Creation of 3D infrastructure model from UAV and TLS data in the frame of PROION Project

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ABSTRACT

Mapping and monitoring of the Earth's surface is a three dimensional question. In any geological, hydrological, vegetation science, urban or ecological planning application there is a need for accurate Digital Elevation Model in order to extract the absolute surface elevation and terrain form (slope, aspect, etc.) information. Other applications, including city modelling and simulation, civil infrastructure monitoring, disaster management and emergency response, require 3D building models of high fidelity and accuracy. In the past, aerial photos or high-resolution satellite data and photogrammetry provided the necessary 3D information. In recent years, aerial images acquired by an Unmanned Aerial Vehicle (UAV) and point clouds derived from Terrestrial of airborne Laser scanners have become the mainstream solutions to 3D reconstruction of photorealistic 3D building models due to its cost-effectiveness and convenience. PROION project carries out an infrastructure monitoring methodology based on remote sensing and in situ measurements. Massive infrastructure like the building of Geology Department and Asteri dam in the Western Greece territory are surveyed using data from SAR interferometry, GNSS and micro-accelerometers sensors. In the frame of such a monitoring there is a need for very fine and highly accurate 3D infrastructure (city) model. The specific study evaluates the spatial resolution and accuracy of a 3D model derived from UAV and TLS data and compares it with classical DSM produced by Pleiades data and other high-resolution optical data in the frame of Copernicus program.

Keywords: Infrastructure, point cloud, 3D, DSM, TLS, UAV

1. INTRODUCTION

For the last two centuries, the percentage of people leaving the countryside to live in cities is rapidly increasing; by the year 2050, the current proportion of 55% of the world's population, which already lives in urban areas, is expected to increase to 68% [1]. The phenomenon of urbanization has shaped every demographic and socioeconomic process of urban growth, creating an urgent need for new international policies and practices that focus on the development of urban resilience and sustainability [2]. Thus, there is worldwide a pressure for accurate 3D data in order to better understand and monitor the built environment.

The 3D building reconstruction or 3D infrastructure model is a scientific topic of interest, due to the increasing demand for accurate three-dimensional building models from various fields, such as urban planning, city modelling and simulation [3], [4] civil infrastructure monitoring [5], disaster management and emergency response [6-9], construction, environment safety, navigation, and virtual city tourism. In the past years, the basic procedure of development of 3D building model was based on manual processing of 2D plans and enhancement with the height info, a very slow procedure. For example, it was necessary to measure or digitize the length of all the wall edges to make a wall face. The specific operation was very time-consuming when the target building contains too many edges, and/or there are many buildings to be modeled. Manual building modeling was also proved to be an inaccurate procedure, as the visual measurement of geometric properties (distance/size/area) or the digitization was human depending operation and the experience of the user was critical.

For many years, aerial photos or high-resolution satellite data and photogrammetry provided the necessary 3D information. In recent years, aerial images acquired by an Unmanned Aerial Vehicle (UAV) and point clouds derived from Terrestrial of airborne Laser scanners have become the mainstream solutions to 3D reconstruction of photorealistic 3D building models due to its cost-effectiveness and convenience. Previous studies [10], [11] showed that laser scanning data can be a valuable data source for the automatic building reconstructing. Comparing to digital imagery, airborne and terrestrial laser scanning give explicit 3D information, which enables the rapid and accurate capture of the geometry of complex buildings. In particular, terrestrial laser scanning is able to provide very dense point clouds of building facades, which gives enough raw data from which high detailed 3D building models can be obtained automatically. In recent years, oblique photogrammetry based on aerial images acquired by an Unmanned Aerial Vehicle (UAV) has become one of the mainstream solutions to 3D reconstruction of photorealistic 3D building models due to its cost-effectiveness and convenience [12-16]. The combination of an existing Lidar and orthomosaic dataset (used as reference), with a new aerial image acquisition (including both vertical and oblique imagery) of higher resolution, for the creation of an accurate 3D city model was presented for the area of Kallithea, in Athens, Greece [17]. In another case the development of 3D city model was based on data captured from airborne LiDAR (Light Detection and Ranging) and panoramic images [18].

PROION project [19] carries out an infrastructure monitoring methodology based on remote sensing and in situ measurements. Massive infrastructure like the building of Geology Department and Asteri dam in the Western Greece territory are surveyed using data from SAR interferometry, GNSS and micro-accelerometers sensors. In the frame of such a monitoring there is a need for very fine and highly accurate 3D infrastructure (city) model. The specific study evaluates the spatial resolution and accuracy of 3D data derived from the UAV and TLS data and compares it with classical DSM produced by Pleiades data and other high-resolution optical data in the frame of Copernicus program.

2. 3D MODELS USED IN THE CURRENT STUDY

Five data sets providing elevation info for the buildings and crucial infrastructures in the broader area of Patras are compared in the current study. The main characteristic of these data sets is their height accuracy both in horizontal and vertical axes.

2.1 Cadastral data

The first dataset consists of an orthomosaic and a DSM created for the needs of the Greek Cadastre. The orthomosaic was developed with photogrammetric techniques from digital aerial photographs acquired between the years 2007 and 2009. It covers the whole country and has a spatial resolution of 0.50 m. The respective DSM created from the same imagery has a 5 m × 5 m pixel size and a nominal vertical accuracy better than 2 m. The orthomosaics and DSMs were created by the National Greek Cadastre and Mapping Agency and there was no need for further processing. Both the orthomosaic and the DSM are the most accurate official datasets available in Greece [20]. An update was performed on 2015-2016. Even with the newer cadastral dataset, there is a critical lack of updated information in some areas like the Patras new port infrastructure. In Figure 1, two orthophotos are presented for comparison. At the left, the new port facilities of Partras, as mapped in 2016 for the cadastral, is presented. At the right part, an orthophoto produced from UAV data is shown. In the cadastral orthophoto, a part of the port is under construction and some buildings are totally missing while the UAV orthophoto present the real status of the area.

2.2 Pleiades Stereopairs

The next dataset consists of Pleiades satellite imagery. The Pleiades system comprises two satellites in the same orbit but with 180^o offset. The first satellite was launched in 2011, while the second satellite was launched 1 year later. Each satellite simultaneously collects 1 panchromatic and 4 multispectral bands. The panchromatic band has a pixel of 0.7 m, while the 4 multispectral bands have a pixel size of 2.8 m [21]. Pleiades has the ability to collect 3 images simultaneously (tri-stereo). In more details, the sensor collects a near-nadir (N) image improving the geometry of the classical forward (F) and backward (B) looking stereo pairs. As a result, there is a better retrieval of heights over terrains with high roughness and steep slopes characterized by large areas with shadows. The produced DSMs from the tri-stereo product proved to be well-suited for the analyses of elevation in different geomorphological environments such as mountain glaciers, volcanic ranges, or urban areas [22,23,24]. Moreover, the use of Pleiades data is focused on the multitemporal analysis of DSMs based on multiple acquisitions with the possibility to extract surface and volume changes [22,25]. The combination of the panchromatic and multispectral data are mainly used to produce 50-cm ortho-imagery through fusion algorithms as it was performed in the past for previous SPOT satellites [26]. A could free triplet of the broader area of Patras was processed in ERDAS Imagine Photogrammetry Suite (Figure 2). The three images, the produced Digital Surface Model and the allocation of the ground control points are presented in Figure 2. Three DSMs with a spatial resolution of 1.5 meters and an orthophoto with 0.5m pixel size were produced. According to a previous study [27] these products can be compared with ultra-high resolution UAV data.

2.3 UAV data

A vertical takeoff and landing UAV (Trinity F90+) equipped with a SONY camera (RX1 RII) with 42.4 MP (7952 × 5304 pixels) sensor resolution was used in order to map a part of the University Campus. The specific equipment was purchased in the frame of PROION project in order to create accurate orthophotos, DSMs and 3D point clouds of the sites under monitoring.

During one flight campaign, 434 ultra-high resolution images were collected. A photogrammetric grid with 75% overlap along the track and 70% overlap across the track was executed. The images were imported and processed in Agisoft Metashape software (Figure 3) and an orthophoto, a DSM and 3D point clouds of the university campus were produced. An example of the 3D point cloud of the campus is presented in Figure 4.

2.4 Terrestrial Laser Scanner data

A Terrestrial Laser Scanner (Leica P50) equipped with an external camera (Canon EOS 80D) was used in order to map, ASTERI Dam and the department of Geology in the University Campus. The specific equipment was purchased in the frame of PROION project in order to create accurate 3D point clouds of the sites under monitoring. The scanner collects up to 1 million points per second with a range of 1km. Periodic 3D data collection campaigns are performed in the frame of PROIN project. The 3D point clouds are georefenced to the Greek Geodetic Reference System (EGSA87) using ground control points. In Figure 5, a 3D point cloud of the building of the Geology department is shown.

2.5 Building Block Height Model

The Copernicus Land Monitoring Service (CLMS) provides freely available geographical information on land cover, land use, vegetation state, water cycle and earth surface energy variables, to a broad range of users all over the world working on environmental applications. CLMS information is based on space data combined with other sources. The Urban Atlas (UA) suite of products of CLMS was the first in a series of land monitoring services on so called hotspots addressing urban areas. It was the first service to create harmonized Land Cover and Land Use (LC/LU) maps over several hundred cities and their surroundings. The Urban Atlas adds a spatial component to the statistical data, which enables comparison of urban spatial patterns across Europe. A newer additional information layer available in the UA suite of products service is the Building Block Height Model (BBHM). Building heights within cities are important hot spots as the information can be used to make simple 3D-visualisations of buildings and structures and to assist a range of analytical applications like the infrastructures monitoring. The Building Block Height Model covers 845 European cities and 14 Greek cities (Athens, Thessaloniki, Patra, Irakleio, Larisa, Volos, Ioannina, Kavala, Kalamata, Chania, Xanthi, Katerini, Serres, Trikala) within them. It covers the urban centers and is based on satellite images from high-resolution multispectral sensors (like WV-01, WV-02, WV-03, GE-01 and IK-02) capable of collecting stereo-pairs. At the beginning, a digital surface model (DSM) was generated. Afterwards a digital terrain model (DTM) was derived from the DSM with different filter algorithms and the assistance of Urban Atlas 2012 datasets. The calculation of the normalized DSM was done by a simple subtraction of the DTM from the DSM. It is important to note that because the DSMs are derived from LiDAR and very high resolution satellite information, the initially generated Digital Height Model (DHMs) have a spatial resolution of between 0.5 and 2 meters. For the final product to comply with other similar data sets of European Environment Agency (spatial resolution of 10 meters), a resampling operation was performed to transform the DHM pixels from 0.5-2 m to 10 m.

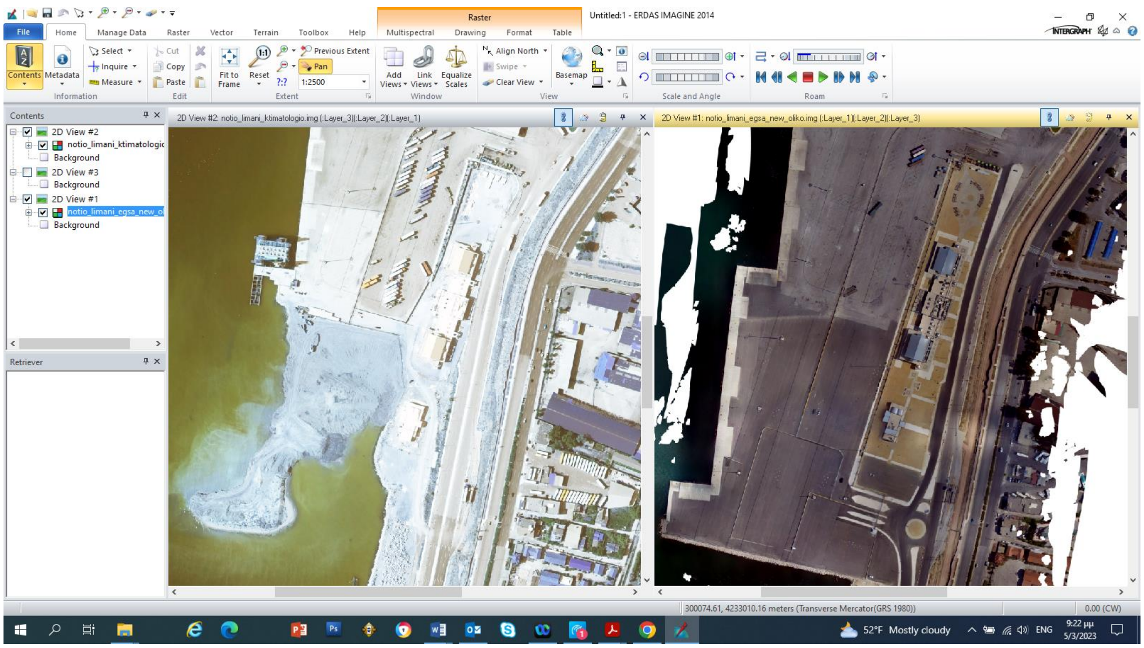

Figure 1. At the left, orthophoto of the new Patras Port facilities in 2016 as mapped from the Greek Cadastral. At the right, the same place 5 years later as mapped from UAV data.

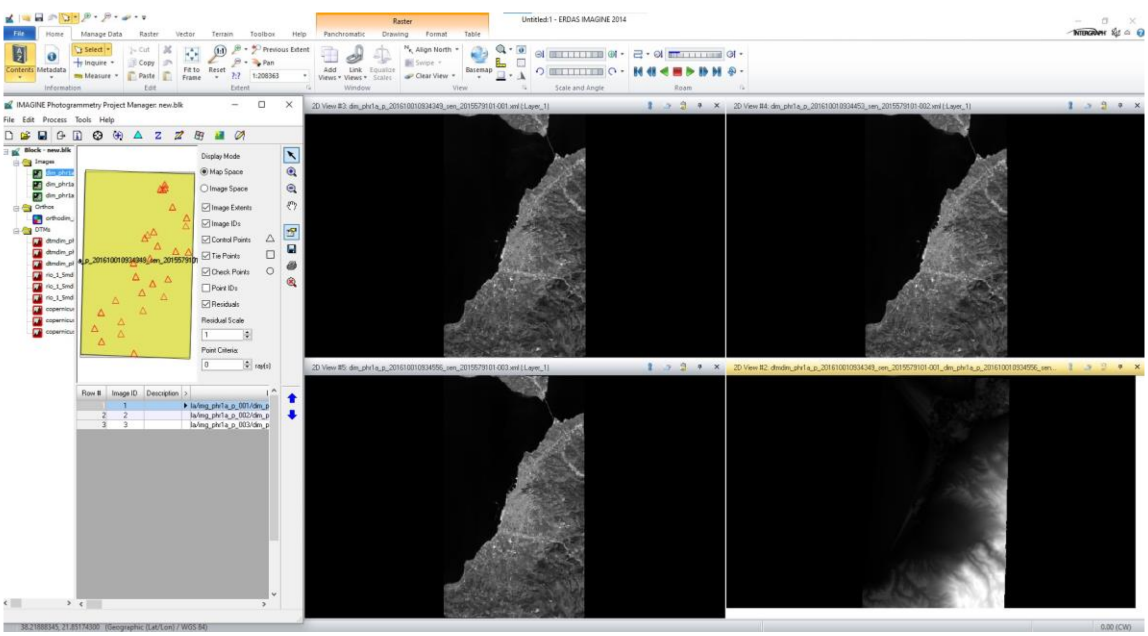

Figure 2. Pleiades tri-stereo image processing in Leica Photogrammetry Suite of Erdas Imagine software. At the left, the allocation of the ground control points is presented. At the upper part of the image, the first and the second image of the triplet are presented. At the lower left part the third image of the triplet is shown, while at the right part, the produced DSM with 1.5 m pixel size can be seen.

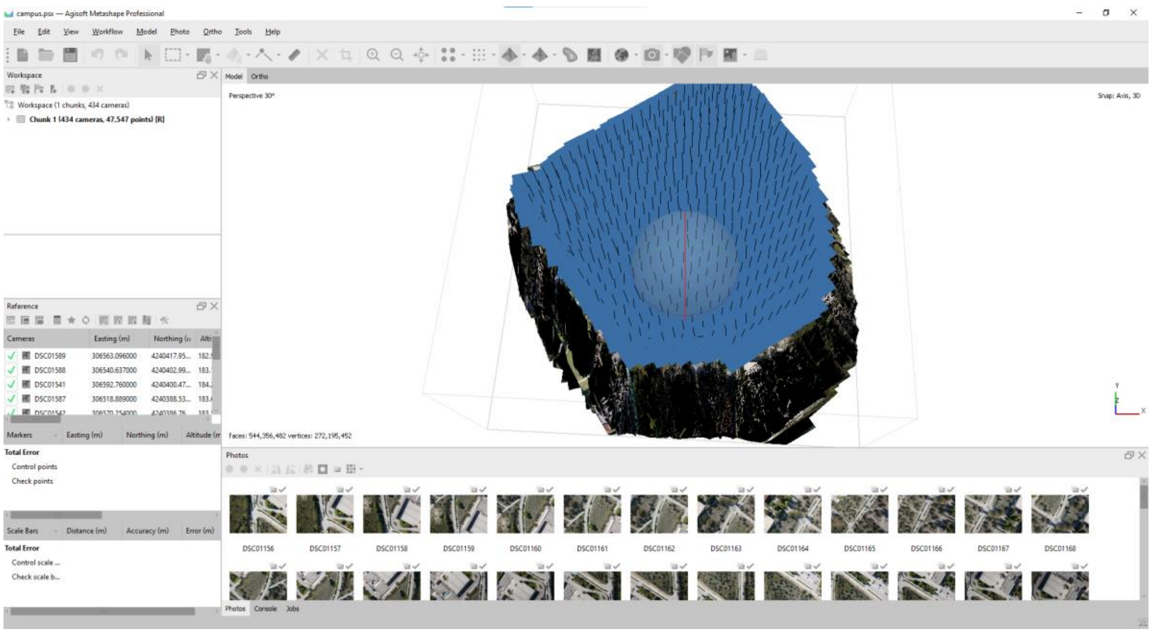

Figure 3. Processing of the UAV imagery in Agisoft Metashape software.

Figure 4. 3D view of the University Campus. A dense point cloud was produced by the Vtol UAV imagery.

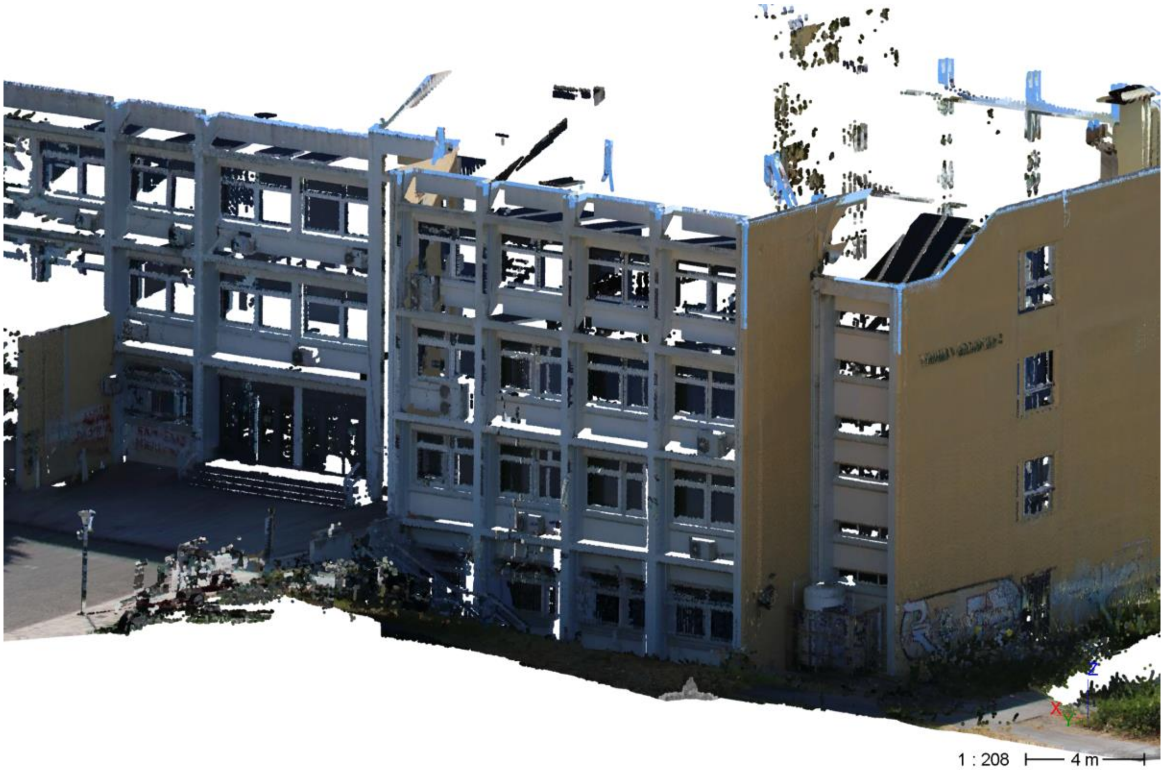

Figure 5. 3D view of the building of the department of Geology. The dense point cloud was produced by the Leica P50 laser scanner. At the lower part of the image the scale is presented.

3. RESULTS

The building height was extracted from the above-mentioned datasets in three sub-areas in the city of Patras. The first area is the University Campus, the second is the infrastructure of Patras new port and the third one is an archaeological site, Patras Castle. The results of each sub area are presented in the following paragraphs.

3.1 Patras University Campus

In the sub area of the University campus, there are many high and big in extent buildings (Figure 6). The height of each building was measured and the results for three among those buildings are presented in Table 1.

Table 1. Building height for the University campus area.

	Geology department building height	Deviation %	Civil Engineering department building height	Deviation %	Central library building height	Deviation %
UAV	15.11	0	8.16	0	18.05	0
Cadastral	0	-	0		0	-
Pleiades 1-3	14.86	1.65	7.9	3.18	17.44	3.37
Pleiades 2-3	12.50	17.27	8.88	-8.82	13.82	23.43
Pleiades 1-2	13.03	13.76	6.55	19.73	12.53	30.58

As it can be observed, from Table 1, cadastral DSM did not provide any useful information for the buildings height. The three DSMs derived from the Pleiades data present different height values for the three buildings. The DSM from the Pleiades 1 and 3 images presents the more accurate results regarding the building heights. The deviation (%) from the respective UAV values ranges from 1.65% for the Geology department building to 3.37% for the central library building. The other two DSMs from the Pleiades data present higher differences meaning that the building height information that these data sets provide are of lower accuracy.

The building height was also validated from the 3D point cloud derived from the Leica P50 laser scanner (Figure 5). The height difference between the UAV and the TLS was 0.03m, i.e. 15.08m instead of 15.11m.

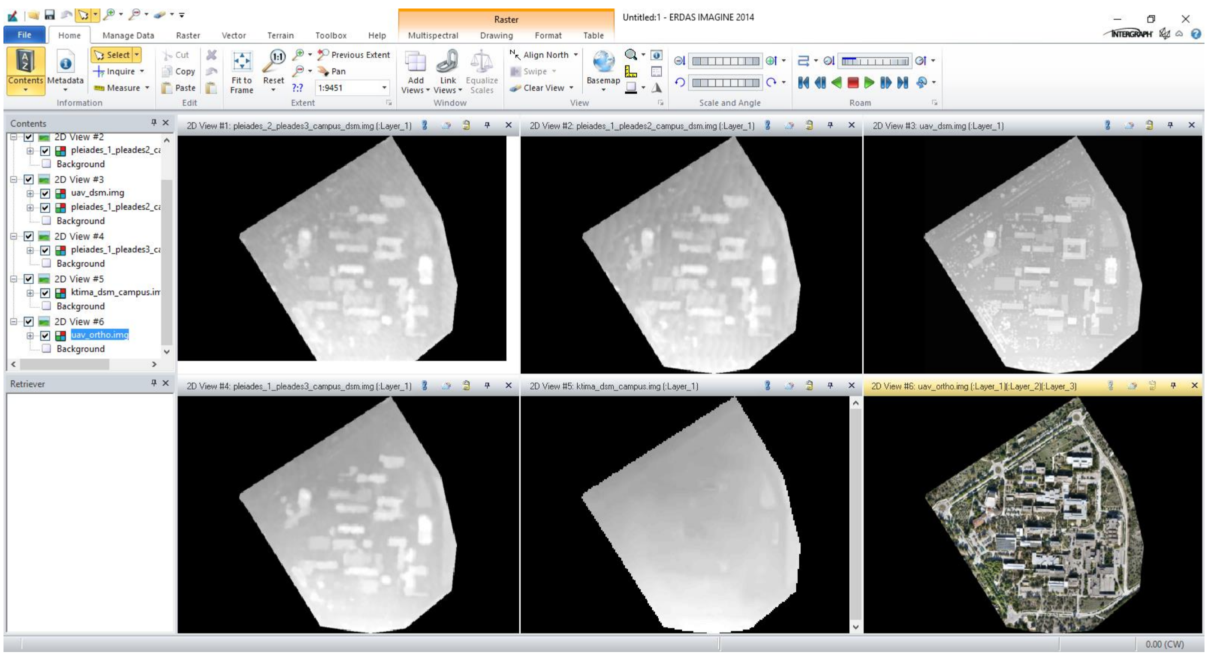

Figure 6. Digital surface models for the University campus area. Upper part: the DSM from Pleiades 2-3 stereo pair is presented at the left. In the middle the respective DSM from Pleiades 1-2 DSM. At the right, the DSM from the UAV data. Lower part: the DSM from Pleiades 1-3 stereo pair is presented at the left. In the middle the Cadastral DSM. At the right, the orthophoto of the campus derived from the UAV data.

3.2 Patras castle

In the sub area of Patras castle, we have measured the height of two towers (Figure 7). For the specific sub area Copernicus BBHM data are also available. As it can be observed from Table 2, Cadastral DSM provided the less accurate results. It is characteristic that the heights of the two towers is 14.81 and 9.1m while the respective height values extracted from the cadastral DSM are 5 and 4m. Copernicus BBHM data set provided height value only for one of the towers. The deviation from the UAV height values raises to -21.53% as the height value for the specific establishment is 18m, 3.19m higher than the UAV height value.

As it can be observed from Table 2, the three DSMs derived from the Pleiades tri-stereo images present diverse accuracies. Contrary to the results of the University Campus, in the Castle site the Pleiades 1-2 stereo-pair provides the more accurate results. The deviation (%) to the height values from the specific DSM ranges from -12.08 to 24.17%. The height values of the other to Pleiades stereo-pairs are less accurate. It is also characteristic that there is not any clear lead to a specific Pleiades stereo-pair. Even the stereo-pair Pleiades 2-3 that present the lower accuracy (higher deviation) in the current sub-area, it presents excellent accuracy in the case of the second tower and very low accuracy in the case of the first tower. In the case of the second tower, the height difference between the UAV DSM and the Pleiades DSM is 0.7m while the respective difference for the first tower is 6.56m.

Table 2. Building height for the Patras castle area.

	Patras castle 1st tower	Deviation %	Patras castle 2nd tower	Deviation %
UAV	14.81	0	9.10	0
Cadastral	5	66.23	4	56.04
Copernicus BBHM	18	-21.53	0	100
Pleiades 1-3	9.74	34.23	7.9	13.18
Pleiades 2-3	8.25	44.29	9.80	-7.69
Pleiades 1-2	11.23	24.17	10.2	-12.08

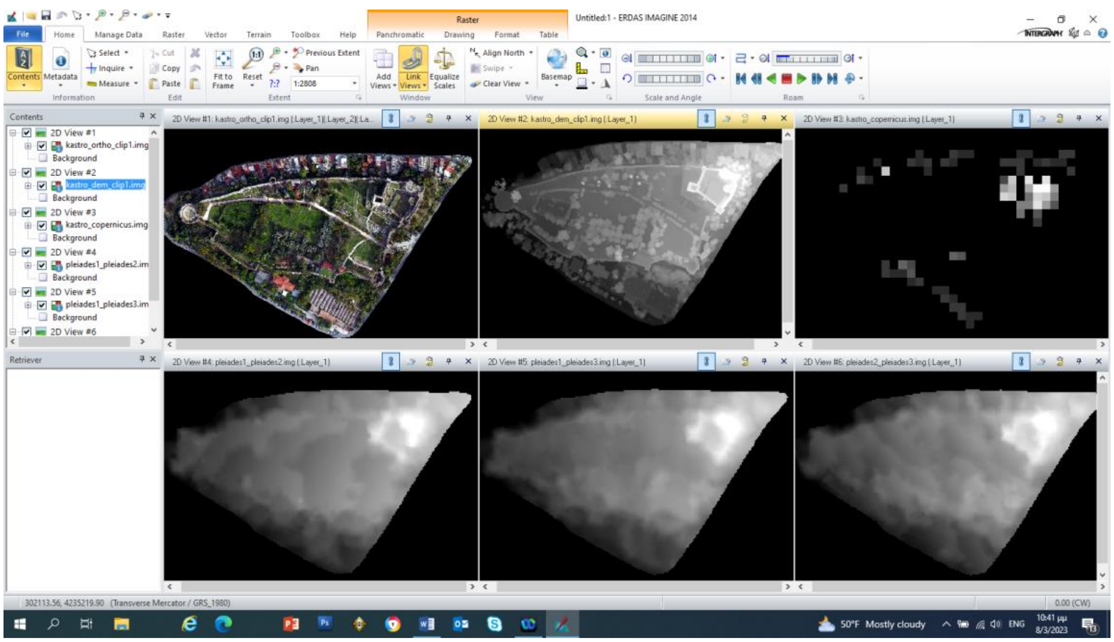

Figure 7. Digital surface models for the Patras castle. Upper part: the orthophoto of the campus derived from the UAV data is presented at the left. In the middle, the DSM from the UAV data. At the right, the Copernicus BBHM is presented. Lower part: the DSM from Pleiades 1-2 stereo pair is presented at the left. In the middle, the DSM from Pleiades 2-3 stereo pair is presented. At the right, the respective DSM from Pleiades 2-3.

3.3 Patras port

In the sub area of Patras port, (Figure 8) we have measured the height of three buildings (Table 3). For the specific sub area Copernicus BBHM data are also available. As it can be extracted from Table 3, Cadastral DSM provided again the less accurate results. It is characteristic that the heights of the buildings range between 8.12 and 11.60m, while the respective height values extracted from the cadastral DSM are around 0 for the two buildings and only 4,97m for the third building (higher one). Copernicus BBHM data set provided height values for all the buildings. These values present a divergence ranging from 25 to 40 % compared to the UAV height values. All the DSMs from Pleiades stereopairs gave quite accurate results for building no 3 (higher), however the same data sets provided less accurate height results for the other two buildings. It is characteristic that the height deviation values for the building no3 of

Pleiades 1-2 and Pleiades 1-3 DSMs range around 10%. The height deviation values from the same data sets increase to 90% when we examine building no 2 (Table 3).

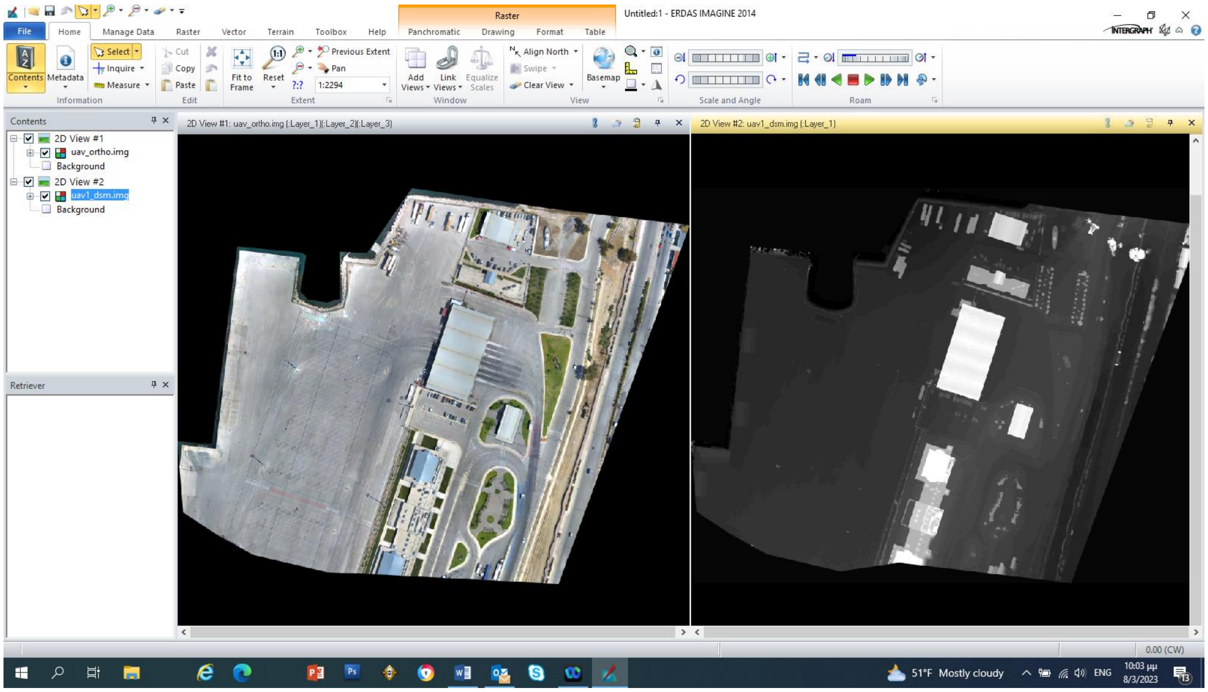

Figure 8. Orthophoto and Digital Surface Model of the Patras port from UAV data.

Table 3. Building height for the Patras new port facility.

	Building 1	Deviation %	Building 2	Deviation %	Building 3	Deviation %
UAV	8.12		9.24		11.60	
Cadastral	0	100	0.82	91.12	4.97	57.15
Copernicus BBHM	6	26.10	6	35.06	7	39.65
Pleiades 1-3	2.75	66.13	1.21	86.90	10.35	10.77
Pleiades 2-3	2.88	64.53	0.82	91.12	5.07	56.29
Pleiades 1-2	2.82	65.27	1.31	85.82	10.29	11.29

4. CONCLUSIONS AND FUTURE WORK

Four different data sets, providing height information for the creation of an accurate 3D city model, were compared in the current study. Those data sets present diverse spatial resolution ranging from 0.02m to 10m pixel size. The fist data set is the Cadastral DSM, the second one is Copernicus BBHM, the third one is created by UAV data and the last data set contains DMs ctreated from Pleiades stereo images. Three sites with different characteristics in the broader area of Patras were used as test areas: a part of the university campus, a part of the Patras new port, and Patras castle.

It was proven that the Cadastral DSM provides the worst results. The pixel size is five meters however the height accuracy is very poor in comparison with all the other datasets, Copernicus BBHM data set provides quite good building height in some cases and lower accuracy in others. Despite, the broader pixel size (10m) it is better than the cadastral

DSM. The three DSMs created from Pleiades data have a pixel size of 1.5m. The specific data sets present quite accurate building height info, however the accuracy varies from place to place. There is no specific lead between the diverse Pleiades stereo-pairs. The DSM created from the UAV data presents the higher accuracy. Furthermore, it is the more recent and easily updated dataset, thus it is the most suitable for the creation of a 3D infrastructure model.

The specific study was the first step for the creation of 3D infrastructure model from UAV and TLS data in the Frame of PROION project. In this work, emphasis was given on the accuracy of the available data sets containing building height information. There are many effective algorithms for (semi) automatic object reconstruction from 3D point clouds or by combining information from ground plans and DSM's. In the future, we will work on the semi-automatic 3D point cloud classification.

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