Image based Aerial 3D Documentation of Inaccessible Archaeological Sites using UAS

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Abstract: The following paper refers to the Large-Scale Documentation of Cultural Heritage in extreme regional and environmental conditions, with the use of Unmanned Aerial Systems (UAS). Three large scale survey sites in Greece are presented, all located in Southern Greece at the Peloponnese region. Case studies are: The Old Philosopher's Monastery, the Penteskoufi Fortress, and the Acrocorinth Castle. The paper focuses on the encountering difficulties on site, the methodology and techniques used for surveying, the workflow followed during documentation and the deliverables of each study.For each case study, detailed documentation of the difficulties faced on site due to inaccessibility takes place. The most common problems for the working team where: extremely bad or quickly changing weather conditions, dense vegetation that covered the surveying sites, frequent rock falling, lack of power charging spots near the site and the inability of transporting heavy equipment. Additionally, the combination of methods applied to overcome every challenge is elaborately presented. The sites were surveyed with the use of Unmanned Aerial Systems supported with high accuracy geodetic equipment. Stereoscopic Photography took place not only in vertical and horizontal position, but in diagonal also, in order to capture detailed aspect and all the ground folds. Finally, using 3D Photogrammetry, billion numbered Point Clouds, Digital Surface Models (DSM), Digital Elevation Models (DEM), 2D Cad Blueprint visualizations and Orthophotomosaics were generated.

Keywords: *photogrammetry—aerial—inaccessible—documentation—large scale—castle—3D*

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Old Philosopher's Monastery

Precise Documentation & Survey in Inaccessible & beyond line-of-sight UAV flights

The Old "Philosopher's" Monastery is located in the gorge of the Lousios River, south of Dimitsana in the Peloponnese region. The impressive steep gorge extends for more than 15 km and forms an important National Park. The founding of the monastery and the first construction phase dates back to the second half of the 10th century A.C. It is built in a natural cavity of a vertical rock, with a total length of 300 m. The complex has a minimum width of 50 cm and a maximum of 6 m. The smallest preserved height of the Monastery's walls is 3 m while the maximum is 10 m high. A one-kilometer narrow path through the gorge is the only way to access the monastery. The issues to be resolved for the 3D documentation of the monastic complex were:

1. Dense vegetation inside the gorge (tall and thick trees) and the lack of satellite connection prevented the lift-off, of a UAV from a spot close to the monastery. At that time, no vision system stabilizers were commercially available for heavy lift UAVs.
2. Extremely dangerous frequent rock falling, necessitated choosing the fastest possible documentation method. Therefore, a 3D Terrestrial LiDAR Scanner was used in the interior.

The dilapidated condition of the monument, in conjunction with the rockfall and the difficulty of access, required a detailed documentation in the shortest possible time, including both the monastery and the surrounding environment of the natural rock. In the interior of the Monastery natural & artificial GCPs (ground control points) were installed and measured by geodetics, to support the Laser Scanning.[1]

The exterior of the monument was decided to be documented with the use of a UAS and photogrammetry method.[2] The monument had eventually been approached from the opposite side of the gorge, although an automated UAV flight was very difficult due to lack of satellites. Due to the peculiarity of the terrain, there was a limited angle for satellite signal and no mobile phone signal. Beyond Visual Line of Sight (BVLOS) UAV skills, alongside with the aid of sporadic and low accuracy GPS tracking of a handheld GPS unit, were used to overcome the above issues. Many probationary flights took place, in order to define the exact distance and height that the UAV had to fly for best photography results. Four routes at different heights were finally used, delivering more than 14,000 close face shots, of both the monastery exterior walls and the rock formations beneath and above the complex.[3]

The field survey took place from 10 to 17 of April 2014 and a two-month period was required for the processing of the data and the elaboration of the Restoration study. The photogrammetric processing of the photos taken in combination with the 37 terrestrial laser scans delivered:

- Billion numbered Point Clouds,
- Digital Surface Models (DSM),
- Digital Elevation Models (DEM),
- Orthophotomosaics of the facade with a 3 mm pixel size & 5 mm accuracy and
- 2D Cad Blueprint visualizations, both of the Monastery and the rock above.

The geotechnical study for the stabilization of the falling rocks, was significantly aided by the previous derivatives. The 3D created rock model determined the way of transporting building materials for the restoration of the monument. A revealed cavity near the top of the gorge allowed to a special crane move downwards all the materials needed for the restoration.

[1] Terrestrial Laser Scanners used for the survey of the inside: Leica C10 & Leica MS50. Total Station used for the geodetics : Leica MS50.

[2] The used UAS/UAV was a custom made octocopter assembleded & set up by IMANTOSIS.It was set for BVLOS action, with lifting capability of 25Kg in order to resist the gusty winds, equipped with a 5D gimbal & a DSLR camera.

[3] DSLR camera used: Nikon D800 36Mp Full Frame / Lens : Nikon AF-S Micro Nikkor 60 mm.

Fig. 1. Orthophotomosaic / Facade of Old Philosopher's Monastery (© IMANTOSIS [2014]). Details of original Orthophotomosaic: accuracy 1cm / pixel size 3 mm / more than 300 physical targets all measured by robotic total station & 3D Scanner. Processed & Produced in Agisoft Photoscan Software.

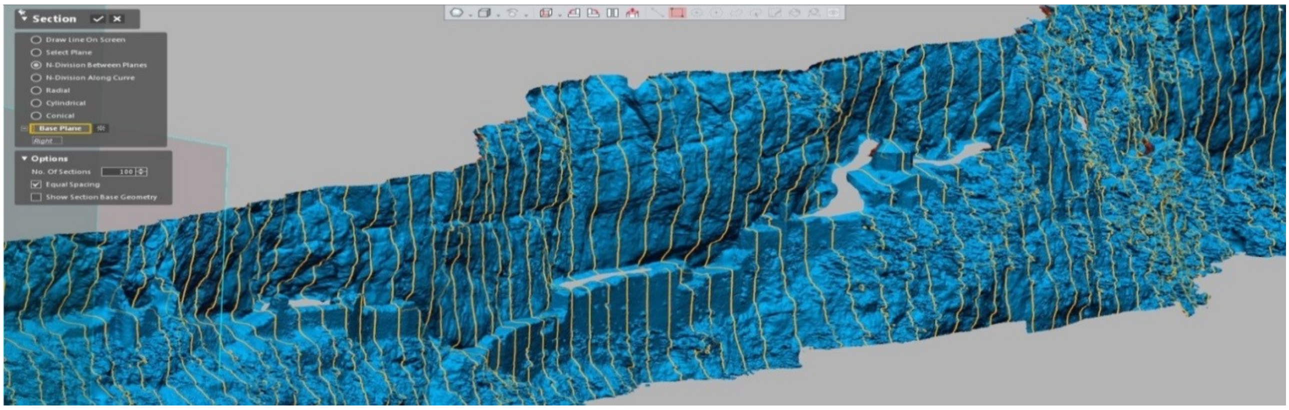

Fig. 2. Digital Surface Model (DSM) & Computer Aided Tomography Scan (CT scan). Facade of Old Philosopher's Monastery & natural rock. Processed & Produced in Agisoft Photoscan Software. Post processed in 3DS Geomagic Studio Design Software (© IMANTOSIS [2014]).

Penteskoufi Fortress

Precise Documentation & Aerial Survey against adverse weather

The "Penteskoufi Fortress" project, encompasses all the methodology deployed on workflow during documentation of inaccessible Archaeological sites. The Fortress is located on one of the two unique elevations of the generally flat landscape near Ancient Corinth, at a height of 500 m above sea level. With 600 m^2 surrounding area and 100 m of the snakelike fortress wall and a rectangular tower, it stands on the peak of a fortified rugged rock, enclosing an area of 8,000 m^2. An one-hour hike in a medium difficulty terrain is needed to reach the Fortress. The survey expedition had to face the following challenges:

1. The gusty winds demanded the use of a UAS capable of lifting heavy loads and operating in difficult conditions of extreme wind resistance and light rain.
2. The dense low vegetation on the fortress hid 80 % of both the monument and its significant elements. A complete clean-up was decided to unveil the fortresses' details. However, due to the rapid regrowth of the vegetation, detailed and precise documentation had to take place rapidly, regardless of weather conditions.
3. The use of 3D Terrestrial Laser Scanner was excluded due to the distance from the provincial road, the hike needed to approach the monument and the inability of transporting heavy equipment. In addition, no suitable area existed for setting up such equipment.

4. Traditional time-consuming measurements supported by geodetics, could not fulfill the requirements of capturing all the details.

The potential loss of details or larger elements of the fortress due to collapse, required detailed three-dimensional representation of the entire monument. The field survey and the processing of the data took place in March 2013. The Survey included the fortresses' surrounding natural area, in order to collect all the necessary scientific evidence that would allow restoration and a reconstruction study to take place in case of a complete loss. An octocopter Unmanned Aerial System was deployed, with a 25 kg lifting capability to withstand the usual 7 Beaufort gusty winds. Automated flights aided by a ground station, performed to acquire 5,000 full frame shots.[4] In order to secure accuracy, the position of the fortress in the Greek Geodetic Reference System, 27 GCPs were measured by a ground GPS/GNSS.[5] Scale accuracy of the digital photogrammetric derivatives was assured by the installation of 300 artificial CPs.[6] For the geometry enhancement of the Digital Surface Model, physical CPs were matched at the office's Photogrammetric Station. Billion numbered Point Clouds, Digital Surface Models (DSM), Digital Elevation Models (DEM) and Orthophotomosaics of the facades with a 3 mm pixel size & 5 mm accuracy were generated.[7] Especially for the snakelike geometry of the walls, the photogrammetric Station had to be fused with algorithms capable of creating an isometric unfolded view of the facades.[8] The 3D rock and fortress model determined areas with a high risk of collapse and others in urgent need of salvage downs.

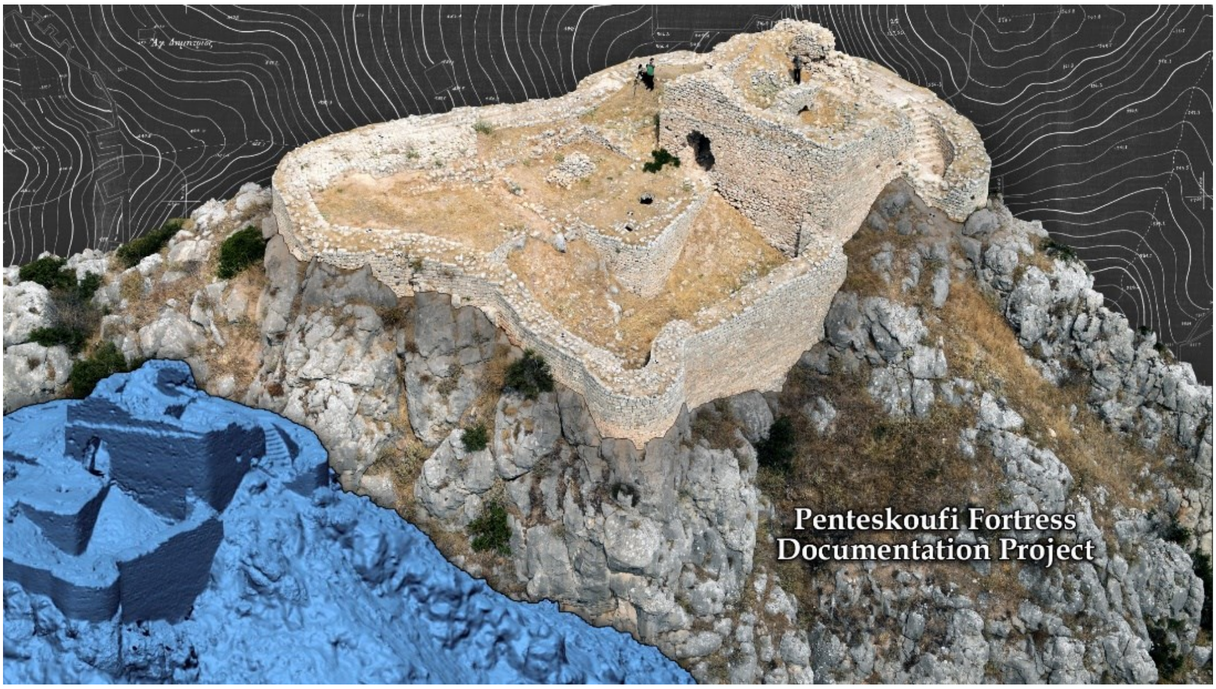

Fig. 3. Aerial View & Digital Surface Model (DSM) / Penteskoufi Fortress (© IMANTOSIS [2013]).

[4] The used UAS/UAV was a custom made octocopter assembleded & set up by IMANTOSIS.It was set for High Wind resistance action, with lifting capability of 25Kg, equipped with a 5D gimbal & a DSLR camera . DSLR camera used: Nikon D800 36Mp Full Frame / Lens Nikon AF-S Nikkor 50 mm.

[5] GPS / GNSS used : Leica Viva GS08plus Receiver.

[6] Total Station used for the geodetics : Leica MS50.

[7] Proccessing Photogrammetry Station : Agisoft Photoscan / Post proccessing : CapturingReality.

[8] Unfolded photomosaic parts produced in Lupos3D. Color refinements were performed in Adobe Photoshop CS6.

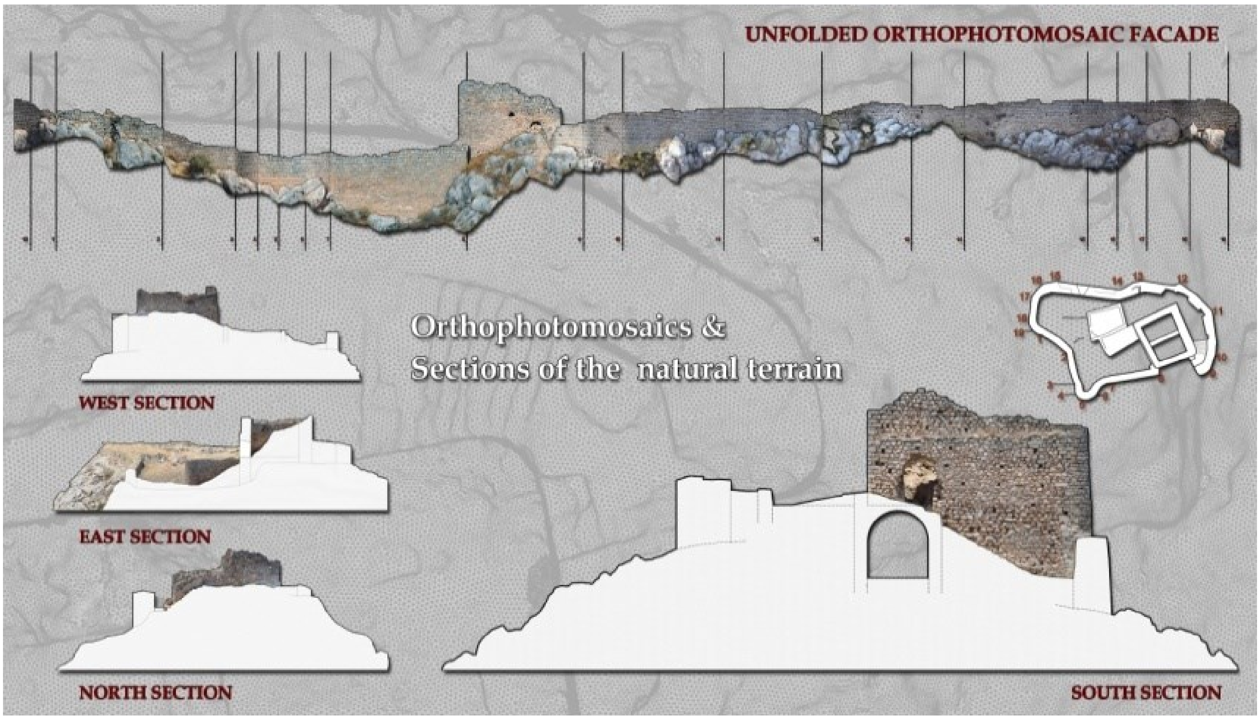

Fig. 4. Orthophotomosaics & natural terrain sections of the Penteskoufi Fortress. Unfold produced in Lupos3D. Color refinement in Adobe Photoshop CS6 (© IMANTOSIS [2013])

Acrocorinthos Castle

Large Scale Precise Documentation

The steep rock of the Acrocorinth rises to the south west of the ancient Corinth. It is dominated by the fortress, also called the Acrocorinth. It was the fortified citadel of ancient and medieval Corinth and the most important fortification in the area, from Antiquity till the Greek War of Independence (1821 A.C.). It lays 600 m high above sea level and its walls run for almost 5.5 km encircling an approximate area of 300,000 m^2.

Three fortification zones lead to the interior of the Castle. Inside the Castle, Remains of various periods such as Mycenean megalithic fortifications, ancient sanctuaries, early Christian vasilicas, Byzantine cisterns, a Frankish tower, a Venetian church, mosques, settlements, and fountains, reveal the significance of the Settlement. Materials in second use, often make it difficult for experts to date and distinguish historical and construction phases.

The field survey took place between September 2013 and April 2014. A six-month period was required for the processing of the data and the production of final derivatives. The team had to deal with common type of problems but on an enhanced scale. UAS large scale documentation involves the use of GIS background. Most of the U.A. Systems use as default, the Google Earth platform as a visual interpretation, to plan the flight missions. In a region with no obstacles, it might be of no concern. On the contrary, where intense terrain is to be documented, involving steep rocks and gorges, mission setup requires high navigation accuracy, aided by precise geographic coordinates. Precision is crucial, to prevent crashing on physical elements, leading to a complete loss of the expensive Aerial equipment and the collected Data. In the Acrocorinthos project, the Google Map location error was more than 30 m horizontally and 5 m vertically, making flights risky.

In order to overcome the risk of damaging the UAV, mission plans were set at gradually inclining levels following the steep and raged anaglyph, keeping photography distance constant by the use of specified Geographical Coordinates. Lack of previous existing documentation surveys to organize the operations in advance led to new ground measuring GPS/GNSS data, that were inserted directly to the UAS algorithm.[9] Stereoscopic Photography took place not only in a vertical and horizontal position but also in diagonal, in order to capture detailed aspect and all the ground folds.

The sheer rock elevation necessitated splitting the Survey into subsections. Moreover, the area covered by the UAV on a single flight was also depending on the prevailing weather conditions. As long strong winds were raising, flight time decreased dramatically due to battery consumption, because of the effort necessary to overcome the wind's resistance.[10] A misplaced and inaccurate flight could lead to increased field-work time, with financial & time derailment consequences. Planned missions that were not performed, after all, led to the loss of all the installed GCPs, which had to be reestablished the day after, as the quality of the measurement was not guaranteed. Targets could have been moved or deformed by weather conditions animals or curious visitors.

Taking all the above into consideration and having the intention of a 3D high accurate photogrammetric documentation, the missions of the UAV were set "traverse" like, trying to achieve a closed-loop survey after the 5.5 km campaign. In addition, one of the major problems faced, was the seasonal changing, as the field operation took more than eight months. For a non-fully automated alignment on a Photogrammetric WorkStation, it is obligatory not only to use artificial control points but also plenty of natural ones. Otherwise, Photogrammetric Station's algorithm may not achieve to detect & solve the geometries & levels. That's due to Photogrammetric Station's weakness to pinpoint the same optical elements on pixels, which change color due to the vegetation, rock movement, subsidence and other – as the seasons pass.

More than 250 aerial missions took place, with more than 170,000 36Mp-high-resolution photos collected data. Fed in a render farm, the photogrammetric station produced a Trillion numbered Dense Point Cloud of 3 mm point spacing. The Point Cloud Accuracy was fused by the dense network of installed ground control points (GCPs) that was acquired by a total station and georeferenced by GPS/GNSS. Some areas were surveyed more than once during the excavations, in order to record all the historical phases. Digital Surface Models (DSM), Digital Elevation Models (DEM) and rendered models were delivered for presentations of the castle.

[9] GPS / GNSS used : Leica Viva GS08plus Receiver / Total Station used for the geodetics : Leica TS06.

[10] The used UAS/UAV was a custom made octocopter assembleded & set up by IMANTOSIS. It was set for High Wind resistance action, with lifting capability of 25Kg, equipped with a 5D gimbal & a DSLR camera. DSLR camera used: Nikon D800 36Mp Full Frame / Lens Nikon AF-S Nikkor 50 mm.

Fig. 5. Aerial Photos & signalization of the main Walls of Acrocorinthos Castle (© IMANTOSIS [2014]).

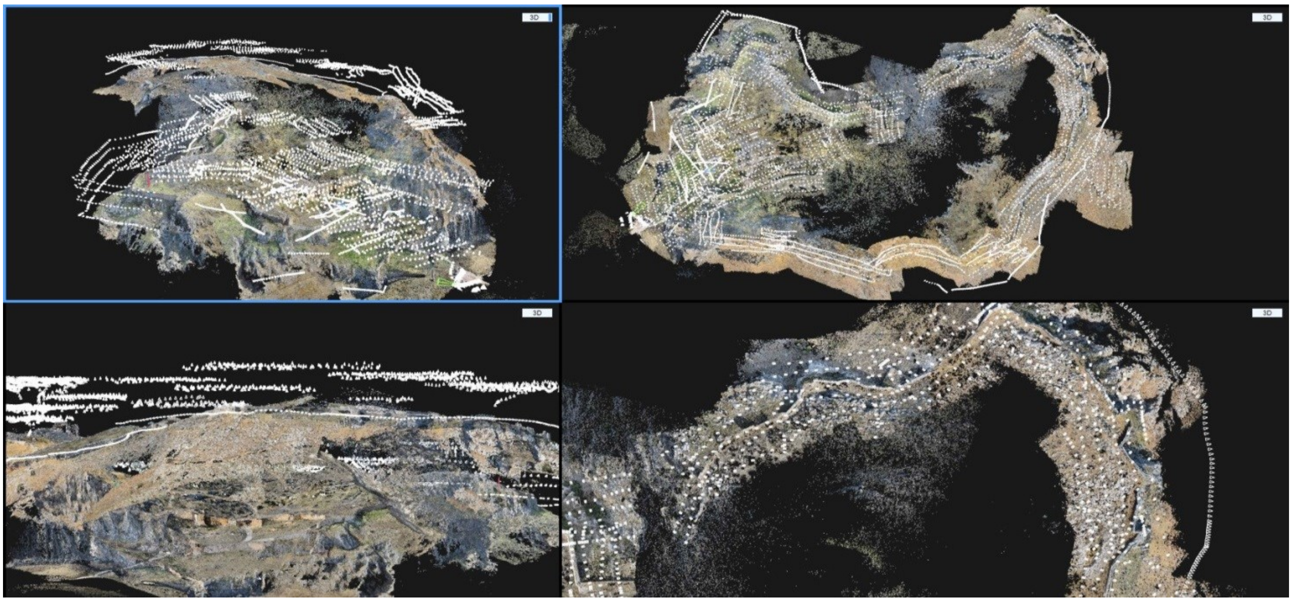

Fig. 6. Snapshots inside the Photogrammetric Station / Photography alignment process. Processed & Produced in Agisoft Photoscan Software. Post processing in CapturingReality Software (© IMANTOSIS [2016]).

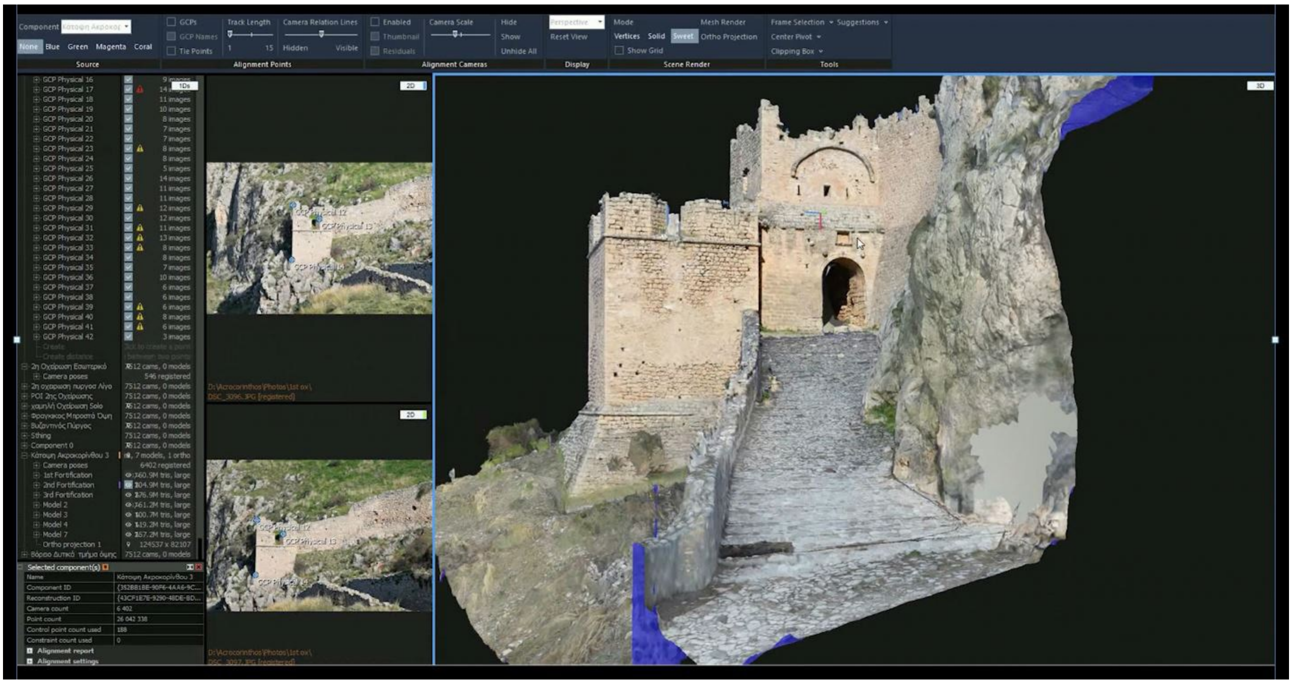

Fig. 7. Snapshots inside the Photogrammetric Station / Virtual Reality (VR) Visualization. Post processed in CapturingReality Software. (© IMANTOSIS [2016]).

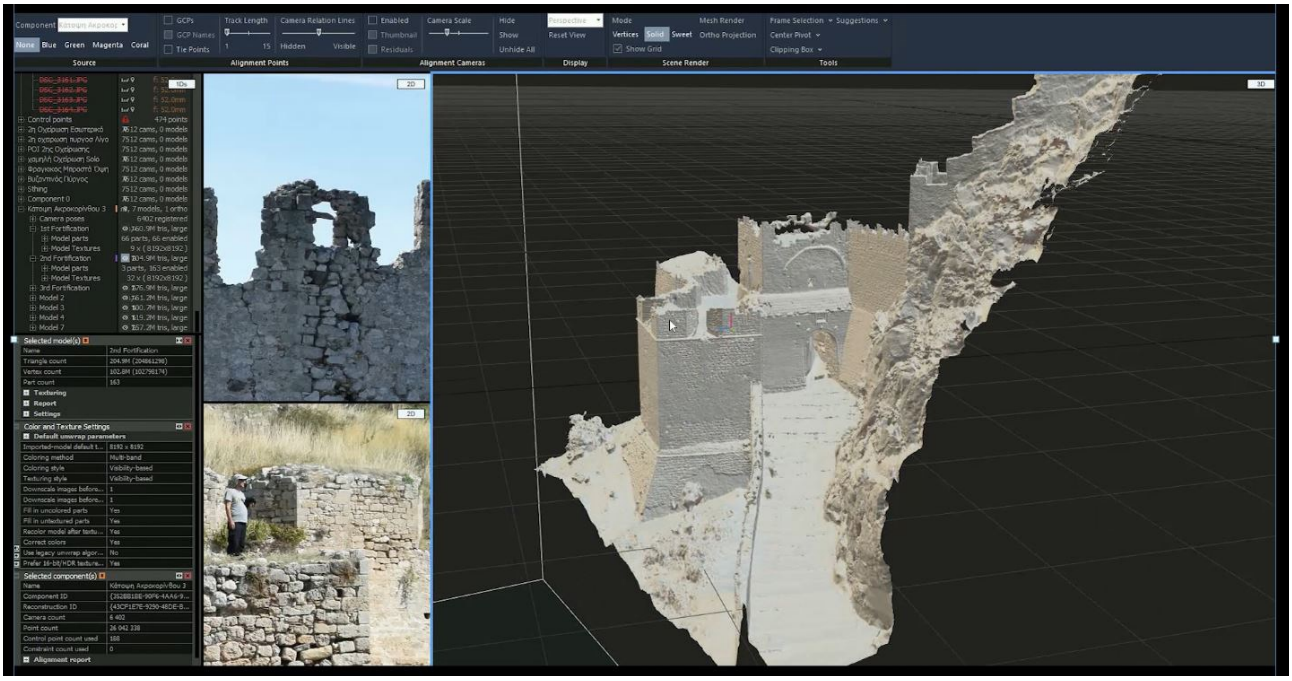

Fig. 8. Snapshots inside the Photogrammetric Station / Mesh Topology Generation & Process. Post processed in CapturingReality Software. (© IMANTOSIS [2016]).

Fig. 9. Orthophotomosaic / Part of West Fortification of Acrocorinthos Castle (© IMANTOSIS [2014]). Details of original Orthophotomosaic: accuracy 1cm / pixel size 3 mm / 50 artificial ground targets (GCPs) & more than 400 physical targets all measured by total station. Processed & Produced in Agisoft Photoscan Software.

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