embraced the buildings and mainly protected them against the water is dated back to the last years of Bronze Age or at the begging of Iron Age (13–10 century B.C.). Up to date 5,000 m^2 have been excavated (left part of Fig. 1) from an area of approximately 17,000 m^2. Among the retrieved artefacts the wooden inscription which resembles Linear A scripture occupies the top place. It is the older writing sample in Europe as it is dated, based on radio timing, back to 5,250 B.C. Close to the settlement in the east of the archaeological site there is a modern time representation of the Neolithic huts (right part of Fig. 1, ER) [22, 23].

The authors have realized numerous surveys of selected parts of the archaeological site form 2006 and onward using various documentation equipment like total stations, terrestrial laser scanners, RC Helicopter (Fig. 2a). Currently they are equipped with a modern multi copter drone (Fig. 2b). During the testing of the new equipment the full extent of the archaeological site of Dispilio was 3D modelled along with the modern representation of the Neolithic huts (Fig. 1).

3 Multi Temporal Survey of the Site of Dispilio Using Various Digital Sensors and Photogrammetric Processing Software

In 2006 the acquisition of aerial imagery and the production of orthophotos of the west wall (Fig. 1, WE), and the central trench (Fig. 1, CT) of the Dispilio prehistoric settlement was assigned to the AUT (Aristotle University of Thessaloniki) team. The west wall part had a length of 60 m and a width of approximately 15 cm (Fig. 1, WE), while the central trench covered a 30 by 30 m area (Fig. 1, CT). The RC Helicopter equipped with an Olympus C-50 5Mp camera (Fig. 2a) was used for the aerial imagery acquisition. Due to the absence of an automated navigation and image acquisition system the images were acquired manually.

A total of 194 images were acquired. 124 covered the west wall (Fig. 1, WE) and 71 covered the central trench (Fig. 1, CT). The flight height was between 6 and 50 m (in some extreme cases it reached 2 m) leading to a spatial resolution of 2–17 mm, respectively. The ground control points were using the Greek Coordinate reference system (GGRS) 87. Natural elements and artefacts were used as control points. Following the image acquisition well defined points were selected in the images and measured in the field using a total station. For the photogrammetric processing of single images and the creation of mosaics the Erdas Imagine® software was used. The processing resulted in an accuracy of 4–5 cm for the west wall rectified images, leading to the production of 1:200 scale orthophotos (Fig. 2c). Respectively the rectified images

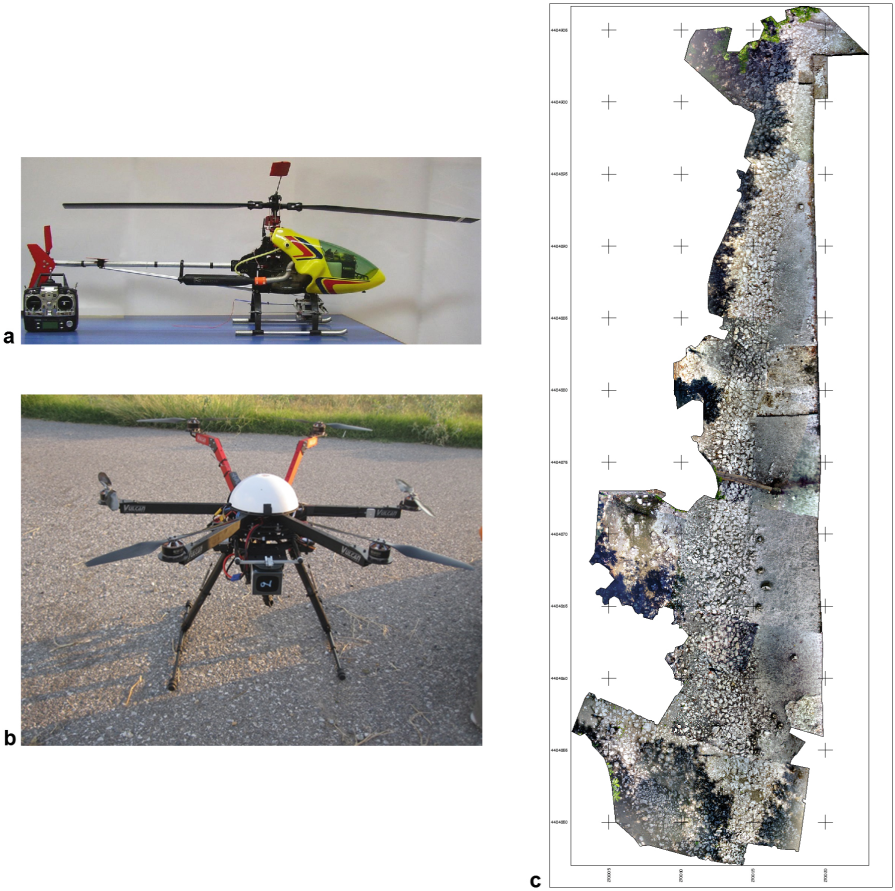

Fig. 2. a. The RC Helicopter. It has a Lifting capacity of 8 Kgr and it is not equipped with an automated flight control and image acquisition. Length 1.39 m., width 0.15 m., Propeller length 1,53 m., weight 5.10 Kgr. The camera mounting is located in the bottom part of the helicopter. b. The new multi copter drone. c. The 2006 orthophoto (5 × 5 m grid) map of the west wall (Fig. 1, WE).

of the central trench demonstrated an accuracy of 1–2 cm, leading to the production of 1:50 scale orthophotos (Fig. 3).

In 2007 the production of orthophoto maps of the east and central trenches (Fig. 1, EE and CT) was assigned to the AUT team. The images were acquired using the RC Helicopter with a flight height of 5 to 50 m., resulting in images with spatial resolution of 2 to 17 mm respectively. In total 410 images were acquired using the Canon 400D 10.1 Mb camera. 250 covering the central trench (Fig. 1, CT) and 160 covering the east trench (Fig. 1, EE). Pre-defined ground control points (tennis balls) measured in GGRS87 were used for the photogrammetric processing. The single photo processing was realized using Bentley IRAS/C. The accuracy of the produced ortho rectified images was 1 to 2 cm for both trenches, leading to the production of 1:50 scale maps (Figs. 3 and 4).

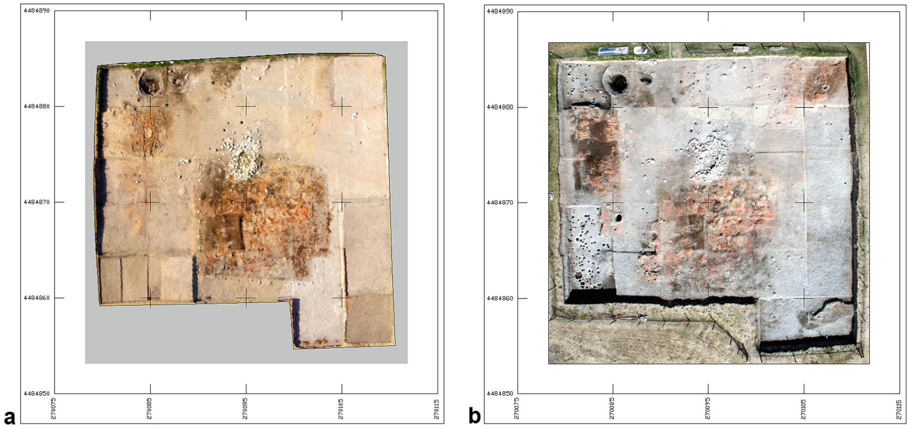

Fig. 3. a. The 2006 orthophoto map (10 × 10 m grid) of the central trench (Fig. 1, CT). b. The 2007 orthophoto map (10 × 10 m grid) of the same position.

Fig. 4. The 2007 orthophoto map (10 × 10 m grid) of the east trench (Fig. 1, ET).

In 2009 the surveying of the east wall was assigned to the AUT team (Fig. 1, EE). In total 77 ground control points were measured using the GGRS87 reference system. In addition 20 images were acquired (from an average height of 8 m) using the RC Helicopter equipped with the Canon EOS 400D 10.1 Mp camera. The stereo photogrammetric processing of the acquired images for the production of the B/W Digital Terrain Model (DTM), the orthophotos, and the orthophoto mosaics was realized using the Erdas Imagine® LPS software. The accuracy of the produced orthophotos was 1–2 cm leading to the production of 1:50 scale orthophoto map (Fig. 5).

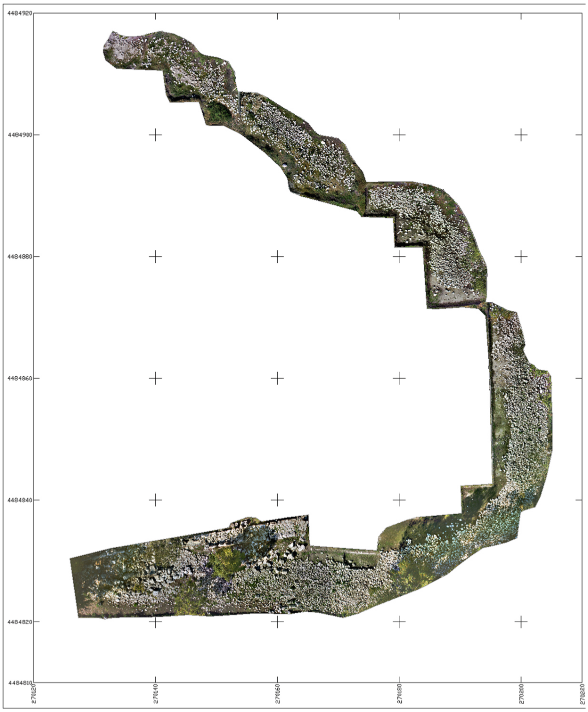

Fig. 5. The 2009 orthophoto map (20 × 20 m grid) of the east wall (Fig. 1, EE).

4 Stratigraphy Mapping Using Laser Scanner

For the mapping of the stratigraphy of the trench (ST) in 2009, the following procedure was applied: at first, the trench facades were scanned using the Optech ILRIS 3D laser scanner, then terrestrial photographs were taken and finally the orthophotos were produced. Each trench façade (side wall) was individually scanned from a distance of approximately 20 m with a resolution of 5 mm. The scans were processed using Innovemetric Polyworks software. At first the 2 scans for the North and South trench facade were merged and then all the scans were merged to a final point cloud. Finally the 3D model (TIN model) of the trench was created and processed in order to fill any holes in the model. After the scanning, terrestrial photographs were also taken. For the creation of the orthorectified images of the side walls of the two trenches, Erdas Imagine software used the calibration archive and the final cloud of the 3D points. The accuracies of the resection solutions were from 0.1 to 0.2 mm and the pixel size of all the orthorectified images of the faces (for example Fig. 6) was 0.2 mm.

Fig. 6. 3 stratigraphies of the north trench-ST. a. Result of two scans with a spatial resolution of 5 mm and a total of 3,382,495 3D points. b. Result of one scans with a spatial resolution of 6 mm and a total of 840,400 3D points. c. Result of two scans with a spatial resolution of 6 mm and a total of 1,782,669 3D points.

5 The 3D Mapping of Dispilio Using a Multi-copter Drone and Image Processing Using Agisoft Photoscan®

5.1 Multi-copter Drone

The multi-copter drone (Fig. 2b) is equipped with 6 electric motors. It can be navigated either using the remote control or the ground station control software. It can lift off and/or land vertical and has the ability to hover at any height. Its on board equipment and control software allows for automated lift off/landing, planning and realization of a predefined flight and image acquisition. The camera gimbal is capable of 180° vertical rotation (±90° from nadir) during flight. It is also equipped with a live video transmitter that allows the ground control station to receive video in real time during the flight. Its lifting capacity (not taking into account the system's weight) is 2.5 Kgr. That capability allows the mounting of different kind of sensors. Its operational flight time is 15 min.

5.2 Mapping of the Archaeological Site and the Modern Time Representation of Dispilio

The main focus of this study was to test in real time conditions the automated navigation, planning, and image acquisition systems (acquisition of vertical and oblique images) and not the production of highly accurate orthophoto maps. As a result the ground control points were acquired from existing ortho rectified images of the national cadastre [24] with an estimated accuracy of 0.5–1 m, and not measured using GPS or a total station. Furthermore during this mission the creation of coloured dense point clouds, and the creation of very high spatial resolution orthophotos using the Agisoft Photoscan® software was also studied.

The images were acquired using a multi copter drone equipped with the Canon EOS 1200D 18Mp camera from a height of 110 m. Following the planning of the flight (Fig. 7) and the initiation of the survey a total of 19 images were acquired with a scale of 1:6,500, spatial resolution of 2.8 cm and ground coverage of 145 × 97 m per image. The photogrammetric processing (stereo, coloured dense point cloud generation, and production of orthophotos (Figs. 8, 9 and 10) was realized using

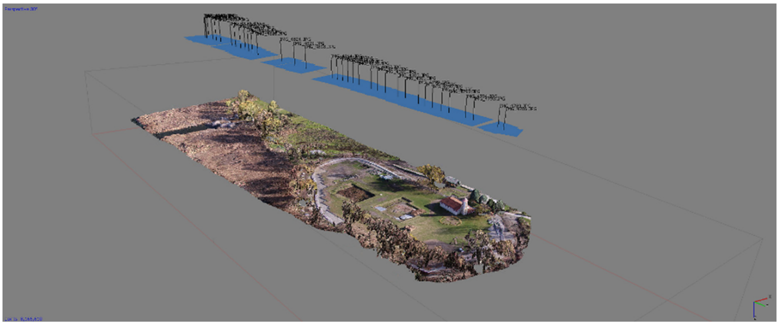

Fig. 7. The image acquisition positions.

Fig. 8. Orthophoto map (50 × 50 m grid) of the archaeological site and the modern time representation of the huts.

Fig. 9. Part of the Fig. 8 orthophoto map displaying the central and east trenches (Fig. 1, CT and ET).

Fig. 10. Part of the orthophoto map of Fig. 8 displaying the site of the modern time representation of the huts.

Agisoft PhotoScan®. The accuracy of the ortho rectified image covering the archaeological site and the modern time representation of the Dispilio was 0.5 m. The produced digital surface model and the 3D photo realistic textured model are presented in Figs. 11 and 12.

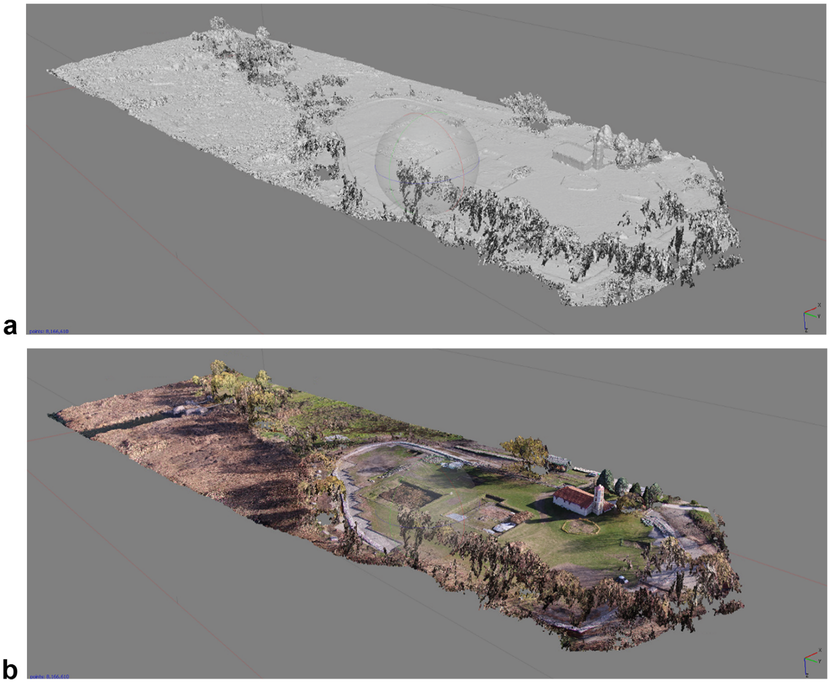

Fig. 11. a. Digital Surface Model (DSM). b. The 3D photorealistic textured model of the archaeological site and the modern time representation of the huts.

Fig. 12. a. Digital Surface Model (DSM). b. 3D photorealistic textured model of part of the archaeological site.

5.3 Mapping of a Part of the West Wall

For the high resolution mapping of a part of the west wall (Fig. 1, WE) oblique images were acquired using the multi copter drone with a flying height of 4 to 25 m. Equipped with the Canon EOS 1200D 18Mp Camera. In total 13 oblique images with a scale varying between 1:1,000 and 1:600 were acquired (Fig. 13). The images covered areas between 26 × 17 m and 13 × 9 m, with a spatial resolution of 0.5 to 0.25 cm. The processing was realized using Agisoft PhotoScan® (Figs. 14 and 15).

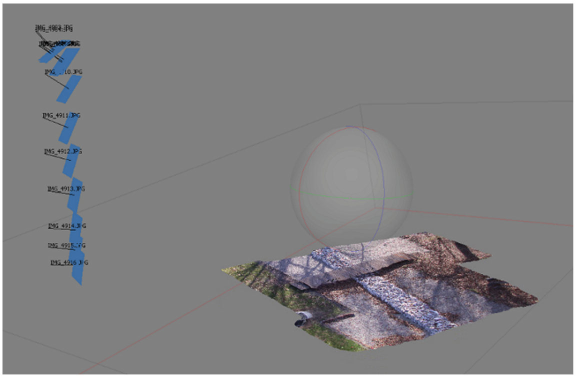

Fig. 13. Image acquisition positions.

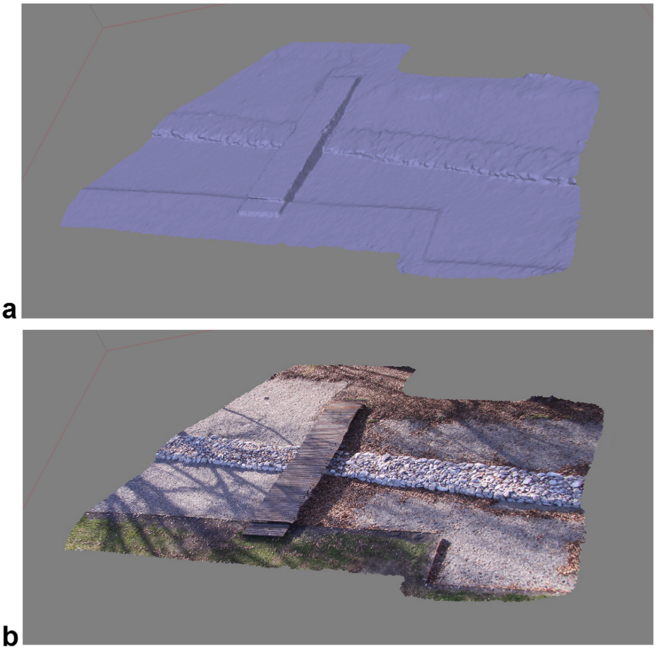

Fig. 14. a. Digital Surface Model. b. 3D photorealistic texture model of a part of the west wall.

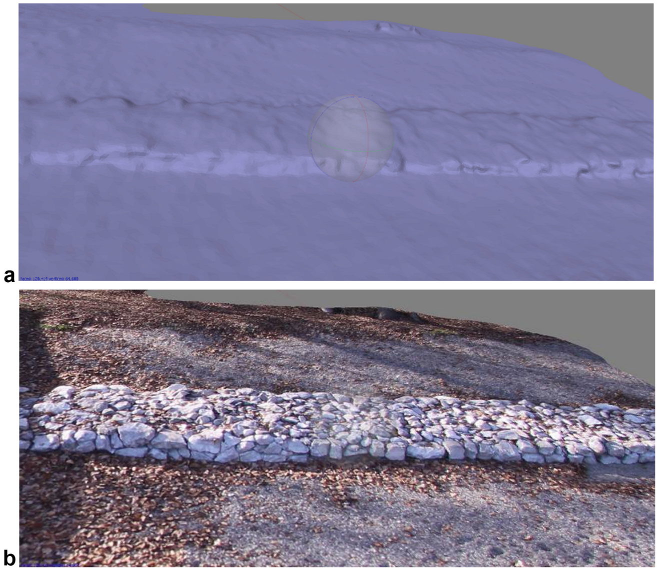

Fig. 15. a. Digital Surface Model. b. 3D photorealistic texture model of a part of the west wall.

6 Conclusions

UAV, digital sensors and photogrammetric processing software technology is constantly evolving presenting new opportunities for the utilization of, earth's surface and its objects, images. Currently easily navigated UAV's with flight stability and automated navigation and image acquisition systems are easily available. Furthermore the capability of hovering and acquisition of vertical, oblique, and horizontal images are some of their present advantages. In addition they also have the capability to mount LIDAR, thermal, multi spectral, and other sensors. In cases that UAV's cannot be used for photogrammetric modelling of objects, other sensors like terrestrial laser scanners are utilized to document them. Finally low cost processing software allows multi photo image processing for the production of coloured dense point clouds, very high resolution orthophotos and creation of optimal presentation results like 3D photo realistic textured models.

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