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Master´s Programme Geomatics

Master Thesis on

From U.A.V. photogrammetry to 3D modeling of the Valencian Silo-Yard in Burjassot

Submitted by

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ABSTRACT

The importance of recording and documenting cultural and archaeological heritage has provided the opportunity to integrate new technologies and other fields of science for their purpose. The incorporation of geomatics tools allows to generate precision and a wide level of detail in the capture and processing of information. The use of Unmanned Aerial Vehicles (U.A.V.) in order to capture of images around opened spaces with photogrammetric processes permit obtain high quality information. After the process and right use of some software, 3d model can be generated. This project seeks to apply this methodology in an area of archaeological importance located in the City of Valencia (Spain) called as Valencian Silo-Yard.

This process has been carried out through different stages where the application and the use of technologies and photogrammetric methodologies applied to the heritage documentation are initially introduced. Further on historical approach has been made to the area under study in order to understand its historical importance and its legacy to the Valencian community. Subsequently the detailed way of the process of acquiring the information and the post-processing performed is described.

Finally, this project pursues to apply the methodology in the construction of a 3D model that allows to visualize graphically the detail of the construction and conservation of the area.

Keywords

UAV, photogrammetry, heritage, methodology.

RESUMEN

La importancia de registrar y documentar el patrimonio arqueológico y cultural ha brindado la oportunidad de integrar nuevas tecnologías y otros campos de la ciencia para su propósito. La incorporación de las herramientas de la Geomática permite generar precisión y un amplio nivel de detalle en la captura y procesamiento de la información. El uso de Vehículos Aéreos no tripulados (U.A.V) con el fin de capturar de imágenes en espacios abiertos con procesos fotogramétricos que permiten obtener una información de alta calidad. Después del proceso y un uso correcto del Software, es posible generar un Modelo 3D. Este proyecto busca aplicar esta metodología en un área de importancia arqueológica está ubicado en la Ciudad de Valencia (España) conocido como La Plaza de los Silos de Valencia.

Este proceso se ha llevado a cabo a través de diferentes etapas, donde la aplicación y el uso de tecnologías y la aplicación de metodologías fotogramétricas para la documentación del patrimonio son introducidas desde su inicio. De igual manera, se ha realizado una aproximación histórica en el área objeto de estudio, con el fin de entender su importancia histórica y su legado a la Comunidad Valenciana.

Adicionalmente se ha descrito de manera detallada el proceso de adquisición de la información y el post proceso realizado.

Finalmente, este Proyecto busca aplicar la metodología en la generación de un modelo 3D que permita observar gráficamente el detalle de la construcción y la conservación del área.

Palabras Clave

UAV, fotogrametría, patrimonio, metodología.

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Laboratory of Photogrammetry, teachers and students from the School of Rural and Surveying Engineering from Aristotle University of Thessaloniki.

My friends in the Polytechnic University of Valencia and the University of Applied Sciences of Karlsruhe.

And my family that from a distance has always supported me.

1. INTRODUCTION

Throughout of the humanity history have been presenting changes, where appear and disappear cultures and customs. The only way to obtain information of these cultures is through their legacy, the records left by the ancient civilizations have allowed to know their daily life and contribution to the following generations. This is how the recording and conservation of the archaeological heritage plays an important role in the knowledge and understanding of ancient cultures and a contribution to future generations.

The integration of new technologies in the documentation of Cultural heritage has opened a new field of science. Where it is possible to combine geographical, computer and design knowledge with archeological theory and practice.

This project is focused on seeking to apply the competences acquired with scientific research, topographical methods and computer tools. Particularly, a case study was used to put into practice the methodology and tools described above. These characteristics are also described in the square known as Valencia'n Silos Yard. A place located in the interior of the Valencian Community in Spain; where the history, design and economic development of an important region of the Iberian Peninsula converge.

Given the topographic and architectural conditions of the place, it allows to carry out a photogrammetric study using U.A.V., Laser scanner and acquisition of uncalibrated photographs for the application of classic photogrammetry.

In the same way this project will be a modeling from the captured images with an Unmanned Aerial System U.A.V. and a camera. The frontal coating of the area is achieved by the capture of images to apply methodologies Structure for motion. Combining later the results to generate a global model that allows to identify both the detail and the current condition of the zone.

The aim of the research is to document the process carried out in each stage of the project, as well as the disadvantages and successes, in order to guide the construction of new models allowing to encourage the documentation of the architectural heritage; linking increasingly knowledge and geomatics tools in areas of interest such as archeology, biotechnology and other areas where 3D modeling is at the forefront of scientific research.

A general diagram illustrates and describes the specific procedures to be carried out during the execution of the project, until finally generating a quality model that is available on a website and allows the user to visualize at different levels of detail the Valencia'n Silos Yard:

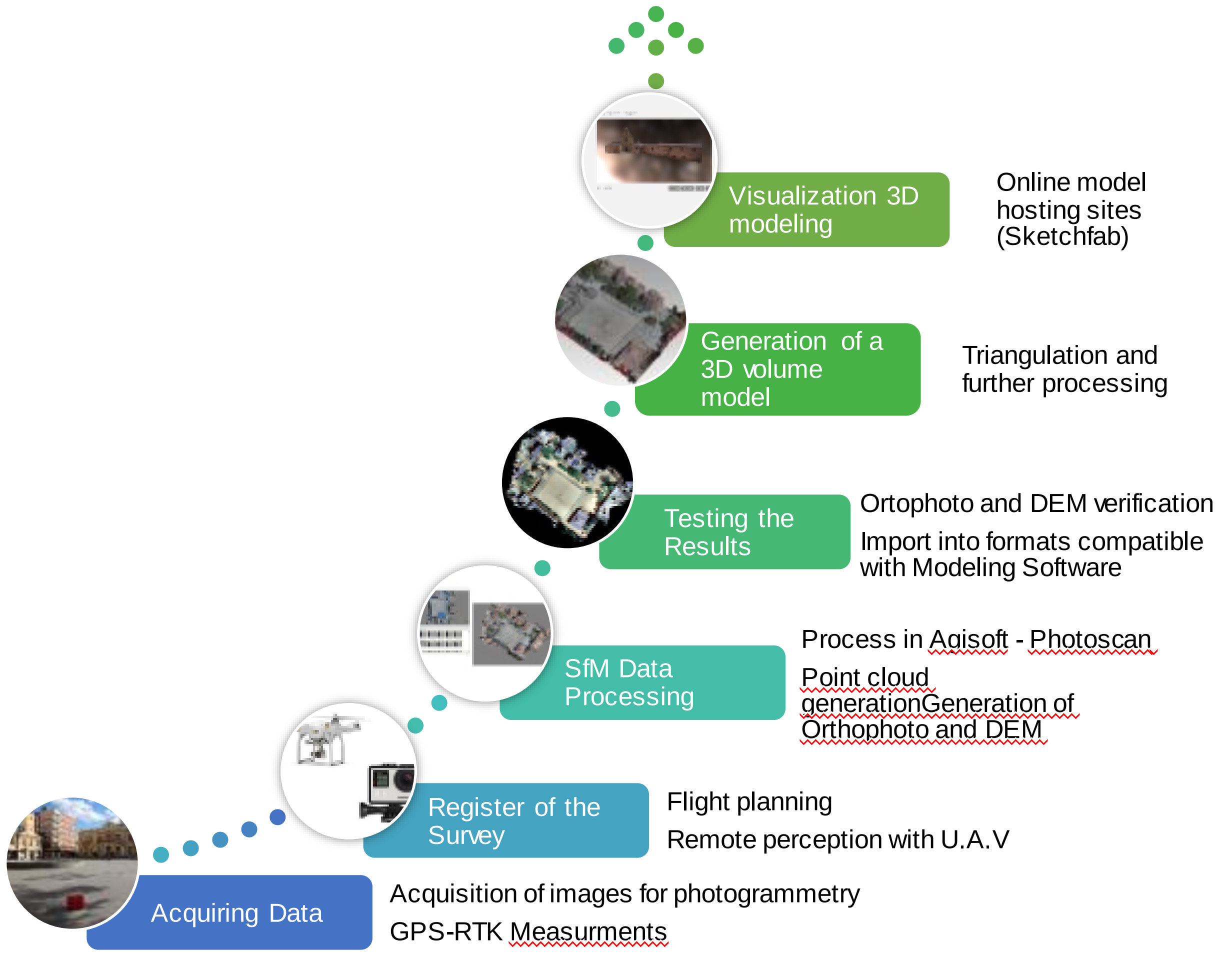

Figure 1. Work flow diagram

2. Background Information

2.1 Localization

The Valencian Silo-Yard is located in the center of the Burjassot municipality, in the west of the metropolitan area of the Valencian Community, whose geographical coordinates are 39 ° 30'33 "N0 ° 24'39" O at height 59 M. Its topography is mainly flat, however it has small undulations that do not exceed 60 m in height, which generate a natural limit with the Valencian orchards. It has a Mediterranean climate where mild and rainy winters prevail and dry summers reach high temperatures, highlighting the variability during the spring and autumn intermediate seasons.

The municipality has a varied access road system, as well as lines 1, 2 and 4 of the Valencia Metro, and several bus lines of the Municipal Transport Company EMT. Likewise it has the CV-35 motorways from Valencia to Ademuz which connects Valencia with the municipalities of Camp de Turia and CV-30 the quality of the North Round, becoming a connecting bridge in the municipality of Burjassot And the neighborhoods Beniferri and Benicalap of the city of Valencia.

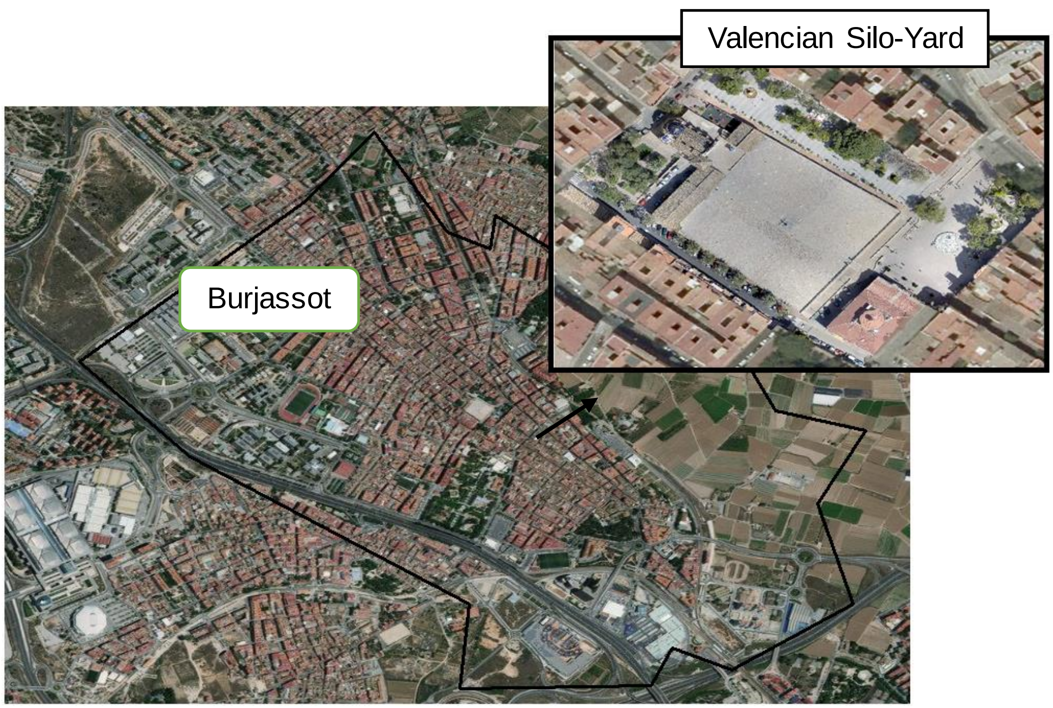

Figure 2. General location

2.2 History

The history of the Burjassot Silo-Yard in the Valencian territory begins in 1573, when the prolonged periods of famine and the fast population growth increased the demand of food in the region. The insufficient space destined to store imported foods from the Kingdoms of Castile, Aragon and Sicily; generated the need to build an alternative storage by the Valencia'n Government.

This construction was assigned to the master stonemason Sacho Camino, who was in charge of the construction of the work accompanied by several builders, and the building was finally finished 215 years later in 1788.

The construction initially had a house for the dependents or (watchers) vigilantes, a gothic cross, the hermitage of San Roque and the Virgin of the Head. Within the square in subterranean level the Silos were constructed, where they are currently preserved 41 of them.

The geomorphological conditions of the soil of the area, which is clayey silty type and its geographical location with respect to the port and the Valencia´s city; they gave the guarantee for the construction of the Silos Square in Burjassot. In addition to the environmental and temperature conditions of the area, allowed the construction of underground silos, conservation and storage of food in good condition.

The silos served as an underground storage for the supply of the city until the 17th century, when with the decrease of wheat consumption the silos were abandoned until 1754 the last works of opening and the construction of an artistic well.

Subsequently with the arrival of the Second Republic the Silos were again abandoned and their degradation continued during the Spanish Civil War, where they were drilled to communicate between them, used as a military warehouse and antiaircraft shelter for the civilian population.

2.3 Description

The Valecia'n Silo-Yard is an important monument consists of storage warehouses that previously used to store wheat and other foods, which was declared a National Historic Artistic Monument in 1982.

This project is based on the exterior part of the square, so it will be described in detail each of the parts that make up the outer part of this. Which were object of 3d modeling.

The construction is composed not only of the silos, but also constitutes an architectural set of structures that are related to each other. In this way are the constructions corresponding to the accesses to the Silos, religious elements, water deposits and warehouses on the surface and underground.

The square of the Silos of Burjassot began its construction the 15 of July of 1573, where they would realize excavations in the rock and limestone. In general the square is constituted of rectangular form; which covers two kilometers of surface in a north - south direction, and approximately 2.5 kilometers in an east - west direction. Its height in relation to the surface oscillates between 55 and 66 meters on the average level of the sea.

The whole square is raised on a sturdy wall built of stone in the shape of ashlar, which has a stone canal, parallel and located next to the wall surrounding the place, in turn is composed of a series of small drains of rectangular size also in stone that protrude from the structure of the wall. This are connected to the top of the square allowing the rainwater to escape through a cylinder also made of stone that gives visible to the outside of the wall as a circle.

Furthermore, the height of the square was designed initially with the purpose of giving a perception of lookout of the city of Valencia; and therefore the urban regulation of the area over the years has maintained the restriction of high buildings around the square preserving the landscape visibility from the top of the square.

The initial access to the silos was built between 1585 and 1590. It was located in the northwest of the square; where there was an access ramp and later a large wooden door framed by jambs of ashlars and with a roof of tejaroz to four waters. The opening to the entrance counted on a curved arch in *pedra picada* of carpantel type, which had an engraving where the shield of the city of Valencia could be seen.

The warehouse building was built in 1771, had access at street level (where is currently the street Mártires de la Libertad). In the same way was a small access door, also with a segmental arch embedded in an old factory of masonry that surrounded the underground store. In 1953 this would become in the entrance of the School of Arts and Crafts after having placed the door of the old church of San Bartolomé of Valencia on this site.

In 1877, a new access to the square was opened, in response to the urban intervention of the time. This entrance connect with the current Burjassot City Hall; which consists of a large stair attached to the southeast wall, with several sections accompanied by a series of landings, culminating in a metallic door with direct access to the silos square. In the front part of the wall are 4 additional stairs which are distributed in the left and right ends of the square, in a first and second level of access to it. They also preserve the masonry in ashlar and the style of drainage in stone that characterizes the outer walls of the square.

Figure 3. Main entrance (Hadabay 2016)

Once is access to the square it can see a cross located in the center of the esplanade and the Hermitage of San Roque that emerges to the end of this, as a sample of the religious influence present at the time of construction of the place.

The hermitage of San Roque was possibly built in the sixteenth century; and it certainly does not constitute part of the Silos Square, but because of its proximity to the building it is immersed in it, despite not being historically included in the process of conservation and storage of grain; which was the main function of the place. However, in this work part of the facade of the hermitage was taken to illustrate in an optimal way the main view of the Plaza. In this way, it is found that the facade has a renaissance style with baroque period finishes, which has a single nave, and are attached several chapels to the lateral sides, an apse and a side chapel next to the high altar. (Valls A, 2014)

Figure 4. Hermitage of San Roque (Hadabay 2016)

In the central part of the square next to the grain deposits, the cross rises, which appears from an altar consisting of a stairway of five square pieces from greater to smaller size. On a pedestal of rectangular type supports a column finely sculpted and raised under a base of two tiers with blava stone ascend a cross of style similar to the Celtic cross; on which is carved a Jesus Christ looking towards Burjassot and the Virgin Mary looking towards the hermitage, and in the capital with four heads of angels.

The construction of the cross was entrusted to Hieroni Munyos and Miguel Porcar in May 1580. Centuries later, at the end of the Spanish Civil War in 1939, only the base was preserved from the cross, because on the pedestal was placed a sound-ranging equipment[1]. After which it was rebuilt faithful to the original. (Cano, 2015)

[1] Sound-ranging equipment: Horn that picked up and amplified the sound mounted in a cross that allowed to identify the course of an airplane.

Figure 5. Central Cross (Hadabay 2016)

In front of the hermitage is the well, whose construction date back to 1795. It consists of a four-story roof of glazed tile, white and blue. At its two ends it is twice as a watering hole for animals. During the restoration that took place during the post-war period, several problems were evident that presented the well, among them to put grills causing damages in the part of the baseboard, destroying the date that was carved in him. The well that had been a place of garbage accumulation for years was also cleared.

Figure 6. Well (Hadabay 2016)

In the western part of the square is the Warehouse. It consists of a building of two floors, basement and ground floor. After the restorations of the postwar period this building also had some modifications, because it was used like School of Arts and Crafts. Among them is the opening of access to the Avenida Mártires de la Libertad, in 1953, where an old baroque cover was placed that belonged to the church of San Bartolomé de Valencia. (Valls A, 2014).

Figure 7. *Casa dels Barrons* (Hadabay 2016)

In addition, there is a building that has the same characteristics as the building next to the Hermitage of San Roque, known as the *embarronats*, *Casa dels Barrons, porchades o botigues.* It consists of simple constructions opened on its sides by means of semicircular arches, closed by a wooden lattice called *barrons*.

The main facade consists of a building called *Embarronats* or *botigues*, which consists of three arches, consisting of pilasters of ashlars and brick arches. Which frame the continuity of the main warehouse described above, giving a homogeneous appearance to the square.

Figure 8. Valencian Silos Yard - General View (stock images)

Finally there is the esplanade of the silos. The construction consists of 47 silos, of which currently 41 silos are visible and 41 deposits distributed in the paving place under an irregular scheme.

On the outside of the square are the semi-spherical stone lids (called *piló* in Valecian), in which two figures were inscribed, the first concerns to the number of the silo and the second to the capacity of the average silo in *cahices* (51,520 M2). The distribution of these is done irregularly along the trapezoidal yard paved with a perimeter of 65 meters.

The mouths that are at the moment in the place do not correspond to those initially placed in the year 1573, since these were placed by King Guillem in the year 1584, in order to modify the orientation of the cover placing them above to avoid that the water Stagnates causing infiltrations, thanks to this new technique the water would slip.

Figure 9. Top of Silo (Hadabay 2016)

3. RESEARCH METHODOLOGY

Geomatics as a science of the earth provides sufficient tools to analyze and interpret the earth's surface, through the use of diverse mathematical and technological tools.

On the other hand, the recording of the archaeological and cultural heritage, although it does not consist of a science as such, can be associated with several branches of anthropology and history; allowing the integration of measurement techniques, cartography and new technologies such as 3D modeling to the conservation and study of places of cultural interest.

These new technologies include measurement techniques such as satellite remote sensing, photogrammetry, terrestrial laser scaners and others. These tools provide the possibility of a more accurate and realistic documentation of the places studied.

3.1. Used Technologies

The measurement techniques used for the development of this project were GNSS RTK, total station and Digital camera capturing data in visible spectrum:

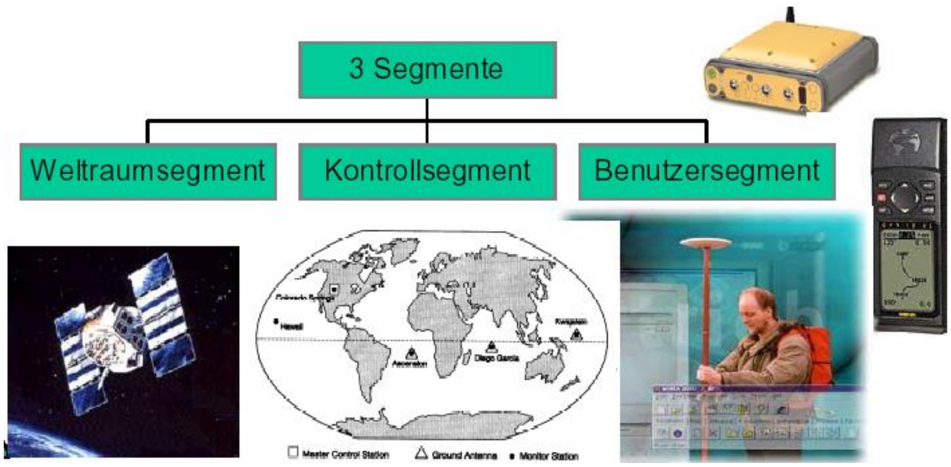

Figure 10. GNSS Components (Bezirksregierung Düsseldorf 2015)

Another of the measurement instruments frequently used for the acquisition of data for the recording of the cultural heritage are Laser Scanner. Whose technology provides the possibility of acquiring data from a complex place in 3d format; through which active systems based on laser light, obtained from the different measurements made on the surface of the object.

This way, the light characterized by the content of information captured, is recognized by an electronic sensor. Allowing detailed information on the volume, shape and size of scanned objects. From this process an image is obtained which has in each pixel the x, y, z coordinates expressed in millimeters and optimized with color information (R, G, B). What is called point cloud and which is the basic input for the generation of 3d models with a certain level of precision.

In addition, it has the use of U.A.V. as an instrument for obtaining data in order to document the cultural heritage. This types of instruments provide the possibility of acquiring detailed field information and high-resolution image capture by using photogrammetry for large-scale, mapping in a low-cost way. They also require GNSS navigation system systems; which allows to predict acquisition points and possibly of georeferencing.

Since the use of U.A.V. allows the generation of DMS from the captured images, are frequently used in fields such as the Agriculture, Forestry, Environment, Architecture and Archeology. In this one, thanks to the 3d topography and mapping of places and structures can be made from images captured at medium and low altitude. (Remondino, 2014).

3.1.2 Photogrammetry

Generally, it is an indirect measurement technique that allows to obtain images of an object or place, taking into account its location, shape and size. This images must be taken in such a way from different points of view that they overlap in a correct way on the cover of the objects.

These images can then be processed, considering the known camera and lens parameters. From the definition of specific points visible in several images taken from different angles, the geometry of the object can be further calculated thanks to the use of special photogrammetry software.

In order to develop this project, it is necessary to take into account this sort of Photogrammetry; techniques were used Terrestrial photogrammetry, which have allowed to realize the general model, visualization and interpretation of objects and generation of textures.

3.1.3 3D -Model

The concept of 3D model integration with archaeological documentation is not a new topic, since from its beginnings archeology has had a graphic documentation base that has been supported to record with a greater level of detail the characteristics of the zones studied.

The use of 3D tools in archeology allow the manipulation, measurement, visualization and interpretation of data depending on the volume, shape and texture of objects.

In this way, it is important that the heritage recording, the generation of the cloud of points and the 3D model are accompanied by a field work in which not only records as much information as possible but also understands and analyzes the place to have a clear vision at the same the time of generating the models. In this context, it is necessary to identify the chronological phases of the site, the technical variations, anomalies and characteristics of the design, such as shapes, colors, state of conservation and quality of materials used in construction.

Solid modelling is understood as the set of theories, techniques and systems oriented to the representation of the solid. This allows to automatically circulate the properties of this. The representation system of an object can be described in three levels: physical solids, mathematical models of solids and representations, which it is possible to understand from the following models (Remondino, 2014):

Topological Model: Consists of the characterization of a solid as a set of 3D points. These solids are defined in Euclidean space, occupying a specific position in space and meet the conditionality of enclosure, dimensioned, rigid and has a three-dimensional homogeneity.

Surface Model: Consists of the mathematical characterization of a solid from the delimitation of its surface. Algebraically is the description of a solid from its border. This must comply with the Closure conditionality of a volume, which indicates that the skin should be closed, oriented and complete.

Volumetric properties: Overall it is possible to represent the properties of the solids as volume integrals of the form:

$$Property\ (Solid) = \iiint_{Vol\ (Solid)} G_p(x, y, z) dV \quad (3.1)$$

Where the integral function G_p varies as a function of the circular property as shown in Table 1.

Table 1. Circular Properties of the Integral Function Gp

Propierty	G_p
Volume	1
Mass	ρ
Gravity center	$P/_{mass}$
Moment of Inertia (axis z)	$X^2 + Y^2$

According to the description of the form it is possible to classify as follows:

Elongation: In physical terms it is defined as the change in magnitude value of an object with respect to its equilibrium value, as a function of its length and amplitude.

$$\frac{lenght}{width} \quad or \quad \frac{MaximunDiameter}{MinimumDiameter} \quad (3.2)$$

Roundness: It is the measurement of the circle obtained from the two-dimensional binary configuration of an object, based on the mathematical fact of increasing its length of a circular object with a fixed area modifies the original circular form of this. The equation in the Figure allows to calculate the roundness of an object according to the area and the perimeter:

$$\frac{4\ Area}{\pi p^2} \quad (3.3)$$

Shape Factor: It is a measurement similar to the Roundness but based on the configuration of the perimeter of the object. Where a circular object compared to other two-dimensional shapes, whether regular or irregular, have a smaller perimeter relative to their area. Defining the area and the perimeter length of an object according to the value of the result obtained, if it is less than 1.0 it departs from the shape of a smooth circle and if it is around 0.78 is square and if the value less than 0 A thin thread-like object is obtained. Figure 9 shows the equation for the calculation of the Shape Factor, where P is the perimeter of the object:

$$\frac{4\ \pi Area}{p^2} \quad (3.4)$$

Quadrature: It is the determination of a square equivalent in a surface to an object. According to the result obtained 1 is equivalent to a square and 0.8 to an isosceles triangle. It can be expressed by the equation in Figure 10:

$$\frac{p}{4\sqrt{Area}} \quad (3.5)$$

After the identification of the mathematical principle after the process of 3D generation model. It is important to know the different methodologies and tools used by the different software for the processing of information in 3d.

In the specific case of this project, data were processed in software such as Photoscan, Cloud Compare, Geomagic, 3D Reshape, among others that will be mentioned in more detail in the methodology.

4. METHODOLOGY

Below is a detailed description of the processes carried out for to create a 3d model of an archaeological site. This methodology is framed in the different stages and technical processes made from the data acquisition in the field, the post process in the laboratory and its subsequent assembly and visualization in specialized software.

The initial idea was to generate a 3d model that was visible and accessible to the user. But during its elaboration process were found several utilities and some disadvantages that must be mentioned to take into account in the development of new projects of this type.

Within the methodology described below will make use of the data used in the campaign conducted in Valencian Silo-yard, Burjassot (Valencia 2016). In order to create a complete modeling of the place, both the inside and the outside of the silos, including the constructions attached to it.

However, the techniques of data acquisition in the field and the post-processing of the information obtained. It was carried out in the same way in the second stage of the Vergina project (Thessaloniki 2017) applying the techniques, procedures and successes learned in the first stage of the project.

4.1. Data acquisition

The initial acquisition of data were made between 11 and 16 April 2016, in the frame of the project "Responsibility for cultural Heritage through Geomatics (2015-2018)". In which they participate the University of Applied Sciences of Karlsruhe - Hochschule Karlsruhe, Universitat Politècnica de València and Aristotle University of Thessaloniki. The project is sponsored and supported by Baden-Württemberg-Stiftung (BWS).

During the data collection campaign, the team was subdivided into five fronts:

The photogrammetry team was in charge of the acquisition of images for the processing of Thermal Photogrammetry and Terrestrial Photogrammetry. And whose supervisors were Saler, Berner and Lerma.

The U.A.V. team was in charge of Berner and the G.P.R. (Ground Penetrating Radar) team in charge of Garcia. This were in charge of collecting data from images taken with drone and information obtained through the use of GeoRadar, respectively.

The Laser Scanner team was in charge of acquiring data for the processing of the point clouds obtained from this measuring instrument. And whose supervisors were Tsioukas, Lerma and Saler. And finally the Survering network team in charge of Saler and Berner.

This multidisciplinary team sought to integrate different branches of engineering around a single objective, which was to acquire enough and accurate data of the Silos Square, in order to generate enough input to create an analysis and recreate a 3d model of the place.

In addition, the team counted on the presence of bachelor and Master students of the different universities attached to the Project. (Hadabay, 2017)

The measurement campaign in Vergina (Greece) had the same structure despite having some different members of the project. The data acquisition took place between June 20 and 23, 2017. Also, students of bachelor, master and Phd participated; and professors from the three universities that make up the project.

The figures 11, 12 and 13 show the places that were the object of the measurements made with Laser Scanner and U.A.V with multispectral camera.

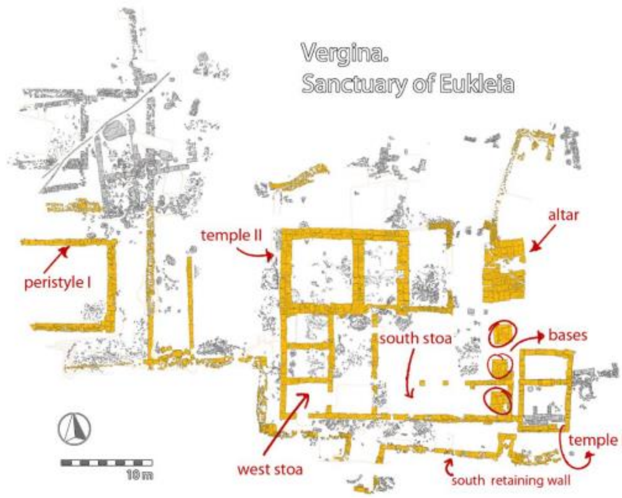

Figure 11: Sanctuary of Eukleia (Vergina, Region of Central Macedonia, Greece) (picture of Aristotle University of Thessaloniki)

Figure 12: In yellow box: Sanctuary of Eukleia and Theater (Vergina, Grece) (picture of Aristotle University of Thessaloniki)

Figure 13: Ancient theater of Vergina (Region of Central Macedonia, Greece) (picture of Aristotle University of Thessaloniki)

Additionally in Vergina data were acquired from the mobile mapping system and Laser Micro Scanner - Measuremente documentation of small archaeological structures.

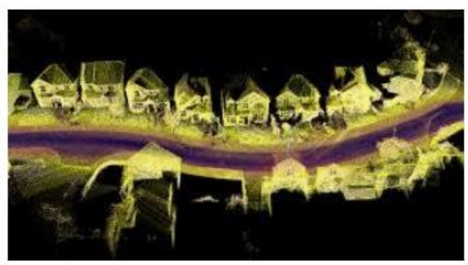

Figure 14: Mobile mapping system (picture of Aristotle University Thessaloniki)

4.1.1. GPS – RTK Measurements

Initially the GNSS sensor was used by the RTK technique. The use of this technique has served to give support and densification to the data that would be taken later with U.A.V. and of the images for photogrammetry. Through GNSS is intended to give geodesic coordinates to all points taken along the square by placing targets that can be clearly identified during the processing of the images.

In addition, checkpoints have been taken which are detailed reference points identified in specific places that will allow the orientation of images where no targets are found.

The Table Appendix 6.1 Table of GCPs points, shows the coordinates taken with the ETRS 89 Reference System and in the Figure 15, it can visually see the location of the points around the square. As will be seen later not all the points taken were used for the generation of the orthophoto made from the images captured with U.A.V.

Figure 15: Location of GCPs points

4.1.2. Remote perception with U.A.V.

The acquisition of images from a U.A.V. of radio control, allows diverse options for taking of data. Through the use of an Unmanned Aerial Vehicle it is possible to capture global photographs, which will allow the construction of three-dimensional models from these with a greater level of precision and detail.

For the acquisition of images using U.A.V. a Drone Phantom 1 and a Camera GoPro Hro Black have been used, as can be seen in Figure 5.

Figure 16. Equipment (Soubry 2016)

The DJI Phantom 1 multicopter contains a support for the GoPro camera; which allows flights and acquire aerial images with a stable equipment in a flight time of up to 15 minutes. This equipment has a remote control unit that incorporates two flight control modes, including the Intelligent Orientation Hold Control (COI) position. Its maximum flight speed is 10m / s and it has high intensity LED lights that facilitate the orientation during the flight.

The using of the GoPro camera allows to capture images from several angles, with an accuracy of 5 Mega Pixels up to 3 frames per second and panoramic field of view, which makes it optimal to capture images that would later be processed for creation of ortophotos.

Additionally in the measurement campaign carried out in the Summer School 2017 in Vergina (Greece). A MAPIR NDVI camera of 12 Megapixels was used for the acquisition of the field images through the use of U.A.V. . It contains several lenses that acquire data in different ranges of the spectrum: visible (RGB), Near Infrared (NIR) and near red-infrared. These types of images allow the calculation of NDVI index and multispectral analysis.

After viewing in a general way the technical specifications of the equipment used in the data acquisition campaign. For the design of the flight plan, the parameters must be longitudinal and transverse, in order to apply the principle of stereoscopic vision to aerial photograms; where the common part among consecutive photographs is the stereoscopic model.

However, due to the topography of the terrain and the different atmospheric factors that can alter the flight; the shape and dimensions of the terrain are captured depending on the inclination of the vertical axis, variations in flight height and relief of the terrain.

In accordance with the above specifications, for the design of the flight plan the following parameters were taken into account:

- footprint on the ground (22 m) : Each image represents 22 meters of the ground
- forward overlap 80%: Overlap between images taken on the vertical flight strip
- lateral overlap 60%: Overlap between images taken on the horizontal flight strip
- 6 strips: Take flight lines

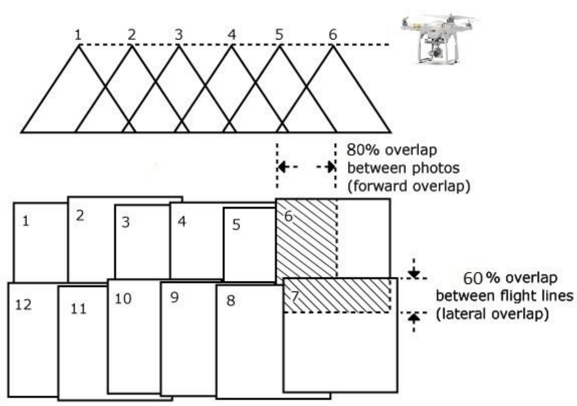

Figure 17. Flight Plan (Soubry 2016)

The designed flight plan allowed a global capture of the area of study, which can help to generate a high precision orthophoto and later the design of a model with a good level of detail.

Figure 18. It represents the flight plan realized with the U.A.V around the Square of the Silos of Burjassot, which was identified from the images obtained and later processed in PhotoScan.

Figure 18. Representation of the flight plan

4.1.3. Acquisition of images for photogrammetry

In order to perform a cloud of points and generate a 3D model, which will serve as support / base for the rectification of the images in the visible spectrum to build a cloud of dense points, it has made use of a digital camera without filter in the infrared to perform a topographic survey of the structure.

It is worth mentioning that the climatic conditions for the realization of the photographic shot were optimal since the course of the day was developed with clouds allowing the same illumination in all the realized images.

In this survey it has taken the photograph of converging images towards the target. This was done with the intention of inserting all the images in the PhotoScan software of Agisoft and obtaining a cloud of points where all the elements of the structure were linked and thus have them all in the same reference system.

For the acquisition of images for photogrammetry in the area of the facade; the pictures were taken during the morning in order to avoid the effect of shading, and the presence of vehicles in the parking areas.

Taking into account the shading, it was necessary to acquire the images of the eastern part of the facade and of the main door during the afternoon hours.

The acquisition of images of the northern part took about two days, because it was sought to maintain the homogeneity, and contrast of luminosity between the photos to generate sequentiality between them. However, an attempt was made to avoid the greater number of obstacles in the area which made it difficult to acquire the images. (Hadabay, 2017)

This will be reflected in the generation of mosaics used to create the textures of the 3d model as seen in section 4.4.2.

4.2. Structure from motion data processing

4.2.1. Data processing for orthophoto generation

For this process was used Agisoft – Photoscan, the software that allows to process digital images from the combination of digital photogrammetry techniques it is possible to generate a 3D reconstruction of the area.

Figure 19 describes the process carried out to generate the different products obtained from this software, which will serve as input to build of the 3d model in each of its stages.

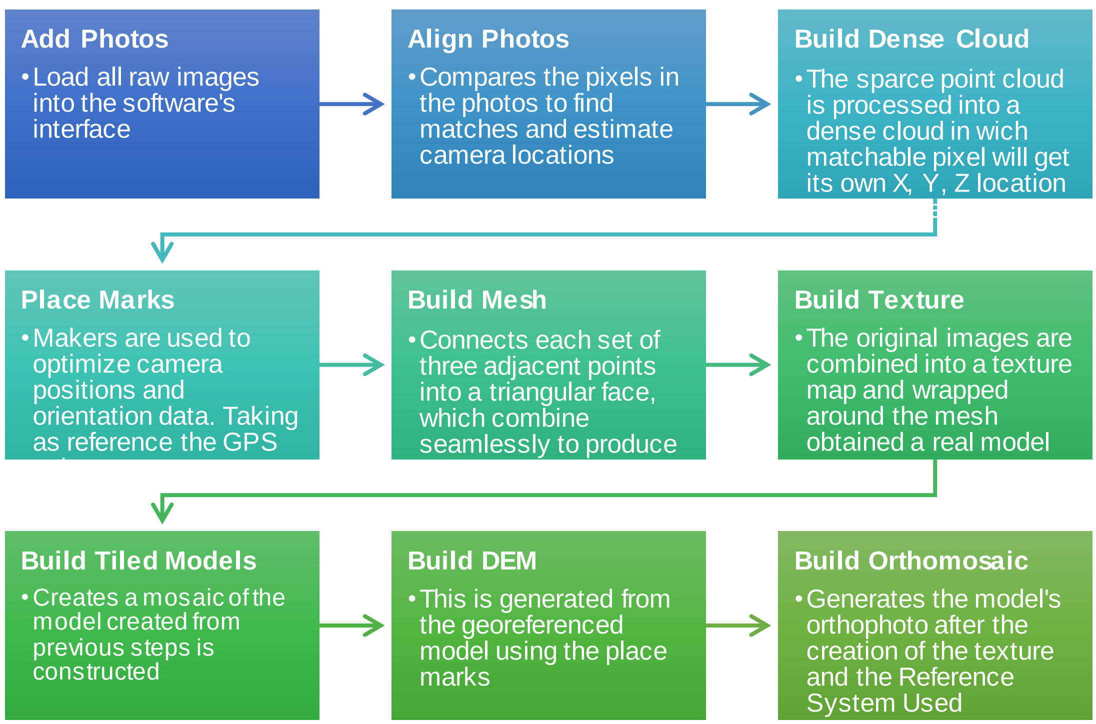

Figure 19. Processing of images in Photoscan and the generation of the point cloud and orthophoto.

In the first stage of adding the photos were taken the images of the files called Line_1_5, line_6 and Roofs; which were composed in total by 481 images.

In addition, was imported the GPS data from the GPS_Data / GCP_1.txt file. Which contained the information that was acquired in the initial stage of the project as mentioned in 4.1.1 GPS - RTK Measurements. After this data was inserted, the coordinate system was established to ETRS 89 -UTM zone 30N (EPSG: 25830) which corresponds to this area of Spain.

Once the reference settings were established, the alignment of the photos was carried out. A process that takes about an hour because of the number of images loaded and finally generates the initial point cloud of the model. In Figure 20 it is seen in the Model view, where the camera positions and orientations are indicated by blue rectangles:

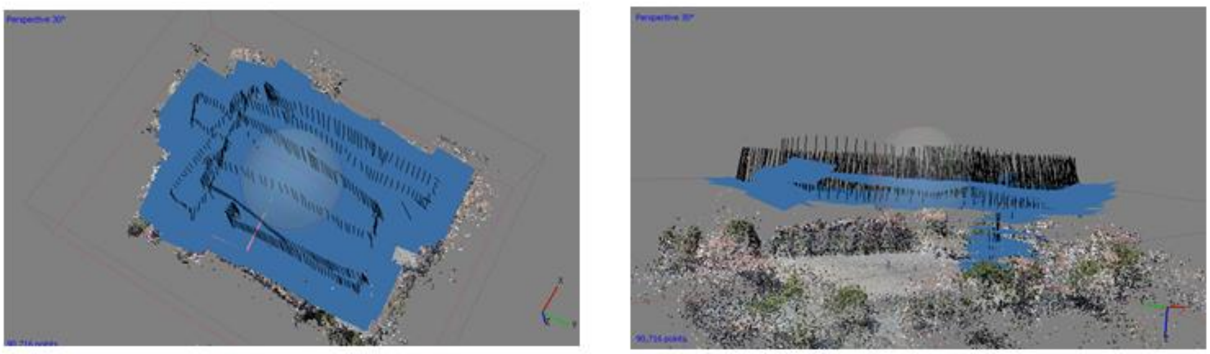

Figure 20. Align Photos process.

The process of Place markers is a fundamental part for the correct georeferencing of the orthophoto, this consists in placing Markers are used to optimize camera positions and orientation data.

These marks were placed with a detail level that will generate the minimum error at the end of the whole process. Table 2 shows the results obtained after placing the marks on the 481 images used. In total, 30 Markers were placed, where 12 Control Points and 9 Check Points, all the data obtained in this process are in appendix 6.2 Result obtained in PhotoScan with the images taken with the U.A.V.:

Table 2. Final Result obtained in PhotoScan with the images taken with the U.A.V

Total Error	Error (m)	Error (pix)
Control Points	0.041	2.3
Check points	0.104	2.9

Following, the dense points cloud was generated; whose process is based on the estimated camera positions where the program calculates depth information for each camera to be combined into a single dense point cloud.

This process determines the Quality that in these case is chose Medium in order to optimize the time process. And the Depth filtering is established taking into account the geometric complexity of the scene to be reconstructed.

The Build Mesh process is necessary for generate a polygonal model as a final result. After to reconstruct, is generate a polygonal mesh model based on the dense cloud data. The parameters that has been used are Surface type: Height Field, Source data: Dense cloud and Face count: High.

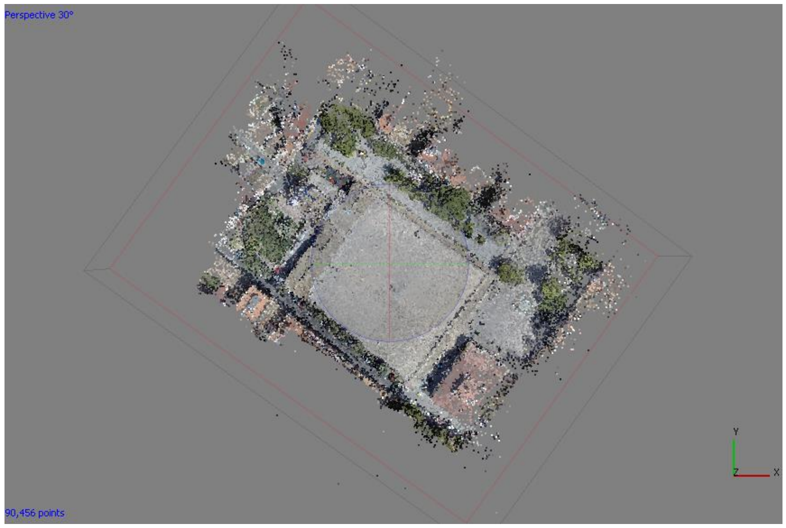

Figure 21. Point Cloud generated in Photoscan with U.A.V. images.

Whit respect to de Build Texture process, this tool has been used for to inspect a textured model before exporting it. The parameters that has been used are mapping mode: Generic, Blending mode: Mosaic (default), Texture size/count: 1024 and Enable color correction: Enable color correction and Enable hole filing.

For the Build Tiled Models generation, the parameters shown in Figure 21 were taken into account:

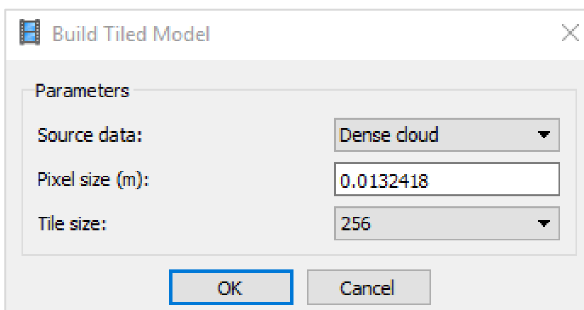

Figure 22. Parameters for to build tiled model.

Digital elevation model can be generated based on the dense cloud or mesh model. The coordinate system specified to do this is the same that was used for the georeferencing of the points, the one used for the acquisition of the GPS points. Figure 23 shows the parameters used for the generation of DEM.

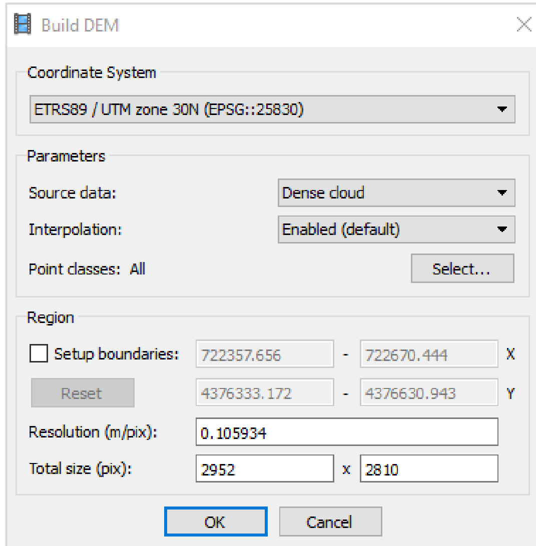

Figure 23. Parameters for to build DEM.

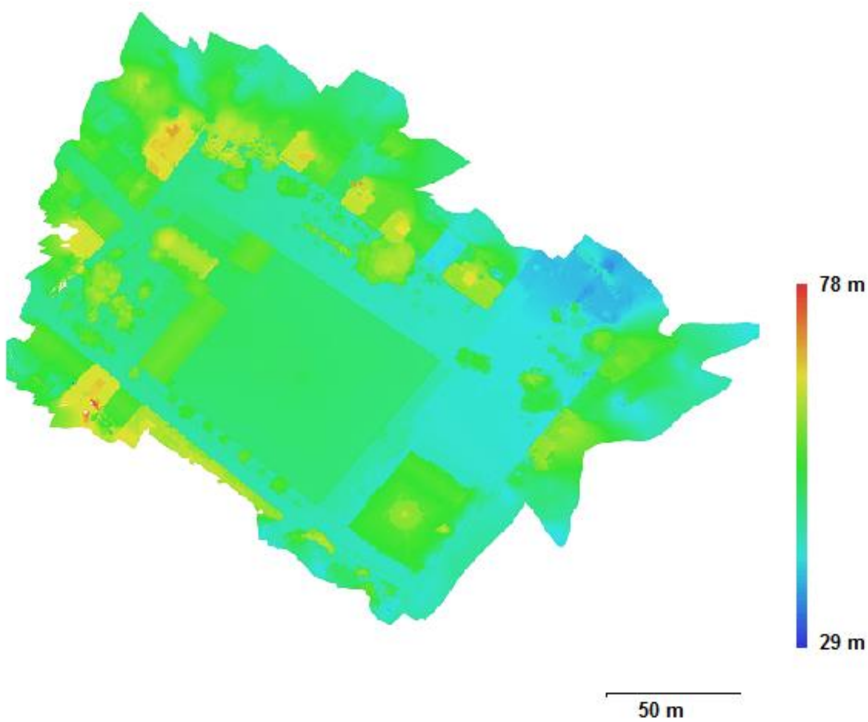

Figure 24. Reconstructed DEM

Finally the orthomosaic was generated, from the DEM in this case, since the reference system assigned to it was used. The program automatically suggests pixel size according to the average ground sampling resolution of the original images. (Soubry, 2016)

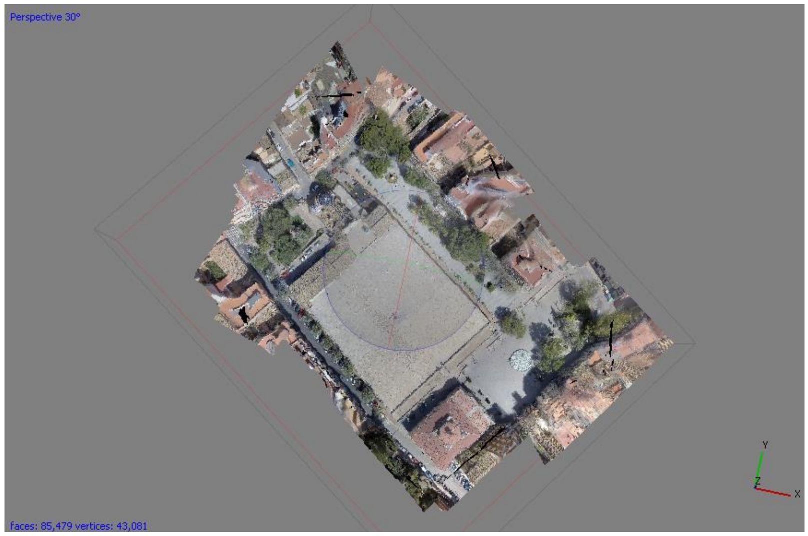

Figure 25. Ortophoto generated in Photoscan with U.A.V. images.

To complement the cloud of points created by this method, they will be used of the clouds of points generated from the results obtained with Laser Scanner and classic Photogrammetry, in order to generate profiles that are not visible or that are generated in a way Distorted by using the images obtained with the U.A.V..

It should be mentioned that the data used for the generation of orthophoto were delivered by the Aristotelic University of Thessaloniky, which was carried out by its students during the data acquisition campaign held in Valencia in April 2016. For the development of this project the process was realized again in its totality. But due to the greater precision obtained in the first exercise, it was decided to use the results obtained in this one.

4.3. Testing the Results

4.3.1. Generated of Ortophoto and DEM verification

Once obtained the DEM and the ortophoto, it is verified in ERDAS IMAGINE 2013, where it can see the level of precision of the generated images; As well as the correct georeferenciation of these. In this way it is also possible to compare and analyze the statistics between the coordinates obtained in the field and those obtained after the generation of the model, in order to calculate the average error and obtain the level of precision. (Soubry, 2016)

The table 3 shows a comparison between the data obtained by GPS and the generation of the ortophoto in PhotoScan. Where ΔE is the coordinate difference in x; ΔN corresponds to the difference of coordinates in y ΔH corresponds to the difference in height in meters.

Table 3. Final Result obtained in PhotoScan with the images taken with the U.A.V

	ΔE	ΔN	ΔH
Average	0,012	0,023	0,015
Max	0,091	0,268	0,160

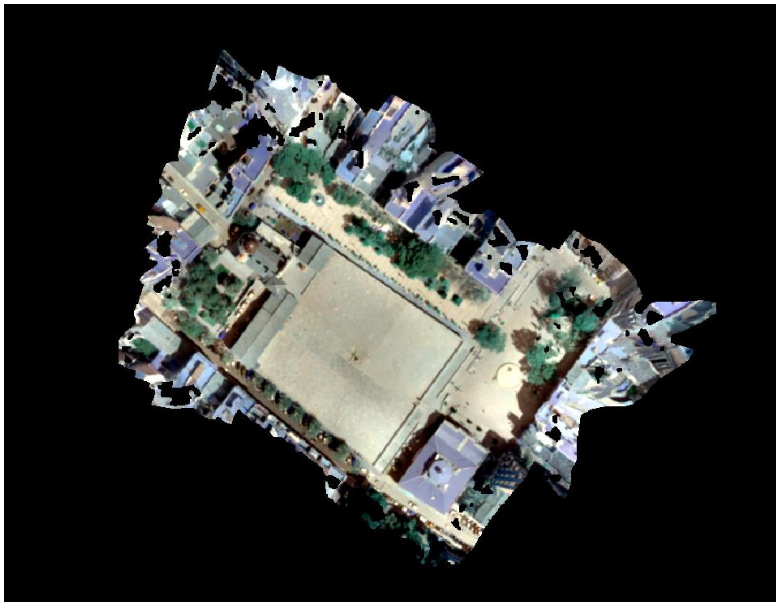

Figure 26. Visualization of Ortophoto in ERDAS

4.3.2. Import into formats compatible with Modeling Software

After verifying the error and precision of the Model generated from the process described above. It is necessary to export both the point cloud and the 3D model to a compatible format in the software in which the 3D model is to be designed, as Cloud Compare, Scene, Geomagic, 3D Reshaper, Meshlab and Blender.

These programs are capable of processing formats with .pts, .xys, .ply, .txt or .obj extension; which are available in Photoscan - Agisoft, so it will not generate inconveniences to export the data obtained.

Similarly for the web publication and the visualizer of the final model, it was necessary to generate final outputs in the formats mentioned above.

4.4. Generated of a 3D volume model

In order to continue with the 3D modeling process of Valencian Silos Yard from the information captured with U.A.V. .The data processing was done in PhotoScan Agisoft. It was then imported into a compatible format in 3D Geomagic.

When was created the DEM from the point clouds of the data collected with the U.A.V, only the information on the roof was available and there was no information on the front of the buildings.

In the Figure 27 can be seen as Photoscan, radiates the information obtained with the U.A.V. to generate the complete DEM.

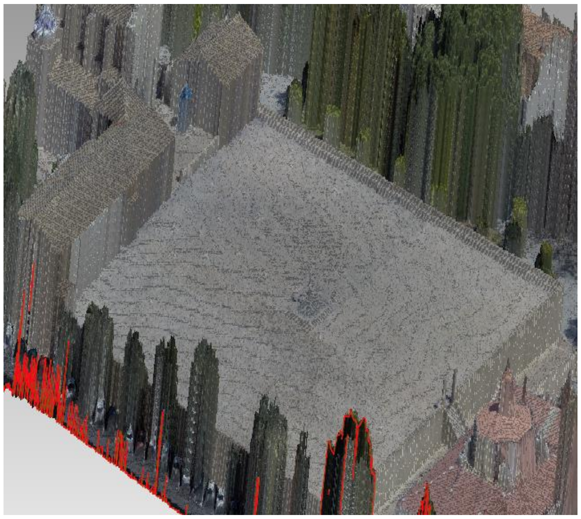

Figure 27. Front view of DEM in Geomagic

As a consequence, it was suggested to create the front side of the constructions from independent models. This process would be carried out using models generated with classic photogrammetry in Photoscan.

In this procedure, the photographs taken in the 2016 measurement campaign were used. Also, the checkpoints and landmarks taken with the GPS from the same campaign were incorporated. The aim was to georeferenced the models and create the DEM in the correct position according to the orthophoto generated with the U.A.V images.

Table 4 shows the checkpoints used for georeferencing the Cross; these were chosen according to their position on the cross in order to generate a cloud whose location coincided with the cloud of points generated from the images of the U.A.V.

Table 4. Table of checkpoints used for georeferencing the Cross

Point	X	Y	Z
A6	722519.048	4376467.106	50.229
A7	722517.069	4376468.204	50.547
A8	722512.609	4376466.268	49.772

Figure 28 shows the processing for generation of the point cloud from classical photogrammetry; and the location of the checkpoints on it. Likewise, it can see the distribution of the photographs used to generate the model with this methodology and the subsequent distribution of the checkpoints in order to get the most accurate position possible.

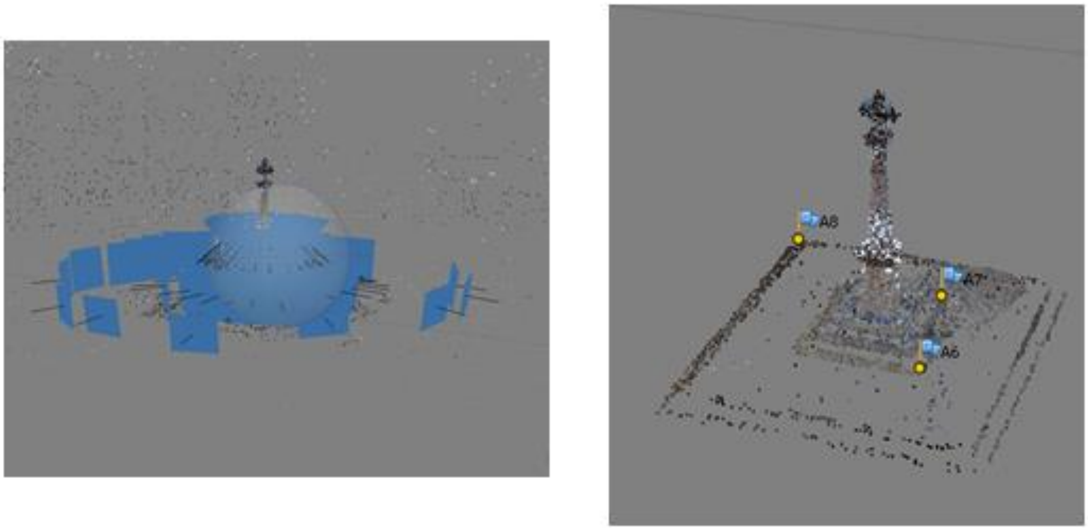

Figure 28. Check points used for generated the Point Clouds of the cross with classic photogrammetry

After executing the process described in figure 19, it was evidenced that due to the lack of images covering the top of the cross the DEM generated in photoScan was not possible to generate it completely.

Figure 29 shows how the generation of the point clouds gave a fairly close result, which allowed to accurately capture the level of detail of each of the figures engraved in both the central part and the upper part of the cross. However the creation of Mesh was not as accurate as expected. Since it can see the detail of the altar where the cross is raised, but the top of the cross disappears almost completely.

Therefore it was decided to use the point clouds generated with PhotoScan, and from these created the model in 3D ReShaper.

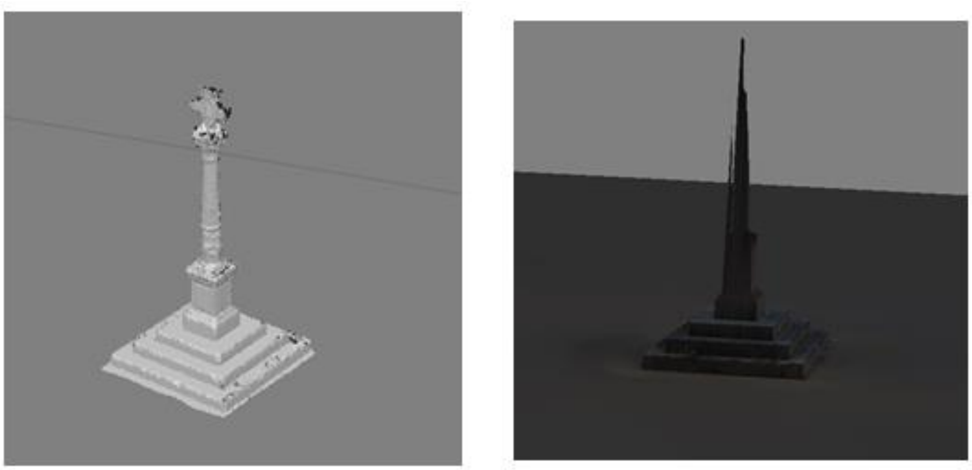

Figure 29. Point Clouds and DEM of the cross generated with classic photogrammetry

Subsequently, it was found that adjusting the point clouds of the cross with the correct position within the U.A.V. point cloud, was a complicated process and did not generate the level of precision necessary to unify both point clouds, despite using Real coordinates and the same reference system. Additionally, process this data using classical photogrammetry for each of the existing constructions in the model was a complex process and takes time.

After demonstrate this disadvantages, it was proposed as a solution combine the laser scanner data to complete the point clouds. This integration provided the possibility of completing the missing information on the front of the constructions with the cover obtained with the U.A.V.

Nevertheless, this process should be accompanied by a process of cleaning the point clouds before to start any transformation of the same. The methodology used for the integration, homothecy and the adjustment of the point clouds is explained in detail in 4.4.1.

The big challenge when cleaning point clouds was to avoid erasing important data and reduce the amount of data contained in each. This is commonly known as noise reduction. They were then generally processed at the start of treatment of the point clouds, and later for each of the zones determined for modeling.

This process served to identify the correct way the data acquired in the field; since being such a complex task during in the post-processing phase, is very important to avoid the presence of objects outside the model when capturing the information. In this way, was taken into consideration for acquire the data during Summer School in Vergina. Keeping out of the area the people, the equipment, the luggage and other objects that could generate wrong points in the data collected, either with the Laser Scanner or during flights made with the UAV for aerial imaging.

After the previous preparation of the data, for the creation of the 3d model it was applied various techniques of solid generation, editing and georeferencing of images.

4.4.1. Point Cloud Treatment

In order to illustrate the process of adjusting the point clouds in Cloud Compare Version 2.6.1, it is possible to briefly mention in a theoretical way in which this procedure consisted.

Initially, there were two point clouds, each with a concentric coordinate system whose relative orientation was arbitrary (in the case of the point cloud of the Laser Scanner). In this sense it was necessary to take the point clouds of the U.A.V. as a fixed point and adjust the other point clouds with respect to this.

This adjustment can be made by representing a rotation in space or what is commonly known as Rotation Matrix:

$$R(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \text{ (4.1)}$$

Since in this case it is a 3-dimensional matrix and we have three components X, Y and Z. This can be defined as an orthogonal matrix of determinant 1.

$$R^T = R^T \ y \ det\, R = 1 \text{ (4.2)}$$

Similarly, using the Euler angles the relative orientation between the two point clouds can be described as a sequence of 3 rotations that correspond to the three degrees of freedom in the coefficients of the rotation matrix.

Then a rotation of angles θ around each of the axes generates different rotation matrixes, the equation 4.3 illustrates the rotation with respect to Axis 1:

$$R_1(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix} \quad (4.3)$$

With respect to Axis 2

$$R_2(\theta) = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \quad (4.4)$$

And With respect to Axis 2

$$R_3(\theta) = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (4.5)$$

The figure illustrates the rotations described above in the plane:

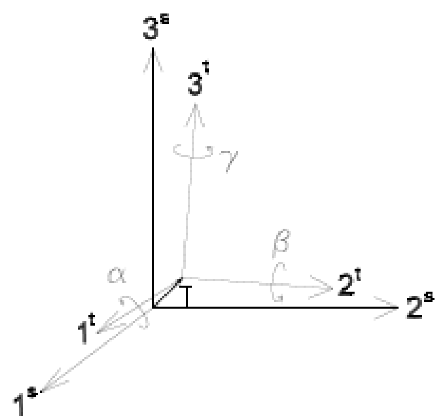

Figure 30. Euler´s Rotation

As a result of the matrix operation, the Rotation Matrix (Asenjo, 2016):

$$C_t^s = \begin{pmatrix} \cos\gamma\cos\beta & \cos\gamma\,\mathrm{sen}\,\beta\,\mathrm{sen}\,\alpha + \mathrm{sen}\,\gamma\cos\alpha & -\cos\gamma\,\mathrm{sen}\,\beta\cos\alpha + \mathrm{sen}\,\gamma\,\mathrm{sen}\,\alpha \\ -\mathrm{sen}\,\gamma\cos\beta & -\mathrm{sen}\,\gamma\,\mathrm{sen}\,\beta\,\mathrm{sen}\,\alpha + \cos\gamma\cos\alpha & \mathrm{sen}\,\gamma\,\mathrm{sen}\,\beta\cos\alpha + \cos\gamma\,\mathrm{sen}\,\alpha \\ \mathrm{sen}\,\beta & -\cos\beta\,\mathrm{sen}\,\alpha & \cos\beta\cos\alpha \end{pmatrix} \quad (4.6)$$

Once it has been generally seen how the rotation of arrays theoretically works, it is possible to understand the procedure carried out to unify the point clouds from different sources.

For the unification of the point clouds obtained by the photogrammetric process generated from the images obtained with the U.A.V. , with the point cloud obtained from the Laser

Scanner it was use Cloud Compare. The Auto-alignment tool generated by the program works from the implementation of the Four Points Congruent Sets (4PCS) registration algorithm.

The process consisted of incorporating the point clouds of the U.A.V. with one of the point clouds of the Laser of Scanner, both clouds had to correspond to the same place. This would allow to verify if they were placed in the correct place or if there was presence of displacement in some of the axes (X, Y and Z).

After this, by using the Clouds registration tool, the cloud of points of the Laser Scanner was aligned taking as reference the point clouds of the U.A.V. from which the rotation matrix shown in the Figure 27 was automatically calculated.

$$\begin{vmatrix} 0.999998927116 & -0.000401396828 & -0.001574452384 & 0.178782984614 \\ 0.000397229043 & 0.999996304512 & -0.002646632027 & -0.174856588244 \\ 0.001575509086 & 0.002646003850 & 0.999995410442 & -0.493401378393 \\ 0.000000000000 & 0.000000000000 & 0.000000000000 & 1.000000000000 \end{vmatrix}$$

Figure 27. Rotation Matrix.

The figure 28 shows the area used to verify the fit between the point clouds. Here it is possible to appreciate the entire area that was used for the first adjustment made between both the point clouds. In the same way, the part of the cross was removed for the purpose of generate an area as homogeneous as possible.

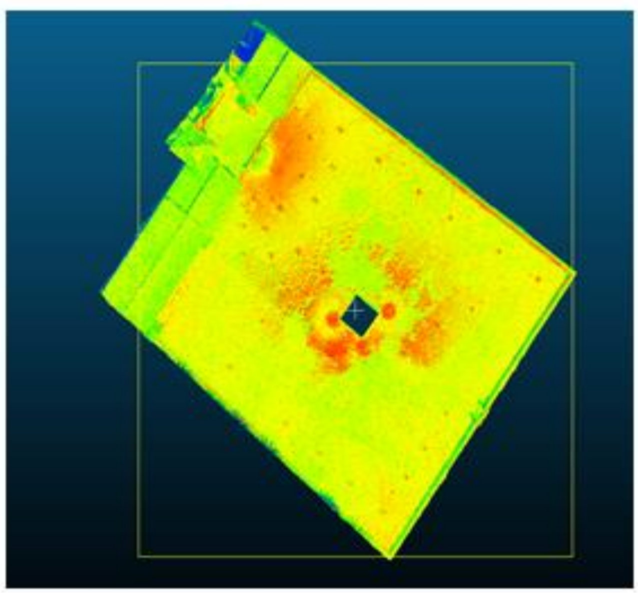

Figure 28. Initial adjustment area between U.A.V. and Laser Scanner point clouds.

In order to verify the resulting distance between the point clouds, after the application of the rotation matrix. The distance computation tool was used, taking as reference the point cloud of the U.A.V. The resulting statistics are shown in Table 5:

Table 5. Computed distance between U.A.V. and Laser Scanner point clouds

Mean distance	0.033
St Deviation	0.024

Also, in the Figure 29 shows the resulting Distance Histogram; where it can be seen that a high percentage of the points are located at a distance of less than 0.2 centimeters, generating an adequate level of precision of adjustment of the point clouds.

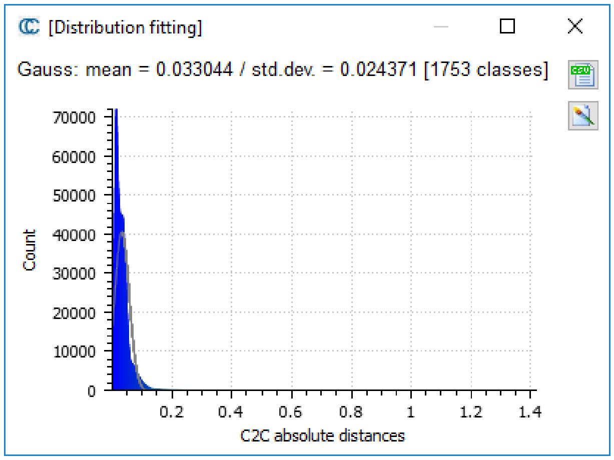

Figure 29. Histograme distances.

To illustrate the above statistics, in the Figure 30 is easily observable the distribution of the points adjusted according to the process of matrix transformation explained above. In this it is appreciated how a high percentage of points is correctly adjusted and with a minimum distance between both point clouds, which shows the precision level of the model.

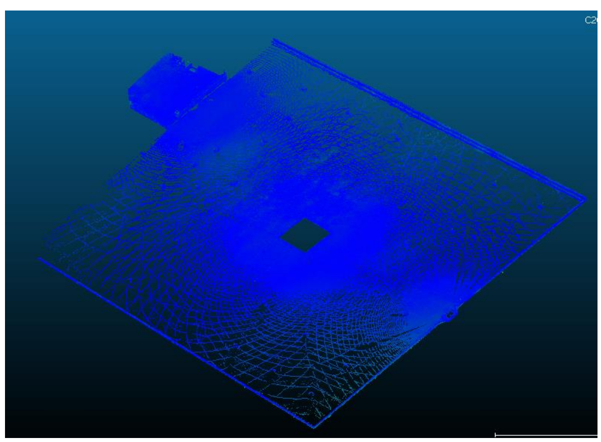

Figure 30. Graphic Distances.

Finally, this rotation matrix was applied to each of the laser scanner's point clouds both those of the outside part and those of the inside part (73 files); by placing all point clouds geometrically continuous. This process allowed the use of the different point clouds collected, in the same position, in order to generate the mesh in the correct location and with as much information as possible.

4.4.2. Zoning of the Valencia'n Silos Yard

After processing of the different point clouds, a global cloud of points was obtained of all the place. (Figure 31. Point Cloud Complete):

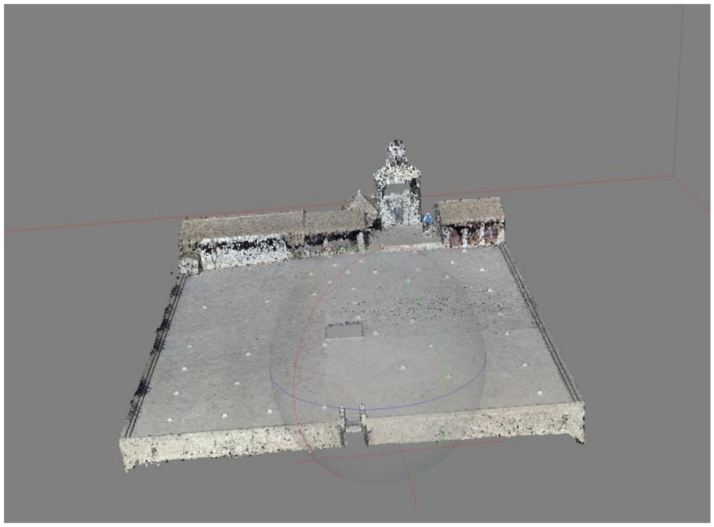
Figure 31. Point Cloud Complete.

However, due to the size of the architectural complex, managing all of the data was a complicated process and required greater consumption of available equipment resources. Due to the level of detail of the constructions that make up the plaza, it was necessary to generate the model from small sections that ensured the original design, both in the elements of the square and in the outbuildings.

Consider the location and the elements that made up each of the sections of the construction, it was decided to divide the entire area in different zones as seen in the figure 32:

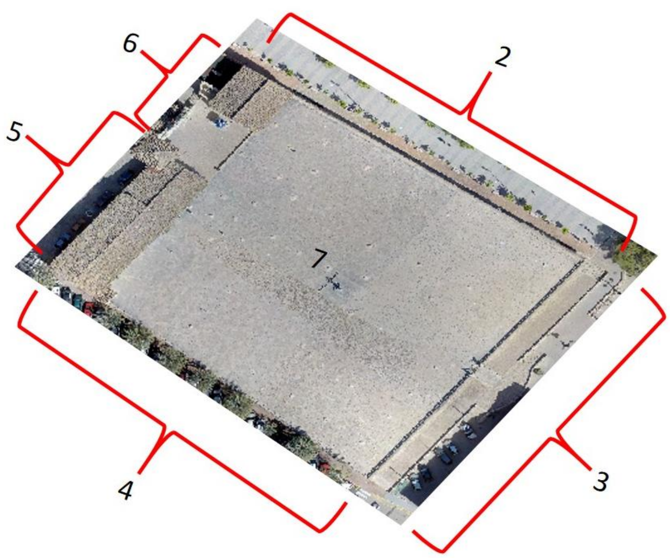

Figure 32. Zone identification.

In Figure 32 the one 1 is not identified, since it corresponds to the inner side of the Silos, which is located inside the square and not modeled in this part of the project.

The modeling of the Silo's inside was carried out in parallel to this project, and after has been integrated into the model to generate a complete 3D Model of the entire architectural complex of the Valencia'n Silos Yard.

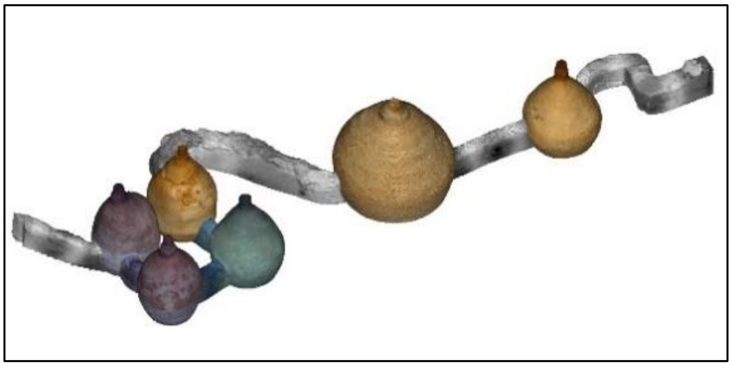

Figure 33. Zone 1 – 3D Model of the inside part of the silos (Goméz 2016)

The numbering of the areas explained below were used to structure the entire modeling process, from the initial cleaning of the point clouds to the final application of the texture.

Zone 2

This zone corresponds to the wall located in the Northeast part of the square; starting in the second construction of the main warehouse until the right access stairway to the square Emilio Castelar. This wall has a door to the inside of the silos; which was used to connect the inner and outer parts of the models. In the Figure 34 can be seen from left to right, the southeastern end, the central part and the northeast end of the wall:

Figure 34. Zone 2 (Hadabay 2016)

Zone 3

This area corresponds to the main stairs of access to the square, which as mentioned in literal 2.3 is one of the most recent constructions added to the architectural complex, connecting the square with the current Burjassot City Hall and the Emilio Castelar square.

The wall goes from the Avinguda Martirs de la Libertat, located at the South West end of the square; to Concepción Arenal Square on the south west side, where it is connected to the wall of Zone 2 and to the second access door to the inner part of the silos.

Figure 35 shows, from left to right, the upper left staircase of the wall, the main entrance to the square from Burjassot City Hall and finally the right end of the wall.

Figure 35. Zone 3 (Hadabay 2016)

Zone 4

This area composed the entire wall which is located on the west side of the square, just above the Avinguda Martirs de la Libertat. Starting at the northwest corner with the Baroque facade attached to the main store and extending along the Avenue to the southwest corner of the square, where it connects with the left stairway of the main entrance of the square.

Figure 36 shows, from left to right, the lateral façade of the main store, the central part of the wall and the southwest corner where it connects to Zone 3.

Figure 36. Zone 4 (Hadabay 2016)

Zone 5

Zone 5 comprises the main store of the Valencia'n Silos yard. Located in the back of the same, it communicates the store with the Silos square and the San Roque's square

Figure 37 shows the front and back view of the square and the door that serves to connect both squares.

Figure 37. Zone 5 (Hadabay 2016)

Zone 6

The area identified as zone 6 corresponds to the construction annexed to the main warehouse, the Basilica of San Roque and the Well. This zone is located next to Zone 5, in the northern part of the square, connecting to the Northeast with the Carrer Hernandez Casajuana, and with the Plaza Concepción Arenal.

Figure 38 shows from left to right the Basilica of San Roque, the well, the construction annexed to the store, and finally the back façade of it, where there is currently a playground.

Figure 38. Zone 6 (Hadabay 2016)

Zone 7

This area corresponds to the surface of the square as such, and to the cross that is located throughout the center of it. In the same way this serves as a connection between all areas of the architectural complex.

In Figure 39 is a general view of the square and an approach to the top of some of the 41 Silos that are on it.

Figure 39. Zone 7 (Hadabay 2016 and Wikipedia 2017)

4.4.3. Modeling process

After preliminary testing with Geomagic, and taking into account that the amount of data generated after the previous process. It was decided to use the 3d ReShaper software Version 2.6.1 in a free academic version. As it allowed to manage the data in the Real Coordinate System and the software has a friendly environment and easy to handle.

This program allows the processing of data for the generation of 3D models or inspection, since it has a specific module of cartography that allows to work with clouds of points.

According to the cultural heritage recording, it has several 3D mesh functions, which allow the visualization of the data of millions of data points scanned in a simple way. In the same way the program allows the generation of textures, by means of the construction of a map based on photos of a 3D mesh according to the parameters of the camera, allowing to obtain a precise and real model.

The among other tools available in this program are a diverse range of elements that allow smooth fill holes, decimation and reconstruction of sharp edges; Ideal for editing the raw model obtained from the cloud of points, which will require time and the highest possible precision in order to generate a real and suitable model. In this way the different tools were used to generate the level of detail required to model the outside of the square.

To begin the generation of the 3D model ReShaper, were identified the scanners corresponding of the areas described in literal 4.4.3. Each zone had about 10 point clouds files from Laser Scanner and a part of the point cloud generated with U.A.V. images.

Processing this amount of data in one 3d ReShaper file, was a complex process. Therefore it was initially decided to unify the point clouds of each zone into a global point cloud and subsequently it was filtering in order to delete the wrong points.

This procedure was not productive, although it was necessary to use several point clouds to obtain the largest amount of data in an area. Overlapping of the points of different clouds generated even more noise. In the case of the Point cloud created with the U.A.V. at the top of the zones generated accurate data. But in the lateral zones it generated a wrong points difficult to clean. Even in areas where laser scanner clouds lacked information.

Furthermore, the use of automatic filters is useful over point clouds of small areas and where the data obtained from various methods is accurate. However, for the development of this project, in order to obtain the greatest amount of information corresponding to each zone, it was necessary to join the point clouds of measurement made from different angles. This generated wrong points between the same point clouds. Thus the program's automatic filter identified as noise, the points that were necessary to preserve the actual shape of the objects to be modeled.

In this way, at the beginning only automatic filters of 0.1% and 0.2% could be used. These filters were applied to each zone and to each point clouds. As explained above, it was evident that to delete the wrong points correctly, it is not recommended to unify the point clouds, but manage them one by one. Objects such as trees, people, spheres used for laser scanners, suitcases or carts, which did not correspond to the construction were removed directly on each cloud of points.

When the first cleaning of wrong points was done, it was decided to model the San Roque basilica and the main warehouse. For this process the point clouds corresponding to zone 5 were unified, keeping the top (roof) and the bottom (ground) of the point clouds of the U.A.V. generating an apparent complete cloud. However, when creating the preliminary mesh was evidenced the presence of many holes and the loss of the original structure. Figure 40 shows the point cloud obtained and the mesh generated.

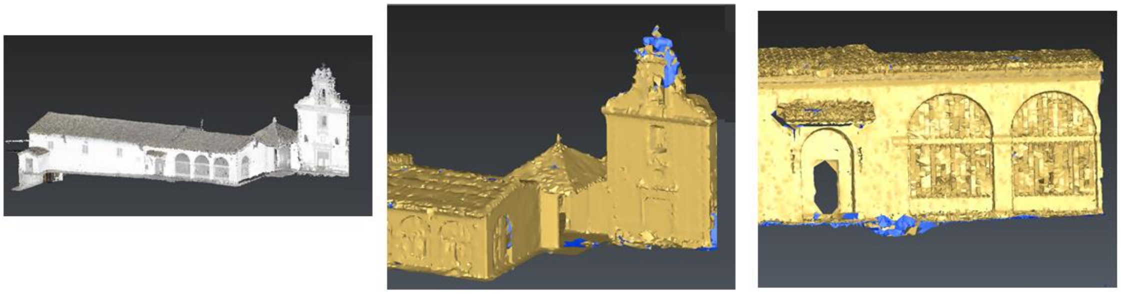

Figure 40. Zone 5. Points Cloud and generation of Mesh

The process of editing the mesh was complex and required too much time. Since by generating the stairs at the bottom of each window with the unification of point clouds, the structure had been completely lost.

After trying to restore the original design of the construction in the mesh, it was concluded that the use of the point cloud obtained with the images captured with the U.A.V. was appropriate only for to model the square and the roofs of the constructions. This restoration process allowed to identify and to know the proper use of the tools with which the program counted. These would be applied later for the construction of more complex structures.

Below is a brief explanation of the general process that was carried out for the model generation. Focusing only on areas where a special level of detail was required.

In general, the procedure used to generate the meshes of the different zones consisted of the previous and exhaustive cleaning of the point clouds separately for each zone. This took a long time due the aim was to eliminate all the noise present in the point clouds.

To perform this cleaning, initially a mesh was generated with the original point cloud, in order to identify the areas where there was presence of noise, using the default parameters of the program. Subsequently the point cloud was cleaned until the wrong points and the noise disappeared in areas where the building had lost its structure.

The Mesh creation was done in two steps. The first step consisted of the generation of a mesh where the largest number of holes were filled, maintaining only the external border of the structure with an average distance between points de 0.03 %. The second step was to refine the mesh from a point cloud, where it was taken into account a Deviation error of 0.003 % and outlet point distance 0.2 %.

Also, a mesh was generated for each part of the construction that had a different texture, in order to avoid the loss of detail during refining. Then the persistent holes in the mesh were filled, the spikes were removed and the structure was finally softened. According to the zoning of the architectural complex, the wall corresponding to Zone 2 was initially modeled. For its generation, only the point clouds captured with the laser scanner were used.

This wall had a series of small drains, which required the generation of an individual mesh in order to avoid losing detail in the design and later were added to the total mesh of the wall. Likewise, the access door to the inside part of the silos was generated separately and in parallel with the inside model so that they adjusted once the models were joined. Figure 41 shows the general view of the wall, the detail of the small drains and the access door with the tunnel that connects the inside of the silos.

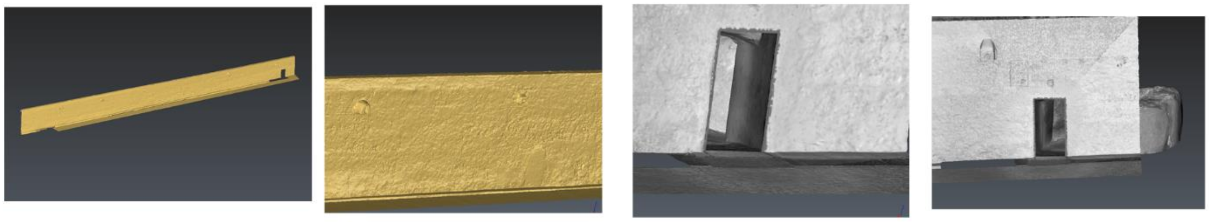

Figure 41. Mesh of Zone 2.

Attached to the wall was a drainage canal which was not captured by the laser scanner due to the data acquisition angle. Therefore, its reconstruction was necessary. For this, a series of additional bridges and triangles were generated in order to create a structure similar to a skeleton, with which, thanks to the tool of filling holes, it would be possible to generate a canal similar to that seen in the photographs, preserving the original design of the place. The reconstruction of the channel can be seen step by step in Figure 42.

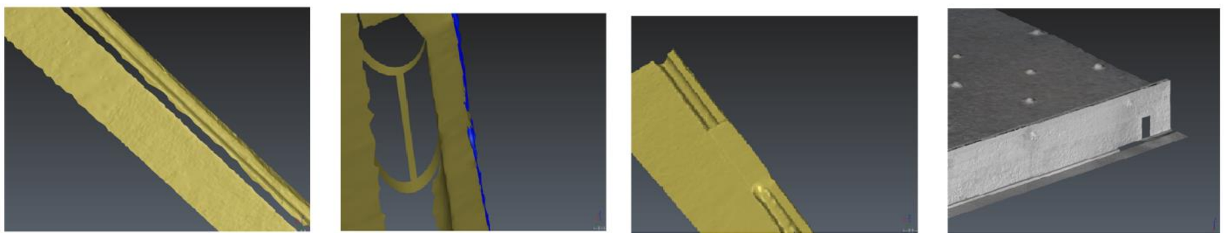

Figure 42. Reconstruction Process of Stone Canal.

The design of several stairways located in zone three, required and only use of laser scanner points, due to the precision level of these guaranteed to maintain the detail of each of the stairs located in this sector.

In the creation of this zone it was necessary to keep the detail of the stairs and the small drains. In addition, reconstruction techniques should be used to fill in the gaps generated by the lack of data in the measurements.

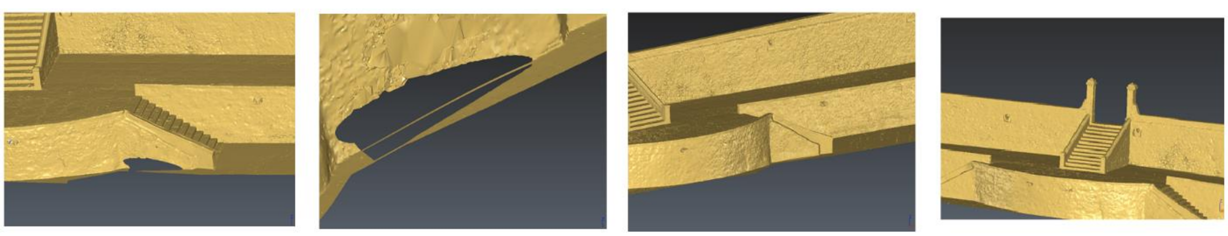

Figure 42. Reconstruction Process of Stone Canal.

For the generation of the mesh of zone 4, the same procedure was made as in zone 2. With the advantage that this wall was simple so it was only necessary to keep the details of the small drains and to merge later the meshes generated.

One of the most complex zones for its constructions were Zone 5 and 6, since these counted on the greater quantity of constructions and details, and required necessarily the use of all the point clouds. In this section, for the generation of the facades of the constructions were used the point clouds from the laser scanner; and for the roofs was used the point cloud obtained from the images captured with the U.A.V. In Figure 43 it can see an overview of the mesh prior to editing each part, and later each of the constructions is detailed.

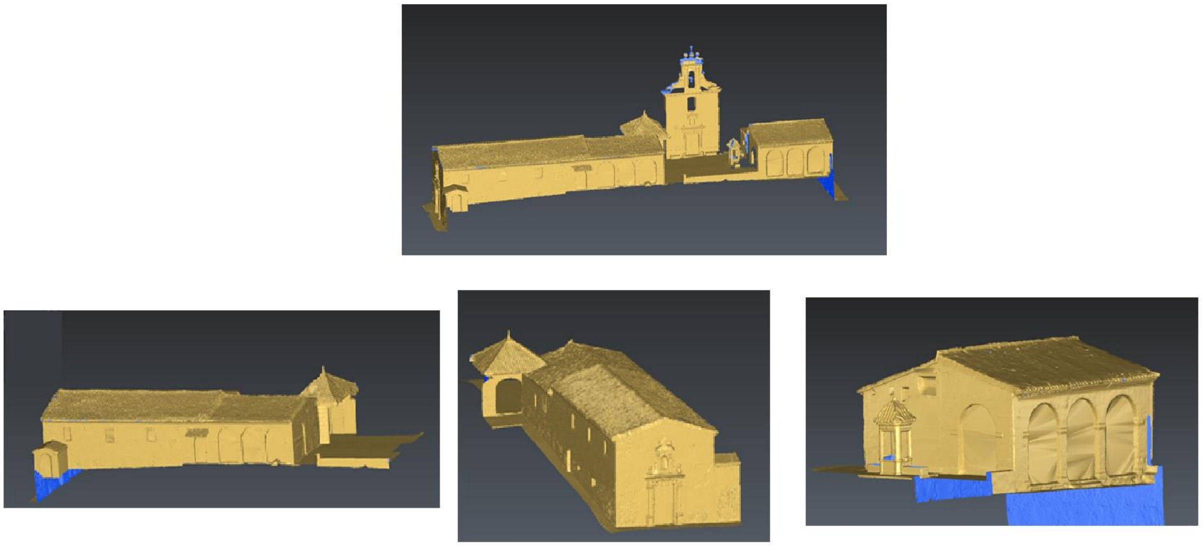

Figure 43. Mesh of Zones 5 and 6.

For the creation of this mesh it was also necessary to apply the reconstruction techniques mentioned in the previous steps, such as symmetry, bridges, filling holes.

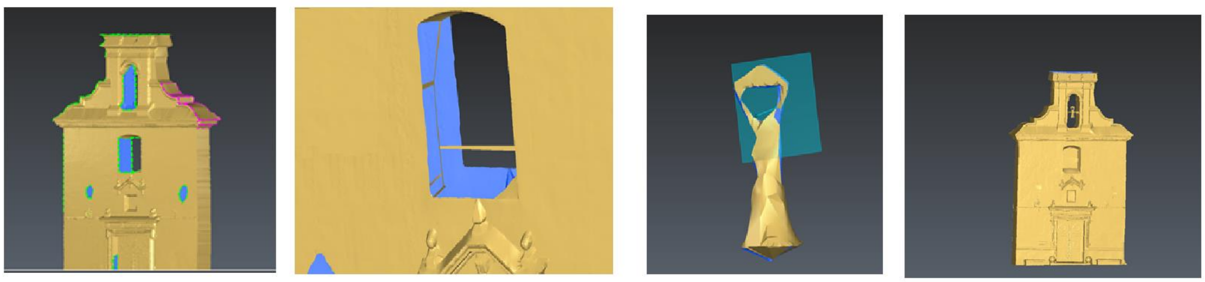

Figure 44. Reconstruction Process of Churche.

In the construction of the Zone 7 model that corresponded to the Square, it was based on the point cloud created from the images acquired with the UA V. However, for the construction of areas that required a greater level of detail it was used the data acquired with the laser scanner; as in the Cross or the silos that were in the area near this one. Where the structure of the meshes generated with the U.A.V. it had completely lost the detail of the objects.

For the generation of the Cross, in addition to the process described above, it was necessary to reconstruct the areas where the point cloud lacked information. As shown in Figure 45 to connect the cross to the pedestal it was necessary to generate a series of triangles, this process was done based on photographs; as because of the data capture angle from the laser scanner it was not possible to acquire information from this part of the structure.

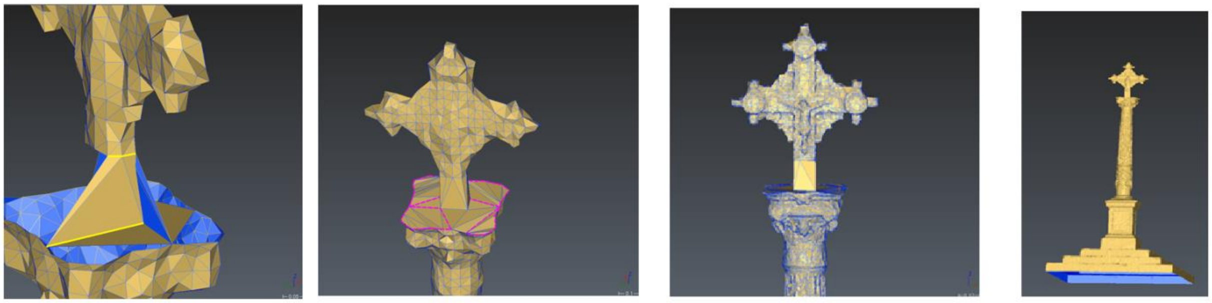

Figure 45. Reconstruction Process Cross.

The modelling of the ring at the top of the silos was firstly attempted to be done from the U.A.V. images. But, the result was not satisfying because of the noise and the wrong points which resulted too important. So, they were finally modelled from the point clouds coming from the laser scanner (see Figure 46), which give them a geometry very close to the reality.

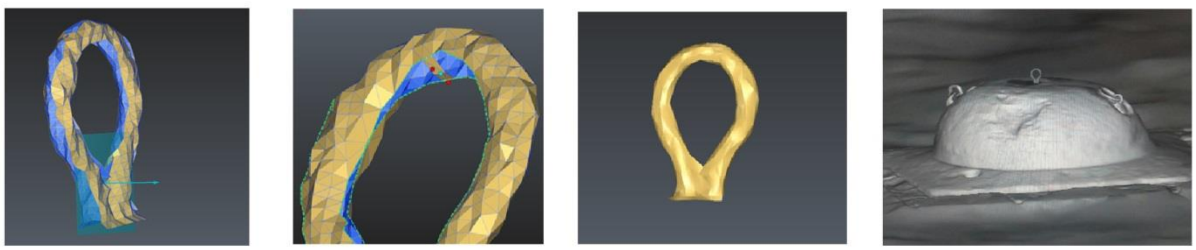

Figure 46. Reconstruction Top Silos.

Once meshes were generated corresponding to all zones; in order to decrease the amount of triangles the points of each of them were reduced and consequently the size of each file. This reduction was taken into account optimize vertices position and try to preserve equilaterally using a deviation of 0.005 % and preserving the sharp edges with an angle between facets of 10 (degrees) and specific deviation of 0.002 %.

The meshes were joined in a global mesh that unified all the zones modeled. And again they were divided into the same zones, for the purpose to generate edges that fit perfectly when all parts of the model are placed in the same viewfinder. The last stage of the modeling consisted in the incorporation of texture. This process was done through the cloud of points or from the photographs

In zone 4 we used the cloud of points of the laser scanner, where the data capture was made taking into account the color of the objects. Also, to give texture to the square was used the point cloud obtained from the images captured with the U.A.V.

In order to fix the texture from photographs, were used the images taken during the measurement campaign. Thus, a single image was used in areas where it was possible to give the complete texture to the facade. Figure 47 shows the texture generation process from photographs. Additionally all the images used were edited in Photoshop, in order to generate a final result with lowest possible noise.

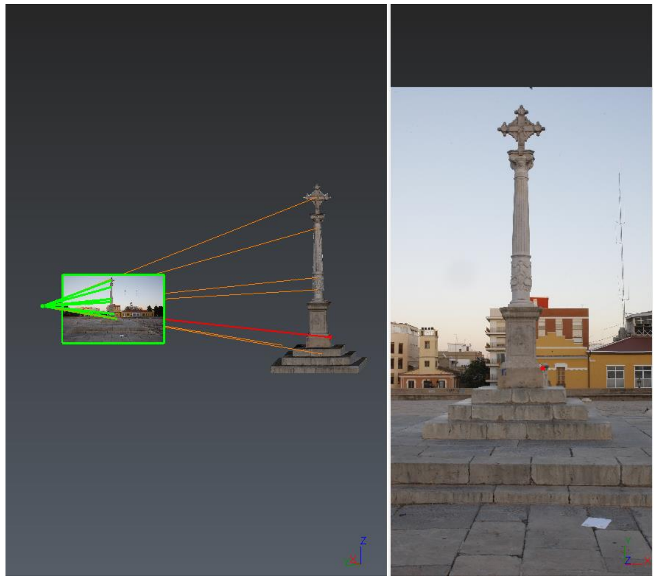

Figure 47. Texture Process from photographs.

For the larger façades were generated mosaics of images in PhotoScan, following the same procedure shown in figure 19. This process was optimal to generate the texture corresponding to zone 2 as shown in Figure 48. However, due to the angle of taking the some photographs; for the generation of the posterior and frontal facades of zone 5, it was necessary to generate the mosaics in Photoshop.

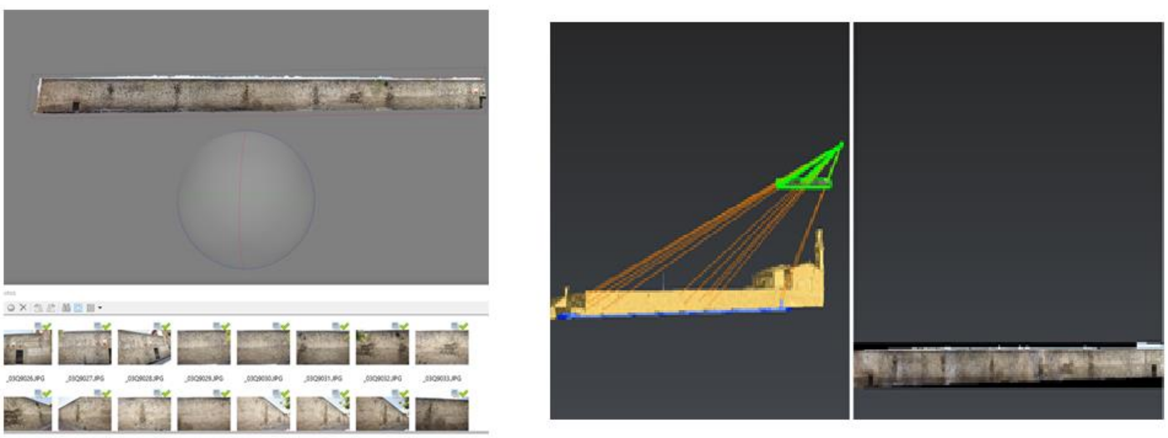

Figure 48. Texture process from orthophotos generated in PhotoScan

Due to the difficulty in taking some images, the capture angle generates inclined images. For this reason, the generation of the texture of zone 3 was complicated and it was only possible to give texture to the left side of the mesh.

Some others areas do not have either photos taken with a correct angle or the laser scanner point cloud is colorless. So, by default, in those areas, a grey color was applied.

This was a brief summary of the process carried out for the generation of the model, but this really required a great level of detail, use of different reconstruction tools and small parts elaboration. In figures 49 to 52 you can see in detail the final result obtained by joining the entire mesh and applying the texture:

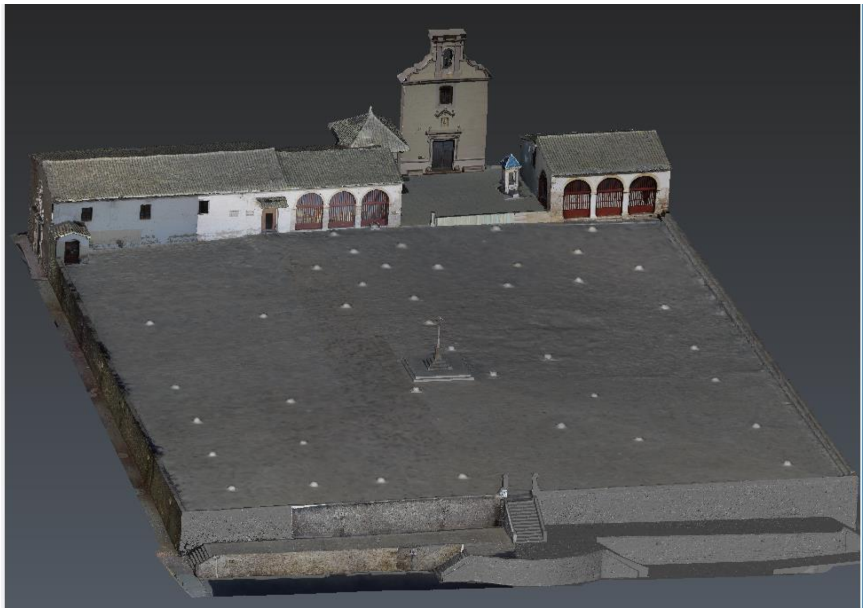

Figure 49. General View.

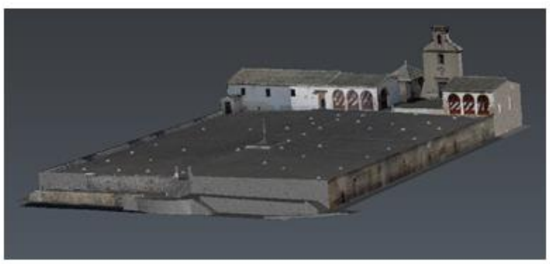

Figure 50. Front View.

Figure 51. Back View.

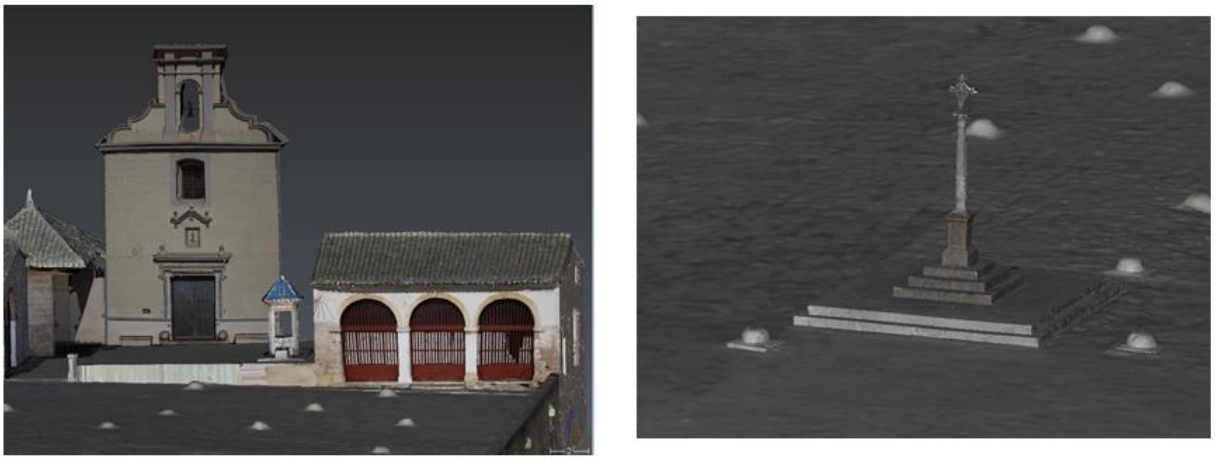

Figure 52. View detail main building and cross.

After the global integration of the model, it was transferred to an imaginary coordinate system for visualization in different software. The table shows the coordinates used for the translation:

Table 6. Translation coordinatesX	-722.430,00
Y	-4.376.410,00
Z	0

The final model was exported in two types of files. The models whose texture was incorporated by the point cloud were exported in *.ply* format, (Zone 4 and zone 7). And the models whose texture was incorporated by images, were exported in *.obj* format (zones 2, 3, 5 and 6). This formats would allow the visualization of the model in other software or in specialized websites.

4.5. Visualization 3D modeling

4.5.1. Viewing on a web server

The main idea of the recording of cultural heritage, in addition to conservation is its dissemination, as a fundamental tool for the management, conservation and analysis of cultural property.

In this context, the main objective of this project is framed. Where once obtained all the products described in the previous literals, it is search to use the available technological tools for the diffusion and the access of the users to the visualization of the project.

For the visualization of the model was used the free access website Sketchfab; which allows to view, publish and share 3D content online (Sketchfab 2017).

In order to visualize the Project in this website it was necessary to merge all the parts of the model. This process was done using Blender. Due to the large size of the final project file it was necessary to use the decimate operation in Blender. With this it was possible to obtain the file size required to upload the model on the website.

As mentioned in section 4.4.3, the final file was exported in .ply and .obj format, as these formats are compatible with various software and websites, such as Sketchfab. However, entering the data on the website did not recognize the texture generated with the point clouds, therefore it was necessary give the color to the mesh directly on the website. This texture can be seen in zones 2, 7 and the right side of zone 3.

Finally the website, gives the option of brightness and background to set the space where the model is displayed. Figure 53 shows the model overview in Sketchfab, which can be seen in the following link: https://sketchfab.com/models/d322b72d93db41229eb68cf47060778c

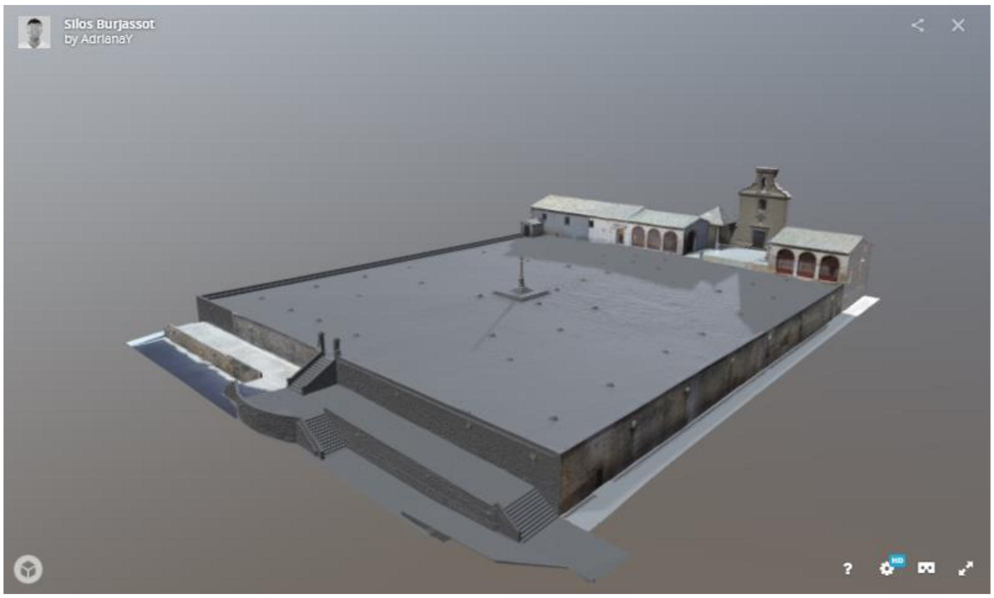

Figure 53. View in Sketchfab

4.5.2. Visualization on a website

For the visualization of the model two methods were generated. First, the visualization of the complete model was generated integrating the external and internal part of the silos in a viewer in Blender. This development was realized by Maria Cristina Gómez (Ref Link) and can be consulted in the project of aim of Master from Laser scanner point clouds to 3D modeling a heritage area.

The second visualization method corresponds to a website that allows the visualization of the model; which it was done through the use of Html, Css and Java Script tools.

For the visualization of the model on the website was used a pre-designed library in Bootstrap, the Google Maps API and the script of the model visualization obtained in Sketchfab that was shown in the literal 4.5.1 Process in Sketchfab.

The website visualization can be seen in the URL: https://adrianayepes.github.io/silosAY.github.io/ and in the Figure 54:

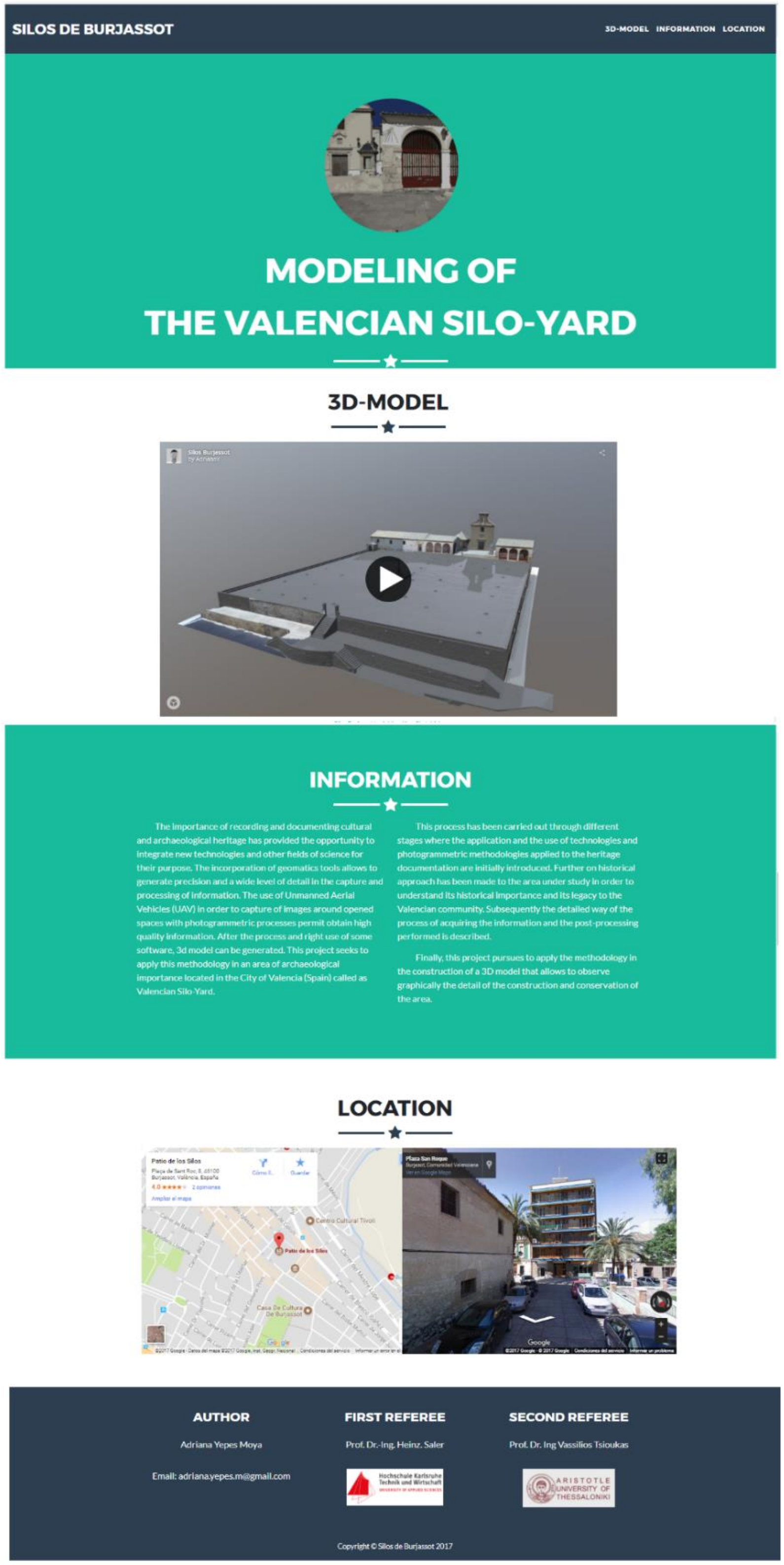

Figure 54. Website Visualization

5. Conclusion

During the realization of this project, it was possible to verify the advantages of use and easy access to new technologies in geomatics, and its application in projects in various areas of engineering, architecture and archeology.

The integration of several methods of measurement and data capture allowed the integration of traditional technic with new technologies applied to precision engineering. The use of photogrammetry, served as a method of structural analysis, design and textures, which allowed to acquire information of diverse types in a short time and without being in situ.

The use of data acquired from UAV and Laser scanner, and its subsequent integration for the generation of a single model, gave the opportunity to verify the techniques, successes and disadvantages in the use of these technologies for the acquisition of data. Thus, it is possible to use each of these methods separately for the generation of an optimal model, but the integration of both guarantees a total coverage of the area to be modeled.

Also, avoiding the presence of people and objects outside the structure, became a vital element for the acquisition of good quality data and the optimization of time in the post-processing of them.

It is important to have an adequate equipment, which has the capacity to process a large amount of data quickly and optimally. In the equipment of low capacity, processing times are increased by 100%.

Although the use of new technologies helped in the acquisition of optimal data. The use of traditional data collection technics such as classic photogrammetry remains a fundamental input for the generation of models that represent the reality of the place.

Additionally, the integration of an interdisciplinary team that guarantees the accurate data acquisition, the awareness and understanding of the archaeological zone measured. They are of great importance to generate the need to preserve and make known the historical and cultural heritage.

Finally, based on the experience gained in this project. It is recommended the integration of existing technological tools for the generation of 3d models and virtual visits of the sites of archaeological heritage. However, the use of traditional techniques such as classic photogrammetry must accompany each stage of the project, in order to obtain a high accuracy and a real view of the place.

6. Bibliography

Asenjo, L 2016, *Notas de Clase*, *Georreferenciación de Sensores y Navegación*, Universitat Politécnica de Valencia [Feb, 2016].

Bezirksregierung Düsseldorf 2015, Gps-grundlagen-bezirksregierung Available at: http:// http://docplayer.org [05 May 2017].

Cano, S 2015, *Los Silos de Burjassot*, Universitat de Valencia. Available from: http://mupart.uv.es/ajax/file/oid/1829/fid/4172/LOS%20SILOS%20DEFINITIVO.pdf [08 Aug 2017].

Consejo Superior Geográfico Infraestructura de Datos Espaciales de España - IDEE, 2017, *Servicios de visualización, Servicio Web Mapas WMS*. Available at: http://www.idee.es/web/guest/directorio-de-servicios [05 May 2017].

Danielgm.net 2017, *Cloud Compare User Manual Version 2.6.1 - 3D point cloud and mesh processing software Open Source Project*. Available at: http://www.danielgm.net/cc/ [22 May 2017].

Djaa, Cultura, Valencia y Benimàmet 2017, *Los Silos – Les Sitges Patio de los Silos*. Available at: http://www.jdiezarnal.com/burjassotsilosdeburjassot.html [05 May 2017].

Hadabay, A 2016, *Creation and Representation of Enrich 3D Model Silo – Yard Burjassot*. Hochschule Karlsruhe,. Master Thesis study program Geomatics [March 2017].

Gómez, M 2017, *From Laser Scanner Point Clouds To 3d Modeling of the Valencian Silo-Yard in Burjassot* Hochschule Karlsruhe Master Thesis study program Geomatics [September 2017].

Núñez, J 2013, *Con un garabato*. Available at: https://conungarabato.wordpress.com/ [05 May 2017].

Pagés, F 1852. *Equivalencia Métricas de las Medidas y Pesas de Castilla, Barcelona, Valencia, Zaragoza y Gerona*. Catedrático de Matemáticas del Instituto de Enseñanza de Gerona.

Remondino, F 2014, *3D Recording and Modelling in Archaeology and Cultural Heritage*. BAR International Series 2598 [2014].

Soubry, I 2016, *The Valencian Silo-Yard through Geomatic*. Available at: https://www.linkedin.com/pulse/valencian-silo-yard-through-geomatics-irini-soubry [18 May 2017].

Sketchfab 2016, *Platform for visualize and interactive 3D Version 2017*. Available at: https://sketchfab.com [01 September 2017].

Universidad de las Américas Puebla 2017, *Estudio y Análisis de la Teoría de la Multiresolución en el Modelado de Sólidos*. Available at: https http://catarina.udlap.mx/u_dl_a/tales/documentos/msp/chacon_m_d/capitulo1.pdf [18 May 2017].

Technodogit 2017, *3D Reshape, User Manual Version 2.6.1*. Available at: http:// http://www.3dreshaper.com/ [22 May 2017].

Valencia Bonita 2017, *Los Silos de Burjassot: recorrido por una de las joyas subterráneas de la ingeniería valenciana*. Available at: http://valenciabonita.es/. [05 May 2017].

Valls, A 2014, *Silos de Burjassot (S. XVI). Origen y desarrollo constructivo. Evolución de sus estructuras. Estado de conservación.* Universitat Politècnica de València [May 2014].

Tables Appendix

A.1. Table of GCPs points

GCPs	E	N	H
1	722514,650	4376448,858	49,121
2	722499,663	4376459,710	49,333
3	722486,494	4376469,250	49,490
4	722477,138	4376476,071	49,570
5	722525,820	4376456,795	49,154
7	722502,312	4376475,390	49,826
8	722489,118	4376485,823	50,091
9	722497,543	4376498,299	49,739
10	722514,170	4376486,345	49,421
11	722529,709	4376475,034	49,203
12	722544,545	4376463,952	48,654
13	722556,917	4376475,314	48,591
14	722542,614	4376487,244	48,784
15	722527,467	4376498,176	48,845
16	722513,054	4376509,490	49,074
17	722491,952	4376505,781	50,303
19	722545,698	4376437,075	46,236
21	722568,368	4376481,892	43,086
22	722548,176	4376495,788	43,735
23	722528,343	4376509,408	44,446
24	722513,861	4376520,201	44,978
29	722524,859	4376430,535	48,622
30	722502,058	4376440,248	48,724
A1	722470,474	4376502,828	49,533
A2	722489,087	4376509,784	50,517
A4	722550,219	4376444,736	45,971
A6	722519,048	4376467,106	50,229
A7	722517,069	4376468,204	50,547
A8	722512,609	4376466,268	49,772
A9	722496,739	4376478,551	49,925

A.2. Result obtained in PhotoScan with the images taken with the U.A.V

GCPs	E	N	H
1	722514,6508	4376448,8549	49,1167
2	722499,6647	4376459,7074	49,3350
3	722486,4947	4376469,2501	49,4920
4	722477,1603	4376475,8029	49,7298
5	722525,8065	4376456,7847	49,1574
7	722502,3144	4376475,4052	49,8235
8	722489,1351	4376485,8354	50,0879
9	722497,5414	4376498,2985	49,7303
10	722514,1697	4376486,3422	49,4147
11	722529,7063	4376475,0285	49,1974
12	722544,5378	4376463,9467	48,6529
13	722556,8934	4376475,2751	48,5971
14	722542,6117	4376487,2297	48,7840
15	722527,4690	4376498,1677	48,8388
16	722513,0577	4376509,4824	49,0759
17	722491,9590	4376505,7808	50,3084
19	722545,6958	4376437,0682	46,2361
21	722568,3512	4376481,8212	43,0805
22	722548,1718	4376495,7674	43,7281
23	722528,3465	4376509,4057	44,4514
24	722513,8638	4376520,1954	44,9765
29	722524,8600	4376430,5337	48,6278
30	722502,0584	4376440,2699	48,7290
A1	722470,3835	4376502,7739	49,5938
A2	722489,0426	4376509,8387	50,4886
A4	722550,2109	4376444,7339	45,9644
A6	722519,0428	4376467,0949	50,2611
A7	722517,0405	4376468,2185	50,5234
A8	722512,6313	4376466,2564	49,7513
A9	722496,7241	4376478,5361	49,9029