Hochschule Karlsruhe Technik und Wirtschaft
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Master´s Programme Geomatics

Master´s Thesis

of

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Development of complex geometric surface with Geomatics techniques

Processing of TLS data of the silos of Burjassot

1st Referee: Prof. Dr.-Ing. Heinz Saler
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Terms of reference

Master Thesis

for

David Montalvá España, BSc

Title: **Development of complex geometric surface with Geomatics techniques -** *Processing of TLS data of the silos of Burjassot*

1 INTRODUCTION

Documentation of cultural heritages is an important task of humanity. Geodesy hereby delivers a significant impact. Modern geodetic methods like Terrestrial Laser scanning and UAV photogrammetry are particularly able to produce high accurate geometric and thematic information within a reasonable time.

The Silos of Burjassot are a Spanish national monument in the area of Valencia. Three universities, Universidad Politecnica de Valencia, Aristoteles University Thessaloniki and Hochschule Karlsruhe worked together with funding from the Landesstiftung Baden-Württemberg to apply several geodetic methods, like geodetic network measurement, terrestrial and UAV photogrammetry, thermography and GPR to obtain a 3d model of the silos and their surroundings in Burjassot.

The measurement and the processing of the data have been split between several students of the above mentioned universities.

2 OBJECTIVES

The proposed thesis can be subdivided into the following subparts:

1. Participation in the field campaign of Burjassot from April 11 to 15 within the Laser scanning team.
2. Creating a 3d model of the silos and their surroundings by using Leica Cyclone and Faro Scene, comparing the results and describing the differences. All data should be within the common geodetic reference frame.
3. Visualization of the silos and their surroundings.

3 REFERENCES

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The written part of the thesis, an internet presentation, the slides of the presentation and the abstract for the audience have to be handed over on a CD.

Duration:	6 months	1st Referee:	Prof. Dr. Heinz Saler
Handing out:	1st March 2016	2nd Referee:	Prof. Dr. José Luis Lerma Garcia (UP Valencia) Dipl.-Ing. (FH) Konrad Berner
Closing date:	1st September 2016		

Prof. Dr. Heinz Saler

Declaration

This thesis is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions.

The work was done under the guidance of Professor Dr. Heinz Saler at the Hochschule Karlsruhe – Technik und Wrtschaft (Karlsruhe) and Professor Dr. José Luis Lerma García at the Universitat Politècnica de Valància (Valencia).

Karlsruhe, 20 August 2016 ______________________

David Montalvá España

“A veces, hay que dejarse ganar
para saber disfruta de la vida”
David M.

Abstract

The documentation of cultural heritage status is indispensable for scientific studies and generates protective measures to preserve its, avoiding effect that the work carried out there. Laser scanner is a very effective technology for this type of work and in recent years has become common because it provides dense clouds of 3D points of the object surface with high precision. In addition, UAV with camera drones are another new method that offers new opportunities such as automatic orientation and measurement procedures, 3D data, generation digital orthophotos and digital surface models.

In this project, making three-dimensional data, processing, storage and management thereof as well as the final products that can be generated to facilitate the task of documentation of heritage explained.

Abstrakt

Die Aufnahme des Statusses eines Kulturerbes ist unabkömmlich für wissenschaftlich Studien und benötigt besondere schützende Maßnahmen um es zu erhalten, sodass die Arbeit nicht In-Situ ausgeführt werden muss. Die Laser-Scanner Technologie ist für diese Arbeit sehr effektiv und ist in den letzten Jahren weit verbreitet genutzt worden, da dichte und präzise 3D-Punktwolken der Objektoberfläche erzeugt werden können. Außerdem können noch Drohnen, mit installierter Kamera als weitere neue Methode genutzt werden, denn diese bietet Möglichkeiten wie eine automatisierte Orientierung und Messverfahren, 3D-Daten, Erzeugung von digitalen Orthofotos, sowie von digitalen Geländemodellen.

In dieser Arbeit werden die soeben beschriebenen Methoden genutzt um drei-dimensionale Daten zu produzieren, speichern und zu verwalten. Das finale Ergebnis wird die Aufgabe der Dokumentation von Kulturerben erleichtern.

Resumen

La documentación del estado del patrimonio cultural es indispensable para realizar estudios científicos y generar medidas de protección que lo conserven, evitando que le afecten los trabajos que se realicen en él. El láser escáner es una tecnología muy eficaz para este tipo de trabajos que en los últimos años se ha convertido en habitual, ya que proporciona densas nubes de puntos 3D de la superficie del objeto con alta precisión. Además, los drones con cámara integrada son otro método novedoso que ofrece nuevas oportunidades tales como procedimientos automáticos de orientación y medición, generación de datos en 3D, ortofotografías digitales y modelos digitales de superficies.

En este proyecto, se explica la toma de datos tridimensionales, procesamiento, almacenamiento y gestión de los mismos, así como los productos finales que pueden ser generados para facilitar la tarea de la documentación del patrimonio.

Resum

La documentació de l'estat del patrimoni cultural és indispensable per a realitzar estudis científics i generar mesures de protecció que ho conserven, evitant que li afecten els treballs que es realitzen en ell. El làser escàner és una tecnologia molt eficaç per a aquest tipus de treballs que en els últims anys s'ha convertit en habitual, ja que proporciona densos núvols de punts 3D de la superfície de l'objecte amb alta precisió. A més, els drons amb càmera integrada són un altre mètode nou que ofereix noves oportunitats tals com procediments automàtics d'orientació i mesurament, generació de dades en 3D, ortofotografies digitals i models digitals de superfícies.

En aquest projecte, s'explica la presa de dades tridimensionals, processament, emmagatzematge i gestió dels mateixos, així com els productes finals que poden ser generats per a facilitar la tasca de la documentació del patrimoni.

Acknowledgement

I would like to express my deepest gratitude to my German supervisors Prof. Dr. Heinz Saler and Dipl.-Ing. Konrad Berner for their full support, expert guidance and understanding my problems because without their help I would not have been able to resolve.

Prof. Dr. José Luis Lerma García for be my inspiration throughout this master's degree and his words of encouragement in the worst moments, without their incredible patience and counsel this thesis work would have been an overwhelming pursuit. I hope to continue counting on your help in the future. Like Prof. Dr. Ángel Marqués Mateu for co refereeing this thesis and always show their most innovative face.

In addition, I would like to extend my appreciation to:

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My life mate, Estefania, for making me overcome every day; we have a lot of moments together, enjoy the present and improve the future.

My Greeks friend, Irini and Vassili, I shared so many technical problems with them and always working together to seek the best solution.

A very big thanks you to my friends, Myriam and Patricia, by always take my smile and make me see the positive side of life.

My fellow students, classes where made fun because of you, those who have already completed, and those still working on their thesis, there is a light at the end of the tunnel.

Contents

List of figures

*All the figures that don’t appear the precedence are own creation

List of table

1. Introduction

This master thesis forms part of an international cooperative project between three European universities, whose intention is to show to their students the real work of Geomatics and which methods are used in other countries to get results. Likewise, the focus of this project is to generate three-dimensional products from cloud point to study and show better the main features of the study area.

In the first place it is gone to explain that composed the project and the main objectives. Then, it is showed how to split the job and explain a bite each of them. And finally, there are some information and conclusion a priori of this project.

1.1. Research Problem and Motivation

In this case, it is wanted to make work in heritage documentation trying to use all those techniques that are part of the geomatics degree and combine all of them in the same product (see appendix I.I Planning).

For this reason, the aims of this thesis consist in creating the 3D model of Silos in the municipality of Burjassot, a village located in the centre of Valencia region, in Spain. Along with photogrammetry, it is also the task of this thesis to examine if there is relation between products obtained with laser scanner and gained by photogrammetry.

It is deemed that the site of Silos has special importance due to its historical relevance and must be taken into consideration. This level of analysis can be useful in bringing to understand national and regional events happened in the past and still to influence in our days; the investigation of some studies may reveal the pattern, forms and structure of Silos, at the same time, it can be important to make some decisions t in the future.

Silos has been studied for many years with some of the earliest research dating back to the early 16^{th} Century when the first three silos were build. Over the last few years, it has been taken up with renewed vigour as scientific research in the domain of heritage sciences find connections between form and materials of silos. Apart from such specific finding, aspect of silos has often been found to be a fascinating subject that is a direct consequence of the industrial economy and social environment of the city.

The first data of Silos has been available since the end of 16th Century, it was imperative that they were analysed and evaluated in order to discover more about its characteristics. The first years of operation had not enough indicators such as geology, components... Consequently, it was decided to do the indicators like surface coating and dimensions because it was easy to get them. Furthermore, as this study is of a scientific nature a lot of the inference is based on investigation and results.

The current state is dependent on multiple factors that play together, from religious and cultural to economic, as well as climatic conditions of the environment. The influence of climatological factors such as: temperature, length of photoperiod, intensity of light and, in certain specific conditions, precipitation can be relevant on the winter months, as well as social and economic flux.

The techniques that have been used in all the process will be explained briefly below (chapters 3 and 4).

- **Topography and Geodesic information**:

Topographic Surveys are used to identify and map the contours of the ground and existing features on the surface of the earth or slightly above or below the earth's surface (i.e. trees, buildings, streets, walkways, manholes, utility poles, retaining walls, etc.). If the purpose of the survey is to serve as a base map for the design of a residence or building of some type, or design a road or driveway, it may be necessary to show perimeter boundary lines and the lines of easements on or crossing the property being surveyed, in order for a designer to accurately show zoning and other agency required setbacks (Adobe associates, inc., 2016).

Figure 1.1. Fellow working on data collection (Ana Valls, 2016)

- **Photogrammetry and UAV:**

Photogrammetry is the science of making measurements from photographs. The output of photogrammetry is typically a map, drawing, measurement, or a 3D model of some real-world object or scene. Many of the maps, they are used nowadays, are created with photogrammetry and photographs taken from aircraft. (Walford, 2007)

In Aerial Photogrammetry the camera is mounted in an aircraft, nowadays in UAV or drones too, and is usually pointed vertically towards the ground. Multiple overlapping photos of the ground are taken as the aircraft flies along a flight path. These photos are processed in a stereo-plotter (an instrument that lets an operator see two photos at once in a stereo view). These photos are also used in automated processing for Digital Elevation Model (DEM) creation.

Figure 1.2. Diferents ways to take the pictures (Ana Valls & David Montalvá, 2016)

- **Terrestrial Laser Scanning:**

3D Laser Scanning is a non-contact, non-destructive technology that digitally captures the shape of physical objects using a line of laser light. 3D laser scanners create “point clouds” of data from the surface of an object. In other words, 3D laser scanning is a way to capture a physical object’s exact size and shape into the computer world as a digital 3-dimensional representation.

3D laser scanners measure fine details and capture free-form shapes to quickly generate highly accurate point clouds. 3D laser scanning is ideally suited to the measurement and inspection of contoured surfaces and complex geometries which require massive amounts of data for their accurate description and where doing this is impractical with the use of traditional measurement methods or a touch probe.

Figure 1.3. Laser Scanner Faro taking data (David Montalvá, 2016)

- **GPR and thermography:**

The Ground Penetrating Radar (GPR) technology uses electromagnetic waves transmitted from an antenna which reflects on layers and objects in the ground. These reflections are received with an antenna and create a picture of the subsurface. As the transmitting and receiving antenna is moved along the surface, recordings are collected and displayed side by side, resulting in a cross section, also known as radar profile (GSSI, 2014).

GPR can be used in a variety of media including rock, soil, ice, fresh water, concrete, pavements and structures and it can detect objects, voids, cracks and changes in material.

In the other hand, Thermography is a non-destructive evaluation technique that monitors the target temperature change. Originally, the technique was used primarily in the military service to observe enemy movement at night and in hospitals to monitor the temperature change of organs and tissues. Later on, as the relationship between mechanical properties and temperature was better clarified and the technique became more advanced, thermography developed into an important non-destructive detection technique in the engineering world.

Figure 1.4. GPR (left) and thermography (right) (Ana Valls and David Montalvá, 2016)

Climatological effects have importance because in this region is typical the Mediterranean climate. It is the climate distinctive of the lands in the Mediterranean Basin and is characterized by hot summers and wet winters. The lands around the Mediterranean Sea form the largest area where this climate type is found, also this climate can be found in many places like a majority part of California, in parts of Western and South Australia, in southwestern South Africa, sections of Central Asia, and in central Chile.

In the case of this thesis, the lack of data produces some difficulties to study all the determinants which are important factors in this building. For this reason, this and others projects, which form part of international collaborative project, are important to know the current state of the construction and take the necessary measures for further conservation and rehabilitation if it required.

1.2. Assumptions and Limitations

- This thesis is part of a collaborative project between three universities, where teachers and students that work in it facilitate the exchange of information and techniques helping to obtain results that can satisfy the needs and objectives of everybody.
- If the changes of Silos were studied during years, it should make an evolutionary study. In this way, it is got periodic data and comparison each other. However, this is the first study done with this importance so it cannot be compared with past data. There are only little documentation which should be analysed and processed to make the study mentioned before.
- Another important limitation is not having the instrument enough time. Faro laser scanner was rented for a period of time. Perhaps, it was inadequate for the magnitude of the project which was used.

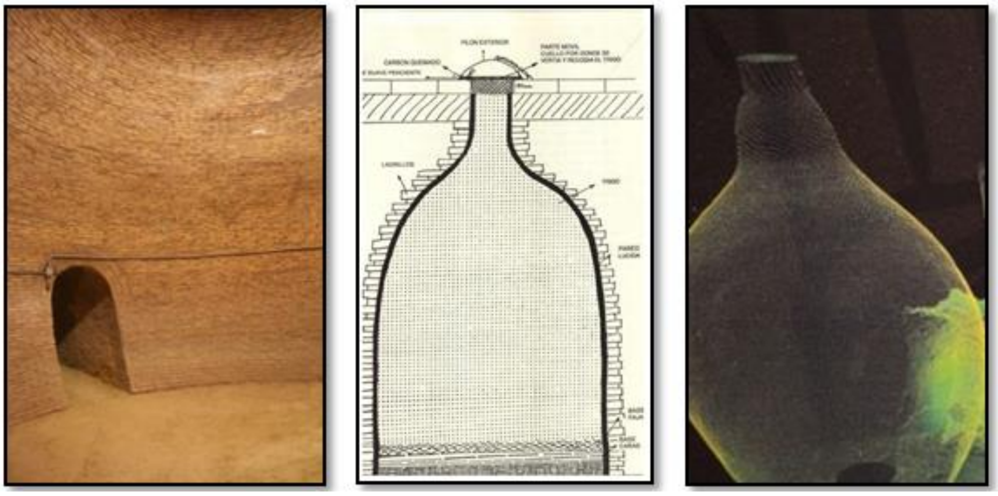


Figure 1.5. Graphic description of silos (Valls Ayuso, at al, 2015)

1.3. Silos: Construction and utility

In first place, is important to know what is Silos and which is the use. For this reason the definition offered by the Oxford dictionary is shown:

"A tall tower or pit on a farm used to store grain. A pit or other airtight structure in which green crops are compressed and stored as silage."

In this study, the meaning of Silos consists in an underground space that brings together a number of characteristics, ideal temperature and wet to preserve some kind of grain.

The processes of creation and operation can be seen in the following image. There are two factors which should be taken into consideration in the characteristics of the terrain: wetness or soil type.

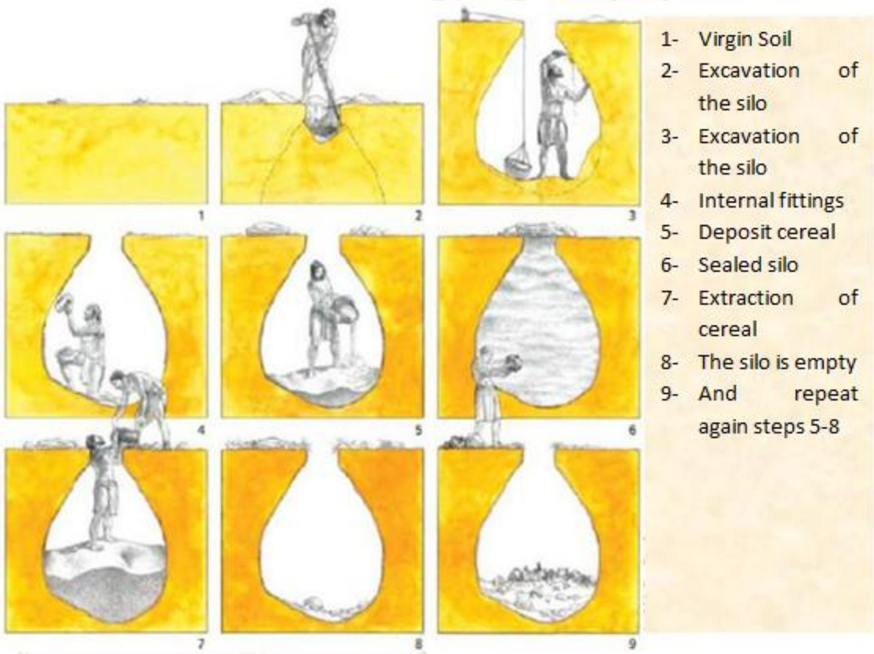


Figure 1.6. Construction method of a Silo (Gutierrez Pulido, 2014)

Depending on where this building was found like so the distinctive customs of citizens, the preservation method cereals could be different. The parts of the silo will be described briefly to know which are the most important parts and its main features:

- Cover: upper and outer part of the silo. Its main purpose is to cover the silo to prevent that the cereal is not degraded by external agents (temperature, animals ...)
- Curb: small size in the study area, it is responsible for keeping the top on the floor together.
- Mouth: inlet and outlet cereal silos.
- Underground: The biggest part of the silos where the food is properly stored. It is characterized by being dug in the ground and covered with some material to help keep the ideal conditions for food.

Figure 1.7. Silo Section (Ramirez Blanco, Valls Ayuso, & Llinares Milán, 2013)

1.4. Location and history of the Silos yard

The study area is located in the Valencia region east of the Iberian Peninsula (Spain). It is the fourth populated after Andalusia, Catalonia and Madrid with more than 4.9 million inhabitants. It is often homonymous identified with its capital Valencia, which is Spain's third largest city. It is located along the Mediterranean coast and it borders with Catalonia in the north, Aragon and Castile–La Mancha in the west, and Murcia in the south. It is formed by the provinces of Castellón, Valencia and Alicante.

The project is situated in one monument in Burjassot. This Town is situated in the centre of Valencia region, 10km the Mediterranean coast. The ornamental and monumental value of these deposits (Silos) in the XVI century is that were used to store wheat for the consumption and commerce of the inhabitants of the city of Valencia and surroundings.

The architectural ensemble of "Los Silos de Burjassot" represents one of the few vestiges of the wheat organization in Valencia sixteenth century, representing well itself a unique monument of its kind in Spain.

Figure 1.8. Situation of Burjassot

The figure of "*Empalador*" (person responsible for introducing and preserving the cereal) appears with the construction of the first three silos, in the year 1573. In addition, the acquisition of large quantities of straw reference from Burjassot and Beniferri (Other city in this region), in July 1576, so it highlights the need and use of the material for coating the interior of the tanks.

Although the way which the straw in the silos are available is not specified, it appears some references to the development of stores. This same system is still used in later centuries, as evidenced in 1816 this system was followed. The way to hold and straw mats to the silo walls came defined by the arrangement of rods on the above described material, in turn; they are anchored on vertical walls with the aid of nails. In this way corroborates, to some extent, the system for the conservation of wheat in the silos Burjassot. It means these Silos were important because the process to save the cereal was a manual task and it was used with natural materials.

The relevance of this engineering job started in 1573, it is given by their valuable function for several centuries, acting as a reservoir of wheat consumed in the city of Valencia and nearby towns.

The construction of this set was transcendental for the subsistence of the City for years, providing greater in times of scarcity and serving as storage in the boom. Los Silos Burjassot represents the old fruit warehouse in Valencia and is one of the most important works of the Valencian civil engineering in XVI century.

Its function as grain tank represented a link in the complex chain of wheat trade, which included the crop and harvest grain; storage silos, barns or earthenware; milling cereal mills -of water, in the case of Valencia for flour; and making bread for the consumption of the population.

All these aspects (the work of those who worked their stones, the important role of the assembly in the subsistence economy and trade in the city of Valencia, and relevance as a work of architecture and Valencian civil engineering), must be added to the pecular Silos Burjassot, which is one of the few urban surviving examples in Europe with similar characteristics, such as Il-pits Tal-Furjana in Floriana (Malta), Carnide (Portugal) or in Cerignola (Italy). (Valls Ayuso at al., 2014).

Figure 1.9. Historic images of Silos-Yard (Alonso Berzosa, 2014)

Also, Silos are located in a population of high agricultural tradition, which is integrated into what is now known as "*l'Horta Nord*". The Valencian plantation is a rural landscape, worked by humans and personality, which forms one of the few preserved gardens in Europe.

There was a day in which this valuable rural landscape could be seen from the Esplanade Silos, whereby said monuments also acquired an important scenic and recreational value during the nineteenth century.

All these unique features make this space an exclusive and really emblematic of the history of Valencia city and the municipality of Burjassot. Through this research, it is intended to delve into the historical and constructive evolution of the monument, as well as clarify some questions that hover over it. This is a contribution to the dissemination and valorisation of an architectural complex that was built on a hill in the municipality of Burjassot and, with little success, has remained forgotten monuments of great impact in the history of the City, muted, preserving history on its walls and soaking up the passage of time, becoming a mere spectator of the lives that have come their corners.

2. Division of labour and define objectives

It should be differentiated between the divisions of work done by all members that belong to the working group in Burjassot silos. On the other hand the tasks to develop in this thesis. Therefore, this section briefly describes the objectives followed in the cooperative project and a small introduction to the work done in this thesis, which is completed on the next sections with more information.

2.1. Aims of the international program

The international project has two clearly different objectives:

- First of all, it is to inform the students about techniques that they can use, not only in their country even in other countries of the European Union and show that they are able to perform real tasks with social and economic relevance.

Figure 2.1. Teachers explaining how split the job (Ana Valls, 2016)

- Moreover, generate a technical document heritage certifying the state in which are the Silos and some rehabilitation and improvement techniques that could be implemented to increase its circulation and increase their social value.

Figure 2.2. Students making presentations (Ana Valls, 2016)

In order to achieve these objectives geomatics engineering techniques have been used, such as: surveying network, laser scanning, terrestrial photogrammetry, UAV, geophysics (GPR) and thermography.

2.2. Main objectives of thesis development

This thesis is developed following the next steps:

- In the first place an early stage of research and fieldwork is considered, which the planning data collection is included, making laser scanner data and taking all the necessary notes for the post office work (during the months of March and April).
- Next, it is the process of generating results, also call office work. This is the stage that more time should be allocated as much time for the generation of 3D model as well as some profiles and a final digital product try grouping the largest number of techniques used (from April to July).
- Finally, a small part of programming which a small display of 3D data using Python to help visualize the results generated will be designed (a few weeks).

All of these sections will be necessary to achieve the goals set below:

- The laser scanner is used for obtaining point cloud, in other words, massive acquisition of points which need a post-processing to be useful as filtering or georeferencing. Therefore, a target will generate a point cloud in which they are all (internal and external) stations in a global framework as could be the reference system WGS84.
- Performing a mesh from the point cloud inside the silos, with special consideration that should eliminate all those elements that must not appear in the meshing such as spheres, electrical wiring or emergency lights. It is wanted to get the mesh as close as possible to the inner wall of the silos.
- After the mesh generation, it is wanted to perform various 3D views to enrich visualization of the data, materializing the digital data into physical models.
- Another aspect to be analysed in this project is the generation of images (2D) showing the entire wall of a silo, pretending to be helpful for architects and restorers who will make future conservation tasks.
- Concluding, it is required to generate a small viewer which helps the visualization of all the above products in one, with some basic functions such as move, zoom in and zoom out, among other.

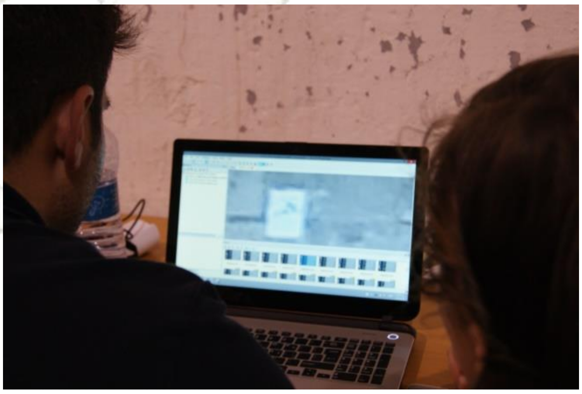


Figure 2.3. Students working in the silos yard (Ana Valls, 2016)

3. Documentation and fieldwork

As it has been commented above, this project is split into three phases. First, there is a process in which documentation is to get as much possible information on the project and field work with data collection. Then, the process is worked in office on which most of the results are generated. And finally, a small section of development wherein you design some tools to help the interpretation of the results.

In the following lines, it is written and explained how it has gotten most of the prior information and how it has developed work in the study area.

3.1. Research documentation and other works

Nowadays there is a lot of information in internet accessible to all. Nevertheless, it is necessary to investigate and verify the information intended to be used before being included in a document such as this thesis. Field notes, reports, maps, photographs or video footage of the site can help to determine possible hazards when recording the object, as previous surveys which may have been created by other means of recording (hand measured, GNSS or total station data).

The Silos site is a big square in the middle of Burjassot that you are able to walk. However, the underground area is closed to the public so a previous visit is not possible. For this reason, is necessary to find all available information and make one idea the magnitude of the project.

Figure 3.1. Aerial photography of the silos (Google maps, 2016)

The city government are interesting in studying this emblematic place in last years, so there are some documents that may be interesting. One of them is the doctoral thesis of Ana Valls which historical data, graphical documentation and updated information are described (Valls Ayuso, at al. , 2014).

On the other hand, it is fascinating to know that instrumental should be used as well as their basic characteristics. In this study, the brand laser scans used Faro (in the chapter 4, the model and some features is shown). Getting its instruction manual, watch some tutorials or see some products obtained with it may be some actions to know how use it.

Also, it could be of particular interest to know the weather conditions during work week, especially whether the days of outdoor work could coincide with rain or thunderstorms. Or how access to the area, charge and discharge areas or parking

3.2. Fieldwork: one week in Burjassot

As there are restricted sectors in the study area, it must obtain a special permission to university for the period since 11 until 15 April, 2016. Teachers and students, all members of the research team, will have full access to place and they will be able to perform all those tasks deemed appropriate, taking special care to preserve the current state of construction and not worse it.

3.2.1. Create a survey Planning

One of the most important aspects to be considered to accomplishment of a job well done is the planning. Therefore, there are some characteristics that must be taken into consideration, as can be the case: working time, the dimensions of the study area or the number of people assigned to that task. The survey planning should at least contain the following topics:

- Determining the goals and objectives.

One of the key issues when recording an object, they are the goals and objectives. To fully understand the needs and requests, some questions have to be answered.

Why does want this object to be recorded and what does it want to do with the recorded data?

The reason for recording an object or building can provide insight on the requirements concerning the deliverables and their accuracy. Often, it is tending to think laser scanning is the ideal tool to solve our problems because it has been used by others, for example competing firm. Or, indeed, the other way around, it might be afraid of using laser scanning to record their building because they are skeptical and rely on using traditional techniques. By listening to the requirements, guidance can be offered on the appropriate measurement technique.

What deliverables are requested?

In close relation to the motivation for recording, we need to define the requested deliverables. These deliverables can range from 2D plans and elevations to 3D models or even 3D animations. In some cases, it is may only want the raw point cloud for archiving. Particularly important is the level of detail (minimum feature size) of the deliverables because it helps in determining the expected resolution.

In the case studied, you want to execute data acquisition for different purposes. On the one hand it is to make some visual results as could be a 3D printing or display of data in a website, on the other a hand exhaustive study for the generation of cultural heritage documentation.

- Analyzing the area to be surveyed and program.

Gathering as much information as possible on the object to be recorded provides insight into the complexity and time required for a certain task, as already mentioned in the previous paragraph. The required resolution and the accuracy of the recording are based on either the scale of the survey area or the minimum feature size that should be recognizable in the final deliverables. Not only the building itself can provide useful information, but also its surroundings. The site can be scattered with obstructions, limiting the possible laser scanner setup positions, or there might even be time restrictions on entering the site Indirectly the possible laser scanner setup positions determine the minimum and maximum range which the scanner should be able to recording.

Using all this data, the recording techniques and the laser scanning that it is used could be chosen properly and the scanner type can be determinant. Laser scanning is a highly developed technique, but it is not always the most efficient solution for every problem. Sometimes it is much easier and time-efficient to use another recording technique. Possible reasons to choose for laser scanning are: Very complex surface structure (organic forms), 3D deliverables required, requirement for surface measurements instead of individual point measurements, data record that can be used by a multi-disciplinary team for different purposes, archiving without a priori knowledge of future use, access restrictions...

The number of the days the project has to done will be in total 5 days. However, for the acquisition of data by laser scanner is disposed only one day. This is due to the equipment used is for rent and will be available for use in the area from 10 to 18 hours.

The area of study is about 9500 square meters on the outside and its perimeter is 500 meters. And inside part, the route is approximately 100 meters. Then, there are 600 meters in total to go and register with the laser scanner in less than a day.

The main idea is to use overall of three days for the task of recording massive points by using the laser scanner, dividing the task in the following subtasks:

❖ **First day**: Generation of a data acquisition plan, indicating the number and position of each of the scans. In addition, place all targets and spheres that will help us in the post-processing.

❖ **Second day**: Data collection using the rented instrument. It must be done quickly and well to avoid problems over time.

❖ **Third day**: Delete all targets, marks and spheres to restore the environment to its natural state.

- Determine optimal scanning locations

Once the site documentation is gathered and laser scanning has been chosen to be the most effective recording technique, the scan and target positions need to be planned.

The optimal locations for the scanning station should be selected to guarantee a maximum coverage and accuracy while minimizing the number of setups. The accuracy of the measurement depends on footprint diameter from a given scanner setup, indicating that the angle of incidence and the range to the object are of great importance when determining the scanner’s position.

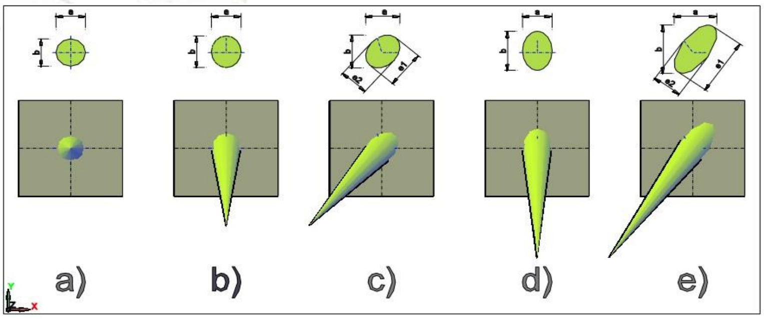


Figure 3.2. Laser footprint when scanning under different angles dims too small (the Learning tools for advanced three-dimensional surveying in risk awareness, 2008)

A thorough analysis of determining the optimal configuration of the scanner to achieve the required accuracy is described it in the last picture. The following list gives a set of prioritized rules that should be kept in mind while determining the optimal position of the scanner.

Figure 3.3 (Above) Bad scanner positioning, containing very inclined angles, (below) Good scanner positioning

Some tips that it is necessary to be in consideration:

- Check positions that provide large area coverage without obstructions in the line of sight and that produce the least shadows.
- Check if the minimum/maximum range limits of the scanner are fulfilled to reach certain accuracy, the larger the distance to the object, the lower the accuracy and resolution.
- Minimize the appearance of low intersection angles, under sharp angles the laser beam is not so well reflected back to the scanner which results in less accuracy.
- Try to decrease the number of scan positions.
- Others important facts that should be taken into account are: Health and Safety, environment (vibrations, wind…), elevation of the scanner above the ground, visibility of artificial or natural targets.

In the case study is proposed 28 stations inside and 62 outside, representing a total of 90. It has special consideration on the outside because on the walls whose orientation is northeast and southwest there are a lot of obstacles such as trees, roads elements or vehicles that obstruct measurement tasks. By contrast, inside the silos will be simple, effective and fast because only there are small informative posters that can be withdrawn at the time of shooting.

- Determining the optimal target locations.

Next to the optimal scanner locations, the target types and their positions and/or geometric configuration are also important. Mainly, targets are used to register scans taken from different scan positions. Currently there is wide variety of target types available: retro-reflective targets, spherical targets, paper targets, prism targets...

One important remark, when using targets, is that they need to be widely spread, not only in x and y direction but in the z direction too. Frequently, it has been forgotten and sometimes all targets are simply placed on the ground.

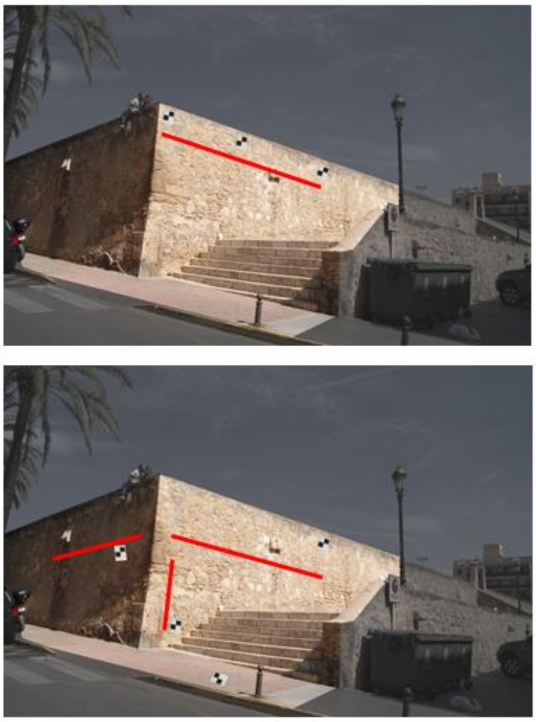


Figure 3.4. (Above) Bad target configuration, (below) Good target configuration

Some target configurations do not imply a unique solution to the registration process. For instance if all the targets lie on a line, 1 degree of freedom remains, namely the rotation around that line.

Special retro-reflective targets and spherical targets are often provided by the scanner developer companies. These targets are designed to reflect most of the laser beam back to the scanner. Therefore the scanner can automatically detect these targets. After, a fine scanning process, determine the exact centre by fitting a primitive shape to the measured point cloud. Sometimes paper targets are used because they are a lot cheaper than the retro-reflective or spherical targets. On occasions a retro-reflective prism is fixed to the scanner head. Knowing the offset between the deflecting mirror of the scanner and the prism, the scanner's position can be determined by measuring the prism with a total station.

In Burjassot, it is used paper targets, provided by Mr. Tsioukas (Greek teacher) and spheres made of expanded polystyrene. It is tried to put the targets so that 6 targets are seen between two scans, combining spheres and paper.

- Data management.

Not long ago, it was important to think about the data storage before starting the scanning. For example, using a Faro Scene Focus 3D X130, 1 scan is approximately 140 Mb. On an average scanning day 70-100 scans can be made, generating a data set of approximately 10 GB. This requires careful planning.

However, today is not so important the size of scans since the technologic advances allow a simple SD card can store more than 100 GB smoothly. It is most important to know that a computer with high performance is needed to handle this amount of data.

3.2.2. Describes all the instrumental and accessories

Current laser scanners are equipped to deal with fast scans. The scanner control panel, internal storage and battery in a single piece combined. Special dual axis compensators are also integrated to automatically level the scanner. Some scanners carry fittings for GPS and compensating for INS positioning and orientation of the scanner directly in space receivers. Some scanners integrated digital cameras or provide a mount for adding information to high-resolution colour point clouds.

In the next table, we can see three different laser scanners. The both first are the modern laser that you can find now in the world and the last one is a model used for quite some time. The big difference between lasers is the number of points per second that they can take. It is important to know because determinate the time that is necessary for regarding 360º. The price is good to know too, because influence directly in the economic budget.

Table 3.1. Comparative laser scanner

Name	Faro Focus 3D X330		Leica ScanStation P40		Leica ScanStation 2	
Range	0,6 - 330	m	to 270	m	to 300	m
Velocity	976000	points/sec	1000000	points/sec	50000	points/sec
Error	± 2	mm	± 6	mm	± 6	mm
Camera	70	Mp	4	Mp	"high-resolution"	
Type of laser	1 class		1 class		3R class	
Weigth	5,2	kg	12,25	kg	18,5	kg
Size	240 x 200 x 100	mm	238 × 358 × 395	mm	165 x 236 x 215	mm
temperatures			(-20)-(+50)	ºC	(-25) -(+65)	ºC
Protection			IP54			
control	display		display		Tablet or computer	
GPS	Yes		No		No	
Compass	Yes		Yes		Yes	
Height Senso	Yes		No		No	
Dual Axis Compensator	Yes		Yes		Yes	
WLAN	Yes		Yes		No	
Price	36.000 €		60.000 €		15.000 € *	

Note: This table is the result of a general survey of some of laser scanner that it is found nowadays in the market.

To the study, it is used the Faro Focus3D X 130, the smallest and lightest laser scanners from Faro, is ideal for indoor and outdoor applications. it is a mid-range device offering precise scanning up to 130m and is equipped with GPS and offers the possibility to perform scanning even in bright sunlight.

Table 3.2. Features Focus 3D X130

	**Name**: Faro Focus3D X 130 **Range**: 0.6 – 130 m **Measurement speed**: up to 976,000 points/second **Ranging error**: ± 2mm **Integr. colour camera**: Up to 70 Mpixel **Laser class**: Laser class 1 **Weight**: 5,2kg **Multi-Sensor**: GPS, Compass, Height Sensor, Dual Axis Compensator **Size**: 240 x 200 x 100mm **Scanner control**: via touchscreen display and WLAN

Note: This table is the result of information that you can see in Faro web site.

3.2.3. Data acquisition using laser scanner

In paragraph 3.2.1 it is explained the need for made a good planning data collection to ensure that all information is taken properly. For this account, it has been taken to change the height of the scanner every scans, changing the distance object-scanner to change the view angle and adjust the parameter point density in function of the distance still a difference between the inside and the outside of the silos.

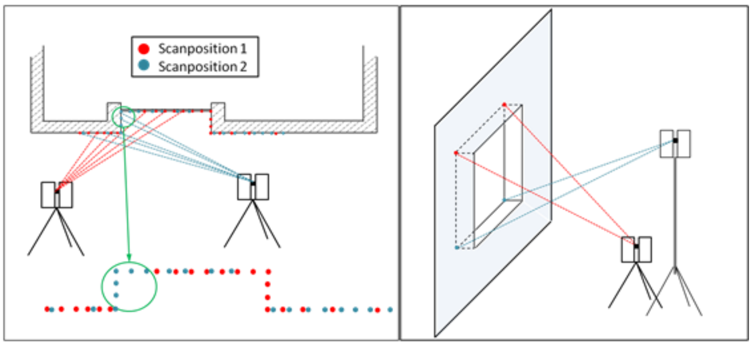


Figure 3.5. Positioning laser scanner in horizontal and vertical (PointCab, 2013)

Also it has to remember that targets and spheres have been used so if it is wanted to made the best solution, it is necessary to see a combination of 3(spheres or targets) between the previous and the next scan.

Figure 3.6. Example 3 spheres between 2 scans

4. Laser scanning and 3D model

This chapter will explain the process performed to generate the register of the point cloud and the products been created with this data. The best thing about these results is that is realistic, easy and quick to understand more thing if compare with 2D results.

4.1. Laser Scanning: Description and modelling

Laser scanning describes a method which a surface is sampled or scanned using laser technology. An environment or real object to take data about its shape and possibly its appearance (eg colour) is analysed. The captured data can be used later to make digital reconstructions, two-dimensional drawings or three-dimensional models useful in a variety of applications.

4.1.1. Laser Scanner theory

The advantage of laser scanning is that can take a lot of points with high accuracy in a short time of period relatively. It is like taking a picture with depth information. And as in the case of photography, laser scanners are instruments line of sight. Therefore, it is necessary multiple captures from different stations to ensure complete coverage of structure.

The current technology of laser scanners can be divided into two categories: **static and dynamic**.

When the scanner is held in a fixed during shooting position data is called **static laser scanning**. The advantages of this method are high precision and relative density points. The static laser scanner is usually the most widely used when it is making scans terrestrial method. However, not all terrestrial laser scans are static.

In cases of **dynamic laser scanner**, the scanner is usually mounted on a mobile platform. These systems require additional positioning other systems such as GNSS or INS, which makes the whole system more complex and expensive. Examples of dynamic laser scanner are found in airplanes (airborne laser scanner), scanners on vehicles or unmanned aerial platforms (Lerma Garcia, 2009).

Figure 4.1. Static and dynamic kind of laser

It is found different laser scanners according to where they are located **on land and air.** It is referred to **land** when the instrument is put on earth and takes measures 360 degrees and can avoid the dome when they are abraded.

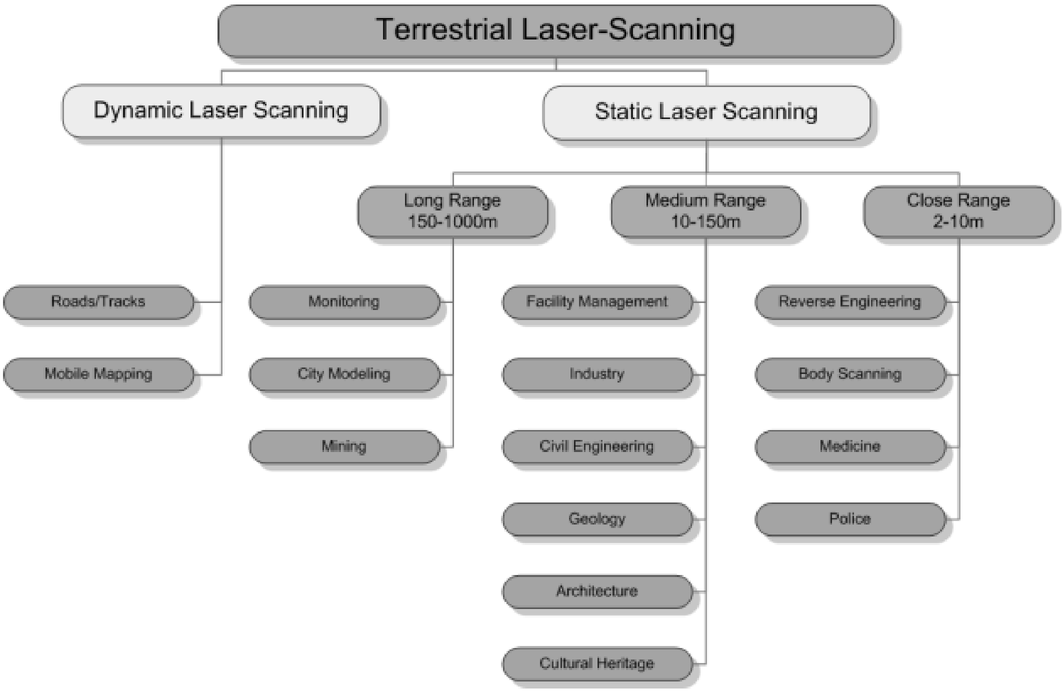


Figure 4.2. Graphic woth describes kinds of Terrestrial Laser (GIFLE,2007)

- **Principles of laser scanner**

Wavelengths of the electromagnetic spectrum vary from long radio waves (the size of buildings) to the short gamma smaller than the nucleus of an atom rays. The electromagnetic spectrum can be expressed in terms of energy, wavelength or frequency. These quantities are related by the following equations:

$$c = \nu \cdot \lambda$$

$$E = h \cdot \nu = \frac{c}{\lambda}$$

Where:

- C is 299.792.458 m/s (speed of light)
- H is 6,626069·10^{-34} J·s (Plank constant)
- v is frecueny
- λ is wavelength

A tool that is able to generate light waves using a narrowband spectrum is called laser. A typical laser emits light in a narrow and little divergent beam wavelength well defined (corresponding to a particular colour if the laser operates in the visible spectrum). This contrasts with another light source such as the incandescent light bulb, which emits light with a large opening and a wide range of wavelengths, which makes us see the light bulb white and not only in one direction. These properties can be summarized with the term consistency.

Actually, the lasers are similar to transistors: generate or amplify light as transistors generate or amplify electronic audio signals, radio or microwave frequencies. The word laser is an acronym for light amplification words of induced emission of radiation (Light Amplification by Stimulated Emission of Radiation).

Currently, lasers are used daily, especially in devices optical storage such as CD and DVD players, in which the laser scans the disk surface for reading data. Other common laser applications are readers of barcodes and obviously laser pointers. In industry, lasers are used to cut steel and other metals and to record patterns such as letters on computer keyboards. They are also used in medical and military applications.

Laser light is simply generated by a laser light instrument. This light has some very special properties which distinguish light from other sources:

- Laser light is generated as the laser beam. This beam has a high (sometimes extremely high) degree of spatial coherence therefore it propagates in a well-defined direction with a moderately diverging beam. The term consistency refers to the electrical signal keeps a constant phase relationship at different points along the beam. This consistency is the reason that a laser beam can spread over long distances and wide focuses producing very little light.
- The laser light has a high degree Present time of coherence (in most cases), equivalent to a long coherence length. Involve long coherence lengths to rigid phase relationship through relatively long intervals, corresponding to propagation distances often several kilometres (long).
- A width of narrow spectral bandwidth (or line width) by combining a large temporal coherence with a time of great consistency is obtained. This means that visible laser beams have a pure colour, for example red, green or blue, but white or magenta. For example, most lasers used in short and medium measurements have a wavelength of 1064 nm (near infrared) or 532 nm (green laser). Notably, long coherence length introduces a tendency to laser noise phenomenon. For instance, you can observe a characteristic granular pattern. This effect can be observed when a laser beam strikes a metal surface.
- In most cases, the laser light is linearly polarized. This means that the electric field oscillates in a spatial direction particular.

The laser light may have other remarkable properties depending on the application:

- The laser light may be visible, but most lasers emit in other regions of the spectrum, particularly in the near infrared, that the human eye cannot perceive.
- The laser light is not always constant, but can be outputted as short ultra-short pulses. As a consequence, the maximum power can be extremely high.

The laser beams remain focused when projected on a distant stage thanks to the properties of coherence another fundamental property of waves of laser light is spreading velocity. Light travels at a finite and constant velocity in a given medium. As a result of these properties, the laser light is very suitable for measuring objects. How it is done is explained in the following paragraphs.

The laser is used in a wide variety of applications, among which are scientific applications, military, medicine and commerce, all developed since the invention of the laser in 1958. The consistency, high mono chromaticity, and the ability to reach extreme powers are properties that permit its use in these specialized applications. Therefore, the laser light must be handled with extreme caution and considers it essential to know the different types of lasers.

To allow users to determine the potential risk, all lasers and instruments that use laser are labelled and classified depending on the wavelength and power of the laser energy produced. The European standard IEC 60825-1 provides information on the different types and associated precautions. Seven kinds of laser are described:

Figure 4.3. Danger sign

a) **Class 1**. They are safe in reasonably foreseeable conditions of use, including the use of optical instruments for intra beam vision.
b) **Class 1M**. They are safe in reasonably foreseeable conditions of use, but they can be dangerous if lenses are used with the beam.
c) **Class 2 lasers** that normally produce a blind reflex to protect the eye. This reaction can provide adequate protection in terms of use reasonably foreseeable, including optical instruments with intra beam vision.
d) **Class 2M**. Lasers typically produce blind reflex leg protect the eye. This reaction can provide adequate protection in terms of use reasonably foreseeable. However, the vision of the output beam can be beam arduous if user employs the beam lenses.
e) **Class 3R**. Potentially dangerous lasers when direct vision intra beam occurs, although lesser risk than in the case of Class 3B lasers.
f) **Class 3B**. Normally they are dangerous if it happens intra beam direct exposure, although the view of diffuse reflections is normally safe. Generally, this kind of laser it is not suitable for field applications.
g) **Class 4**. If you look directly cause damage to the eyes or skin. The lasers of this kind can also produce dangerous reflections. This kind of laser is not suitable for field applications.

In the next table it is possible to see an abstract of the lasers and how affects people. The first row is the class and the second row the comment.

Table 4.1. Types of laser describes in prevention of occupational hazards (UPV)

CLASS	COMMENTS
1	Intrinsically safe in foreseeable conditions
1M	Intrinsically safe, from the visible to near IR, in foreseeable conditions, unless when using beam visualization optics (binoculars, microscope, telescopes, etc. ..)
2	No danger for people with a normal vision system (blink reflex)
2M	Intrinsically safe in the visible under foreseeable conditions, unless when using beam visualization optics (binoculars, microscope, telescopes, etc. ..)
3R	Possible hazards for the direct vision of the beam
3B	Hazards for the direct vision, but not for the diffused vision
4	Hazards for the direct and diffused vision, in addition to fire hazard

Note: In this table it is possible to see the different kinds of lasers.

Users of laser scanning systems should always be aware of the kind of your instrument. In particular, the user must ensure that you are using the correct classification. (See the IEC standard for more information on laser safety).

Individual and procedures to take into account topography, levelling lineation and precautions are described in the IEC standard for laser products Class 1M, Class 2M and Class 3R. These relevant precautions for laser scans are:

- Only qualified and trained personnel should be assigned to install, adjust and use the laser equipment.
- Areas where these lasers are used should be marked with the sign of appropriate warning.
- They should be taken to ensure that staff do not look into the beam (of prolonged and intra beam way as it can be dangerous). The direct view of the beam through optical instruments (theodolites, etc.) can also be dangerous.
- Precautions should be taken to ensure that the laser beam is not directed to mirror-mirror surfaces intentionally.
- When the laser equipment is not in use should be stored in a place where unauthorized personnel cannot access.
- Special laser equipment to be used in explosion-proof environments with a potential explosion hazard (e.g. petrochemical plants, mines). The properties of this equipment are: maximum laser power and the maximum temperature should be limited. Also, non-sparking.

Due to recent developments in computer vision and sensor technology, the light has been used in several ways to measure objects. These measurement techniques can be divided into two categories: **active and passive techniques**.

Passive techniques do not emit any radiation, but instead rely on detecting the reflected ambient radiation. Most scanners of this type detect visible light because it is a readily available ambient radiation. Other types of radiation, such as infrared may also be used. Passive methods can be very cheap, because in most cases do not require more hardware than a digital camera. The problem with these techniques is that they depend on finding correspondences between 2D images, which do not always have a unique solution. For example, repetitive patterns tend to produce errors. The accuracy of these methods largely depends on the resolution of the images and the density of identifiable elements in them.

Active scanners emit some kind of controlled radiation and detect its reflection in order to probe an object or environment. Possible types of radiation used include light, ultrasound or x-ray techniques How are you active measurement requires a laser transmitter and receiver are mechanically more complex than passive techniques. The main advantages of these systems are:

- They do not require ambient light, because they generate their own radiation.
- They provide lots of measurements automatically.
- They can be used in featureless surfaces.
- They capture a lot of information in a short time (1000-500.000 pts / s).

However, some active systems can be affected by external light sources, reflectivity, colour and roughness.

Scanners based measurement time is active scanners determining a time interval between two events. In general, there are two types of measurement principles: Pulse based scanners (time of flight) and phase-based.

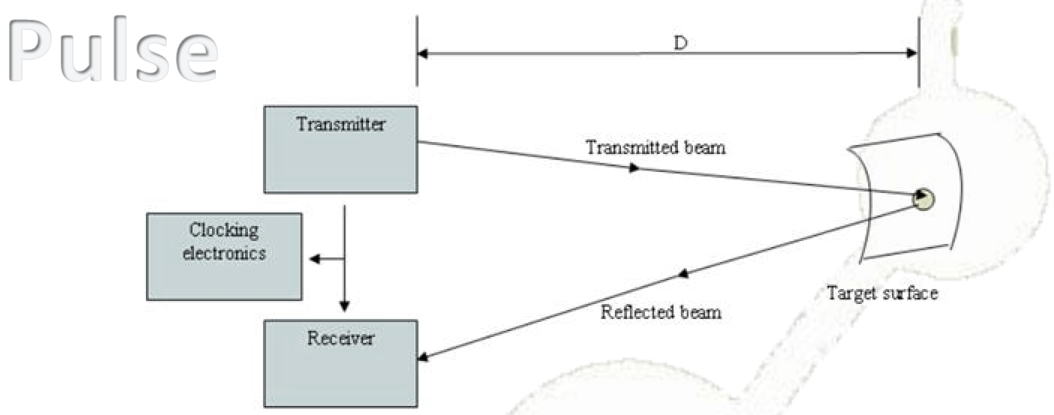


Figure 4.4. Measurement distance using pulse

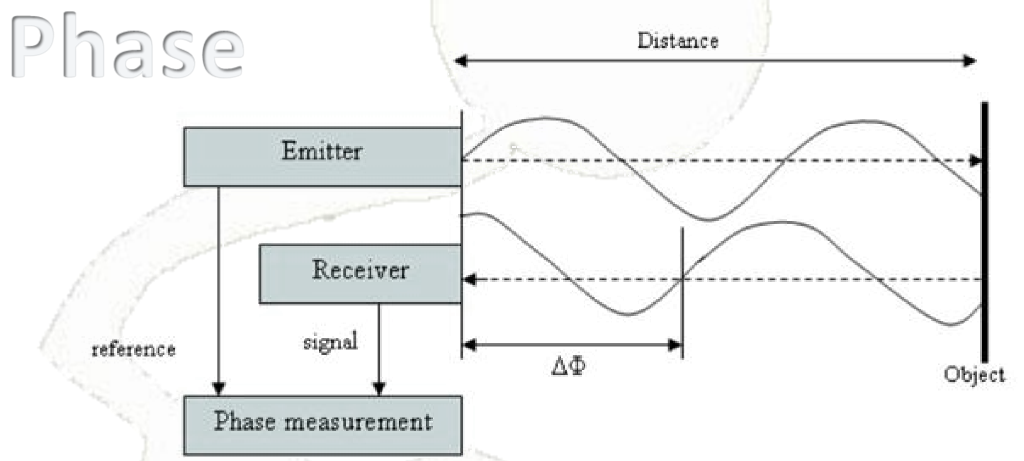


Figure 4.5. Measurement distance using phase

The advantage of using a **pulse system** for laser distance measurements is the high concentration of the energy transmitted. This energy enables the signal to noise ratio (SNR) necessary for high precision measurements of long distance (up to several hundred meters) ratio is reached. The drawback is the problem of detecting the exact arrival of the scattered pulse returns due to the changing nature of optical tolerances and atmospheric attenuation.

To avoid the inconvenience of a range of ambiguity in measuring the phase measurements can be used several frequencies due to the lowest (longer wavelength) frequency point is located to be measured and with high frequencies measured distance accurately.

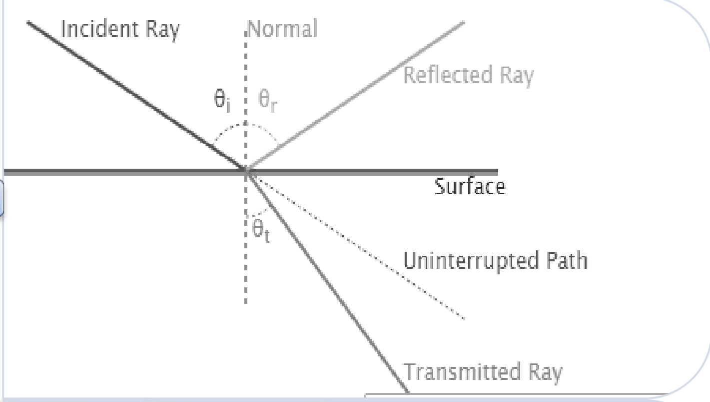
In the latest generation of phase-based scanners, two overlapping have 3 different wavelengths. The long wavelength defines the distance with uniqueness and defines short wavelength accuracy that can be obtained. Generally, these scanners have a higher speed and better scanners flight time or pulse resolution, but less accuracy.

There are some aspects that are necessary to keep in mind when it is wanted to take a measurements using laser instrumental. Materials type, weather or instrumental are some of it and it is explain in the next table, grouped according to similar characteristics.

Instrumental errors

- **Systematic :** can be generated by the nonlinearity of the measurement unit time or temperature drift.
- **Random:** affect the accuracy of measurement andlocation angle measurement systems based flight time pulses.

Propagation of the laser beam



Errors in the axes

- **Vertical:** The axis that allows the scanner to move the laser beam horizontally. Depending on the type of scanner, panoramic camera or scanner, this is the axis of rotation of the scanning head or the axis orthogonal to the axis of oscillation of the mirrors.
- **Collimation:** The axis through the center of the scanning mirror and the center laser footprint on the surface of the scanned object.
- **Horizontal:** The axis of rotation of the scanning mirror.

Environmental conditions

- **Temperature**
- **Atmosphere**
- **Interference radiation**
- **Motion distorsion**

methodological errors

- Methodological errors are due to the chosen survey method or the user experience with this technology.

Figure 4.6. Disruption groups for measurements with laser

4.1.2. Point cloud registration: software and techniques

After the week of fieldwork, it is time to process all the data and start getting results. There are varieties of methods to perform the registration of these clouds of points and join them, but in this section only going to explain three methods. Each represents a different way to get results and used different programs that are currently on the market, such as: Scene of Faro, Leica Cyclone or 3Dvem of GIFLE.

Faro Scene and indirect registration: target to target constraints

In this part of the thesis, it is wanted to show step by step, how to perform a target to target registration in FARO Scene and how to have a point-cloud-based registration combining all scans into a coherent point cloud.

For instance, it is use a data from the silos, which stretches over 2 sites (inside and outside). It is used a laser scanner data, reference spheres and other targets. For this registration method, the overlapping area between scans not is so important because use for the join some points but if you have overlapped of areas the result could become better.

Similar to photogrammetry, an overlap of at least 30% is necessary – the more identical points are available. For example, if it wanted to get the smaller error in the registration, it would be simply scan the targets. In this case, it is used 6 targets between one scan and the next, thus avoiding collinearity there among targets.

Below it is written a small tutorial on how it has worked. First, start FARO scene (it is worked with the current version of FARO scene 6.0.2) and create a new project.

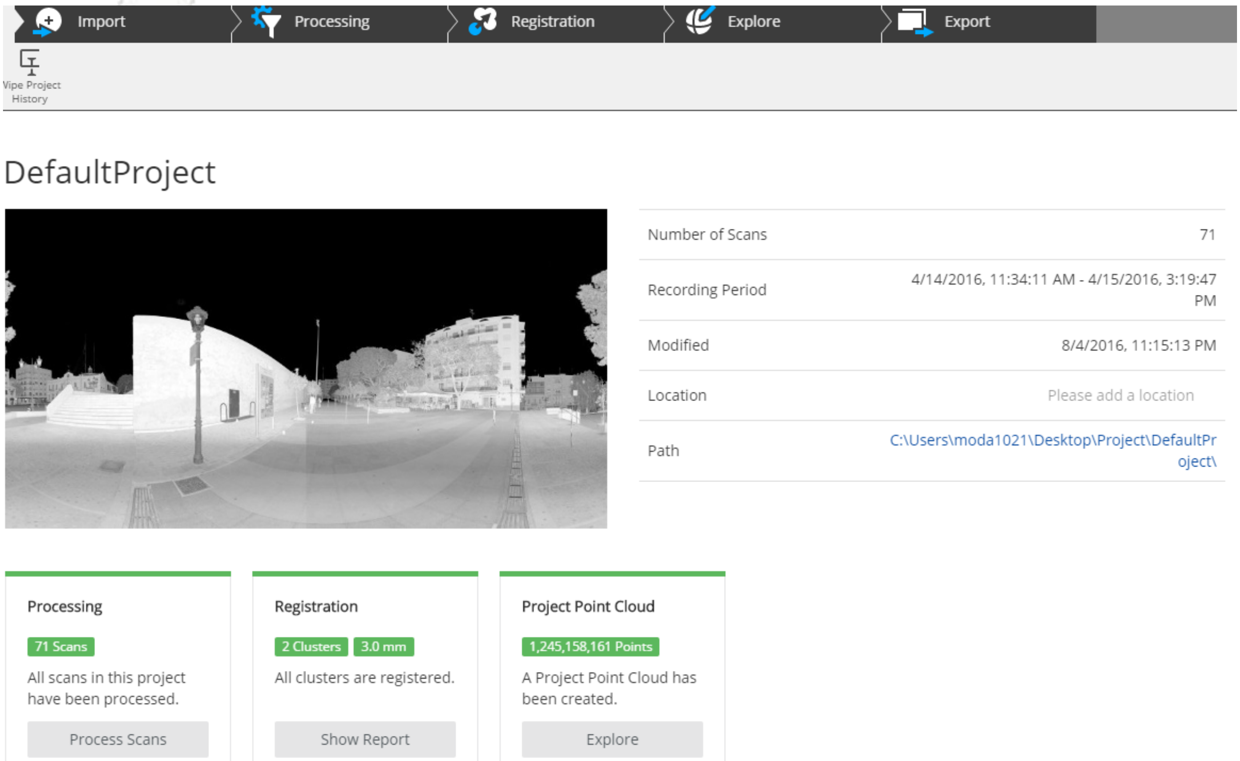


Figure 4.7. Open Project in Faro Scene

The scans can be drawn into the FARO Scene project either directly from the SD card or from another location, simply via drag & drop. In the tree view, a folder named scans will be created immediately below the workspace, where all scans land automatically.

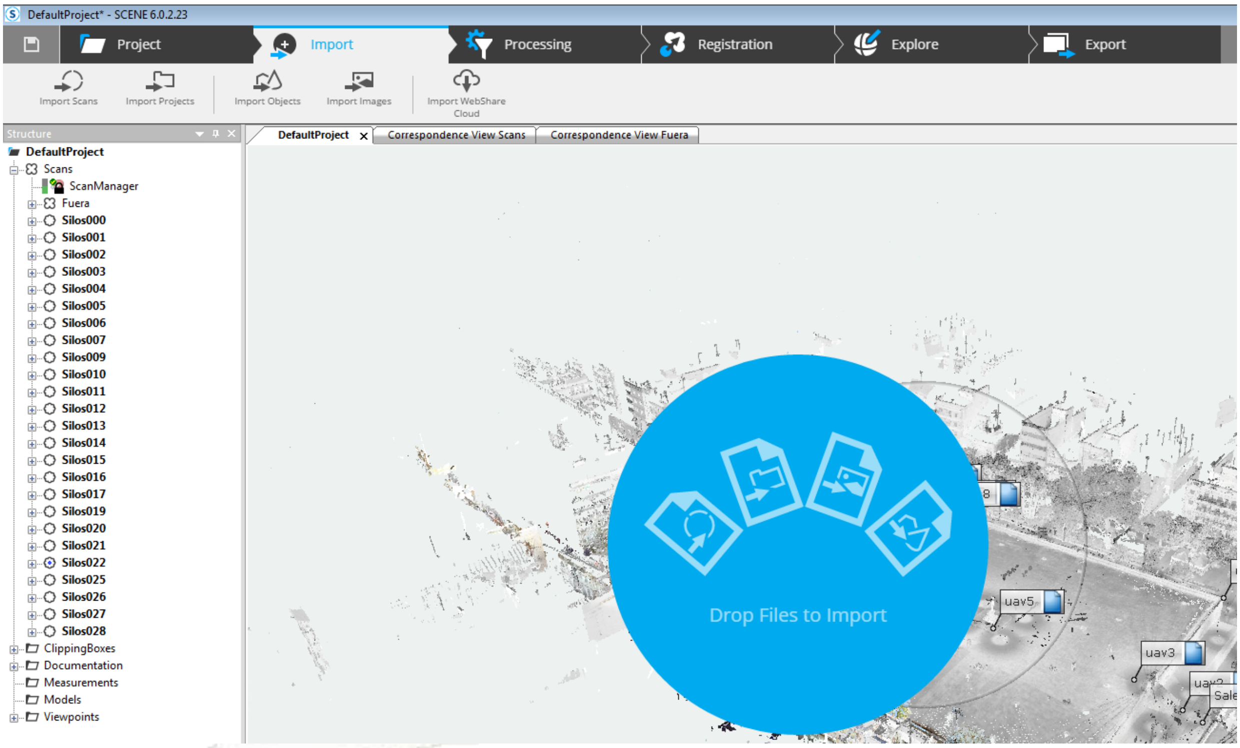


Figure 4.8. Import scans in Scene

When it is saved the project, the FARO Scene typical folder structure is created and the scan data is stored in the database. This first operation takes half minute per scan and will be bit longer, but it is only a one-time process.

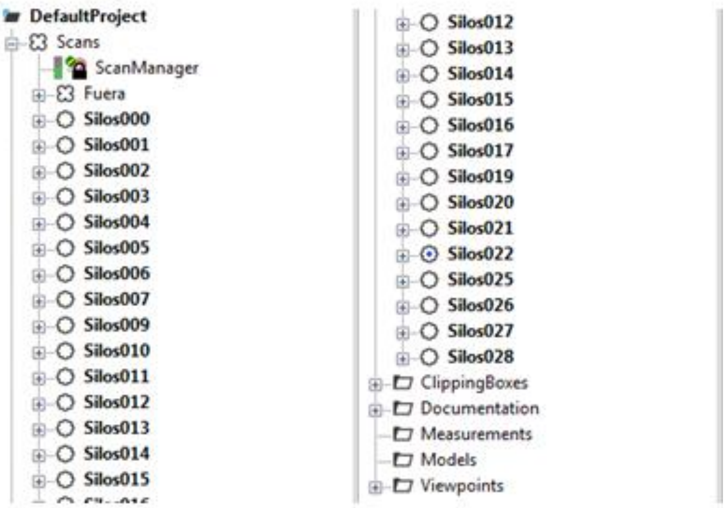


Figure 4.9. Structure Scene

After successfully creating the project structure, one message is appears and specifying that all the data is stored in the first version. We confirm the information with OK.

Now the registration process will be started. Firstly, it is necessary to find all the targets and spheres automatically that appear in the scans, for make it click right button and select operation and Process scan.

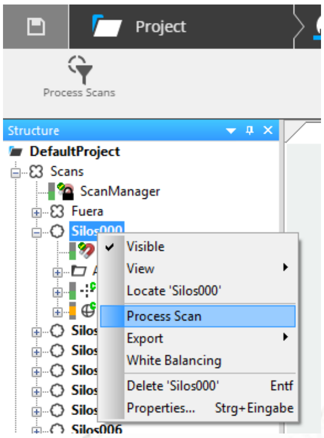


Figure 4.10. Process scans Scene

In this case, it is found spheres and targets because it was used it when work in the silos site.

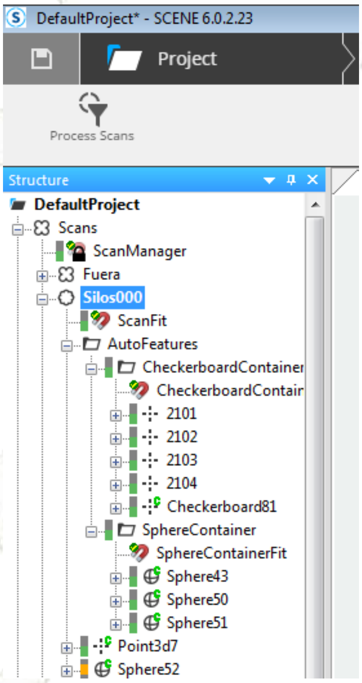


Figure 4.11. Spheres and targets examples

There are two ways to make the register between scans. One of them is the automatic registration which compares point clouds trying to unite by the overlap between them (recommended more than 30% overlap) and the other one is the manual record, it is use now.

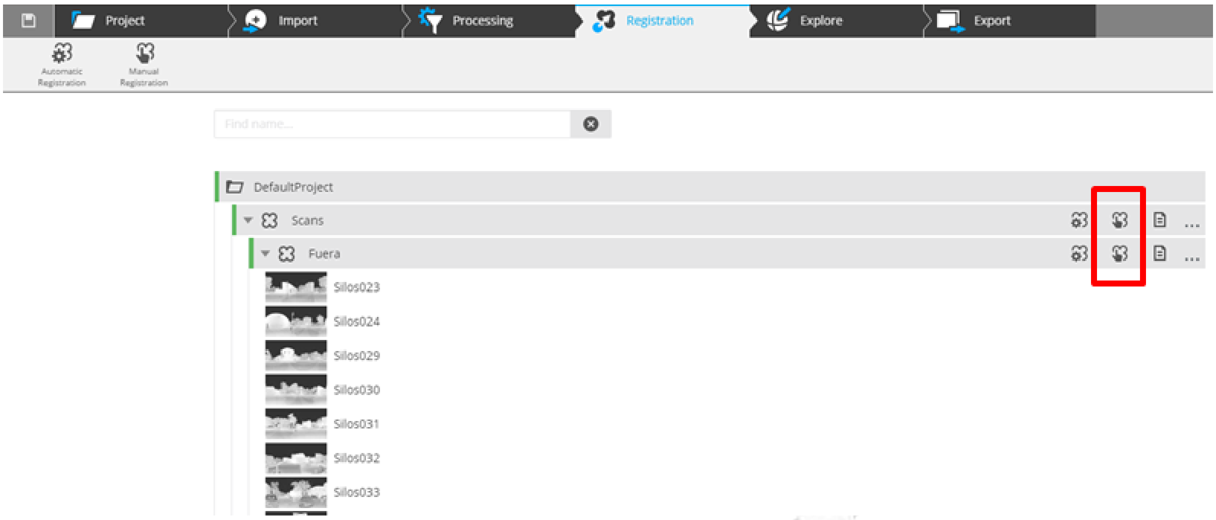


Figure 4.12. Register mode Scene

In the first case, it is needed to select with scans wants to join. In the case used as an example, the number 23 and number 24 scanners are selected corresponding to two continuous scans in the area parks (see the next image).

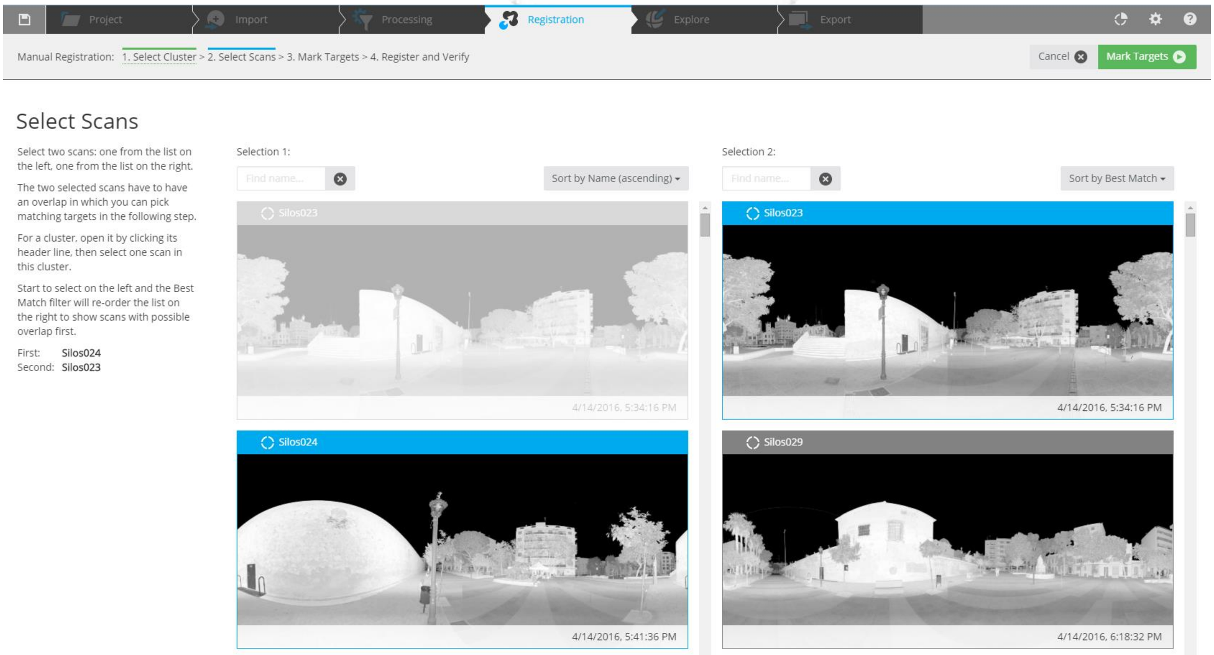


Figure 4.13. Select scans Scene

Then, it is necessary to find the same objects between both scans. In this case, there are some targets and spheres that the software found automatic in the last process and are enough for make the register. But nevertheless, if it is wanted to find more point it is possible to use the tools that appear in the left site, like: find target, find sphere or take natural point.

When it is selected the same point in both scans, the software made the connection and put one label automatically.

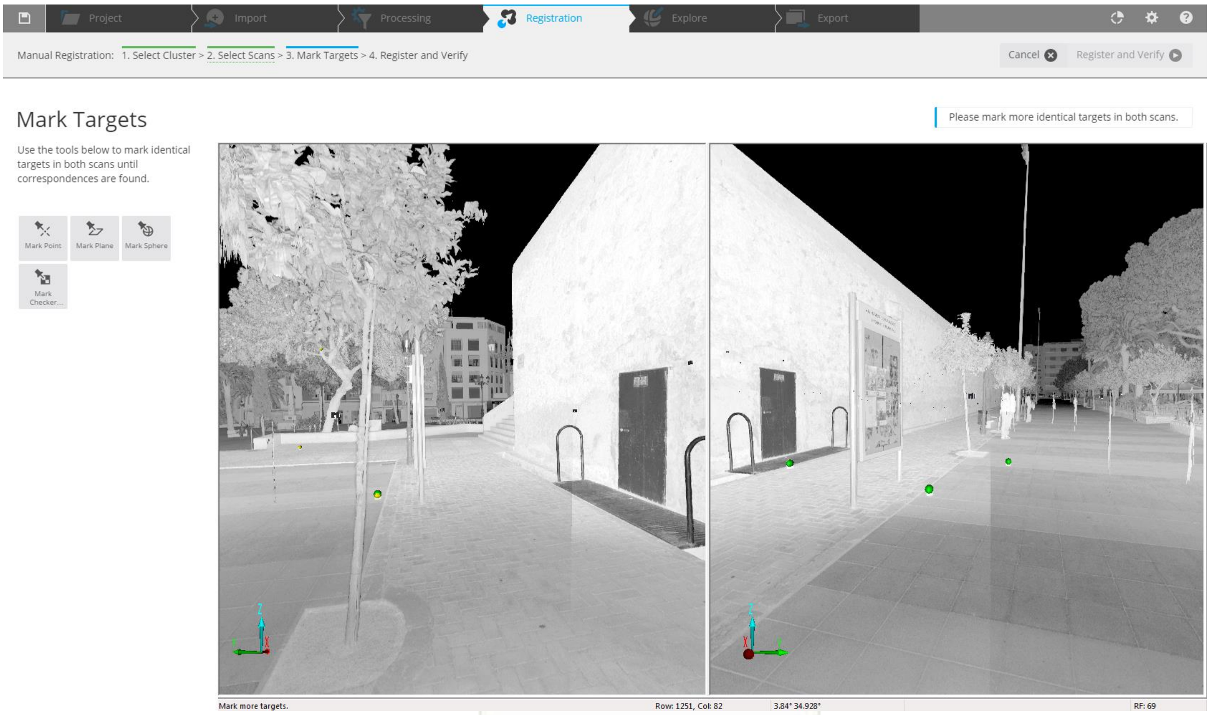


Figure 4.14. Finding homolog points

Repeat the process for all scanners, this time it was decided to divide into two groups: one inside and one outside connection to the outside only. In the next images is possible to see the geometry of the scans: in the one hand are the inside scans and 4 outside scans that they use for made the join well. In the right, it is possible to see all the other scans around the Silos yard.

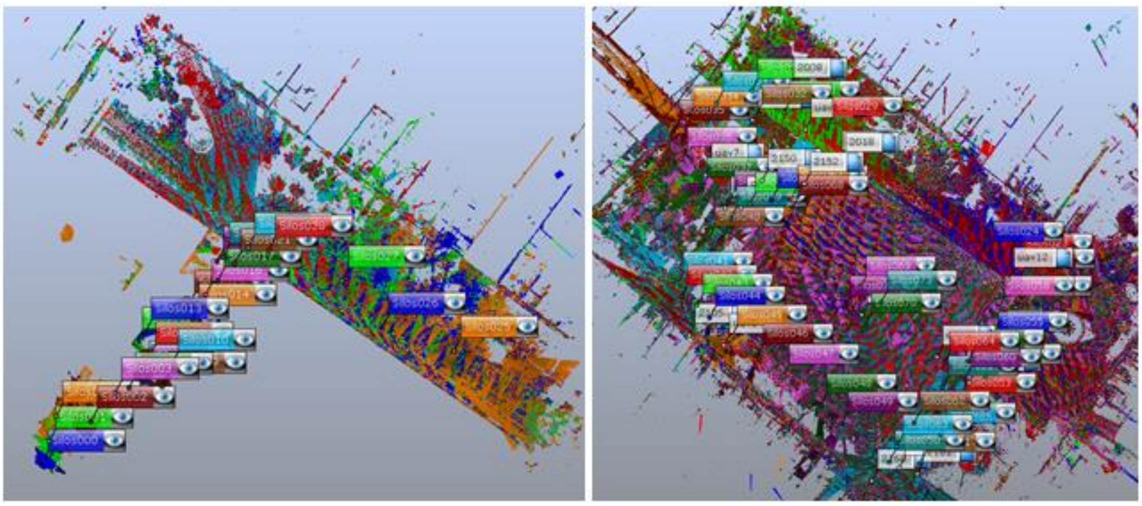


Figure 4.15. Inside group (left) and outside group (rigth)

And finally, it is possible to show all the scans in one viewer. This result is very interesting because from it, it is produce the other results and it is possible to get some general conclusions like dimension of the site or geometry characteristics.

In the next image is possible to see the point cloud and one aerial imagen (Bing map) in the same point of view. It is possible to compare both: for example the point cloud is younger than the image; the trees near to the yard have been changing it.

Figure 4.16. Scene viewer (left) and Bing maps (Rigt)

It is necessary to keep in mind those 2 important things: the error made and the time necessary for made all. In this case the error is 3.5mm and need one day for making the registration. It is explained in the end of this chapter.

In the follow image is possible to see the report that Faro Scene make when it finish the register. In the left site are some statistic information like mean error or maximum error, and in the right site are some graphics that show the relation between the error and the distance. It is meaning that the influence is bigger in near points than others far.

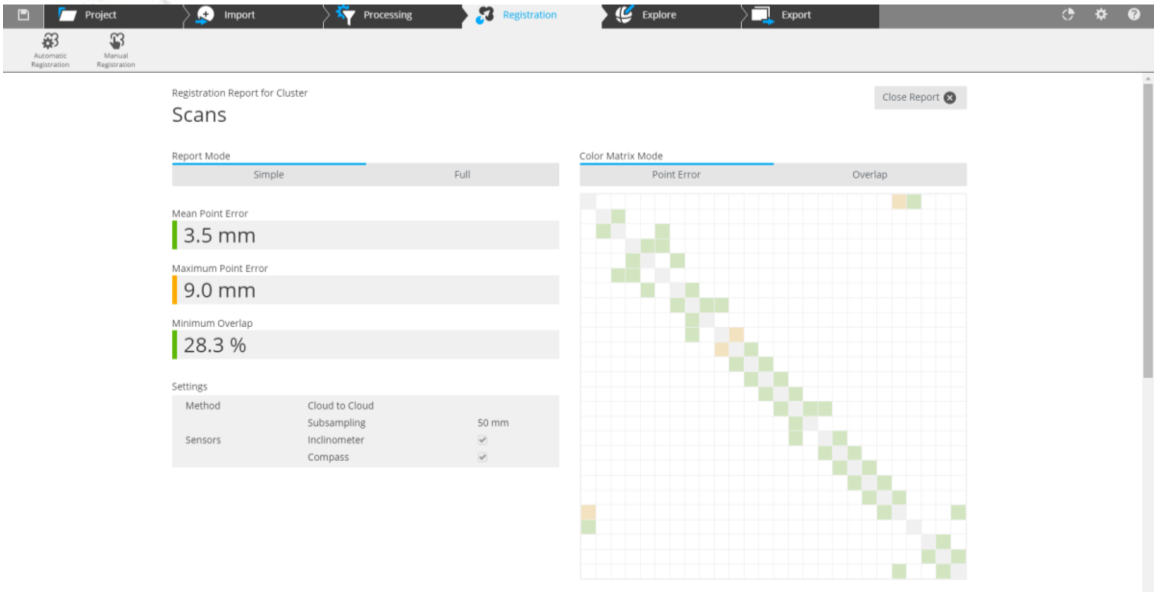


Figure 4.17. Report Scene

On the other hand, the Greeks students are made the outside part and they need 2.5 days for join all the scans and have 20 cm approximately the error. It is know that this error is too large so it is should review the whole process to find the maximum errors and try to correct them.

Leica Cyclone and indirect registration: cloud to cloud constraints

Another way of registering two point clouds, if spheres or targets available, is by using point cloud overlap. If two point clouds have enough overlap (generally 30 – 40%), a technique called Iterative Closed Point processing can be used to align both datasets. This technique requires the user to manually pick at least 3 corresponding points in the point clouds. Since these 3 points will never be exactly the same points (see description in the previous paragraph), this algorithm iteratively checks the distances between all the points of the point clouds and estimates the transformation to align both sets thus resulting in minimal error.

This process is making in Cyclone. Cyclone is the market leading point cloud processing software. It is a family of software modules that provides the widest set of work process options for 3D laser scanning projects in engineering, surveying, construction and related applications and its owner is Leica. The rules on target configurations mentioned in the previous paragraph are also applicable to the point configuration in cloud-to-cloud registration.

This registration technique should be used with caution. When scanning long linear structures where multiple setups are required, small errors in each registration pair may propagate and result in large global errors as the study case is.

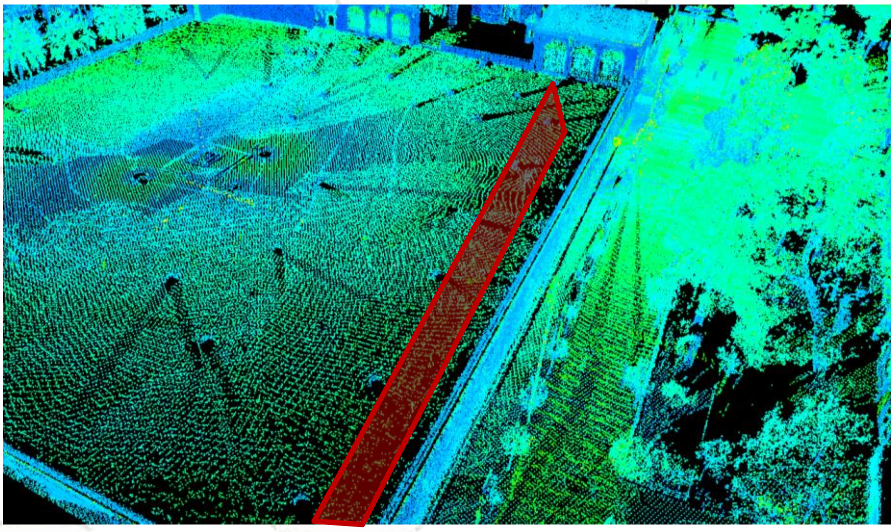


Figure 4.18. Show outside scans Cyclone

To perform this task, Cyclone has been used because it is very versatile program that allows you to open and export to various types of common file in the world of 3D design, and in this case Faro files (.fls).

Now it is describe a little bite the process to create the register and after a few resume for it like Faro Scene.

1. Open Cyclone by clicking on the Cyclone icon on your desktop (Start -> All Programs -> Leica Geosystems -> Cyclone 8.0 -> Cyclone). If it is running Cyclone for the first time, it is should turn off Survey mode (it displays the individual scans in their own folders). Turn Surveyor off mode: Edit -> Preferences -> Scan -> Survey Mode: No. Ensure that Level is set to Default.

A cyclone database is made up of several modules.

Project Folder - This folder contains all your scan data. You can create new project folder (Create -> Project) to re-organize your scan data.

Scan World – Each scan position is called a Scan World.

Control Space – This is a point cloud that contains all the scan data and targets. Only open a Control Space if you need to make adjustments to targets. When you combine scans in a registration, Cyclone refers only to the Control Space, not the Model Space. Normally you never have to access the Control Space.

Model Space – This is also a point cloud that contains all the scan data and targets. Use the model space for your point cloud work (viewing, modelling, fencing, deleting, meshing, etc.). You can create multiple Model Spaces by copy/paste, or using the fence tool inside a Model Space.

Scans – This folder contains all the point cloud data that you acquired whilst scanning, including targets. You only need to access this data to separate scan data into multiple Model Spaces.

Images – This folder contains the photograph that you took with the scanner. By double clicking on MultiImage, you can see all the photos that were acquired.

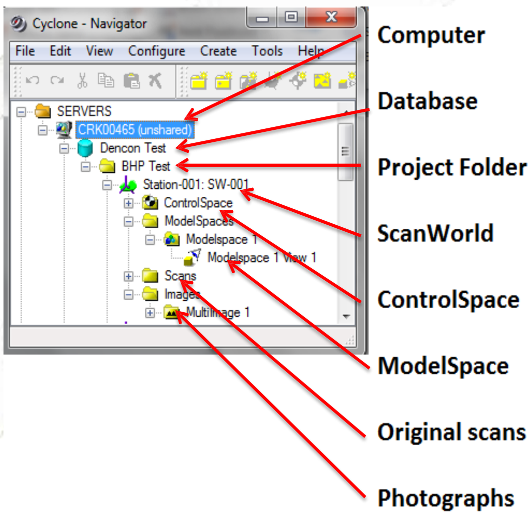


Figure 4.19. Parts of Cyclone

2. Using the shared folder (unshared) should improve Cyclone's performance, this is meant to prepare the data to flow through a network. Right click on Servers folder, the menu will appear.

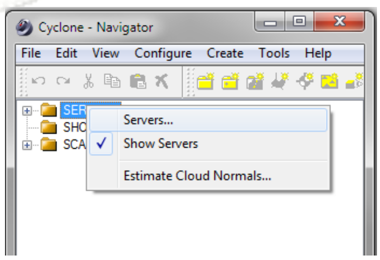


Figure 4.20. Create server Cyclone

3. Next, it is must create a new geodatabase which will go storing all scans.

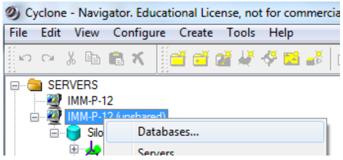


Figure 4.21. Create database Cyclone

4. Now, it will be make the import. As it is had to work with a laser scanner from other company than Leica (Faro) it is must import one by one all the scans. To perform this task, it is had to generate two batches: one with all the silos of the interior and one with all the outside silos.

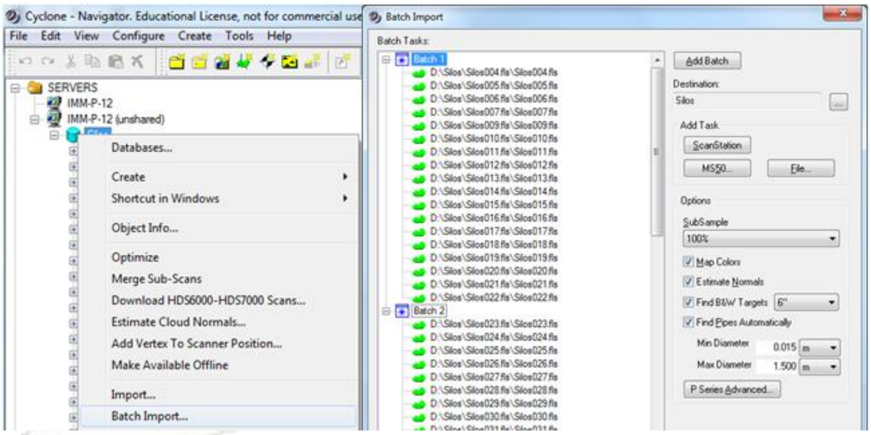


Figure 4.22. Batches import scans Cyclone

5. Remaining, it is begun the registration process. The interior scanners should be used in this example, with the same process to outsiders. Leica defines a Registration as:

"Registration is the process of integrating a project's Scan Worlds into a single coordinate system as a registered Scan World. This integration is derived by a system of constraints, which are pairs of equivalent tie-points or overlapping point clouds that exist in two Scan Worlds. The Registration process computes the optimal overall alignment transformations for each component Scan World in the Registration such that the constraints are matched as closely as possible." (GMV, 2014)

Click on your project folder under your database. Click Create -> Registration, call it whatever you like. Double click on the registration icon to open it. Scans are referred to as Scan Worlds. To add your scans into the registration, click Scan World -> Add Scan World. Select the scans you wish to combine, and copy them to the registration. If you added control, make sure you select the control Scan World as well. Click OK.

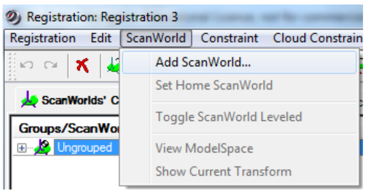


Figure 4.23. Add Scan Worlds Cyclone

You should now see your scans in the "Scan Worlds' Constraints" tab. If you have control, right click on the control Scan World -> Set Home Scan World.

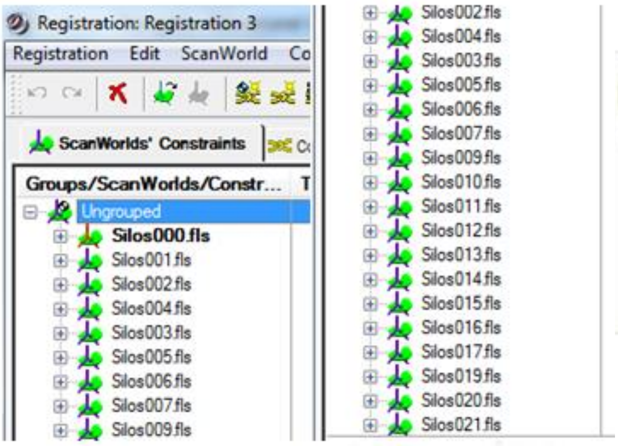


Figure 4.24. Show scans Cyclone

How it is not had any targets in a ScanWorld, it will be needed to manually identify common points between two scans. Rather than adding constraints automatically like before, we have to add them manually. Click: Cloud Constraint -> Cloud Constraint Wizard.

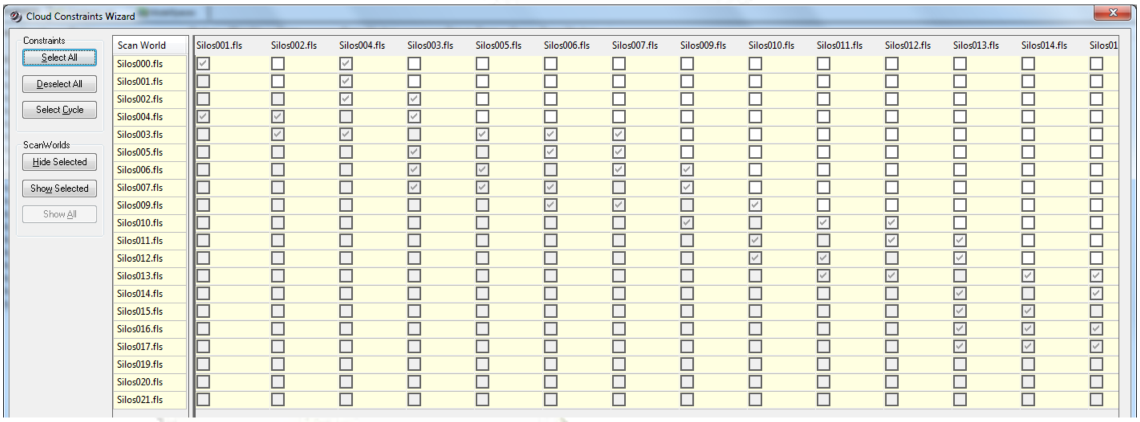


Figure 4.25. Wizard constraints Cyclone

In the Cloud Constraints Wizard, you have to select which scans are overlapping. In this example, it is selected scans 1 & 2, scans 1 & 4...Click Update.

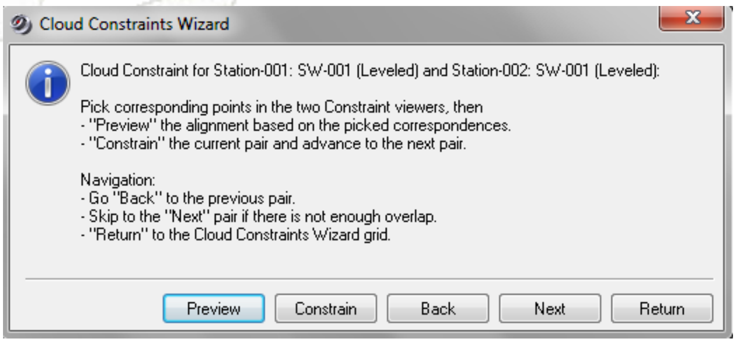


Figure 4.26. Control panel wizard Cyclone

6. Move the Cloud Constraints Wizard window away, but do not close it. You will now see two windows displaying two point clouds on Cyclone. Using the multipack mode, click on at least 3 common points on each scan. In this case, least 6 points between scans.

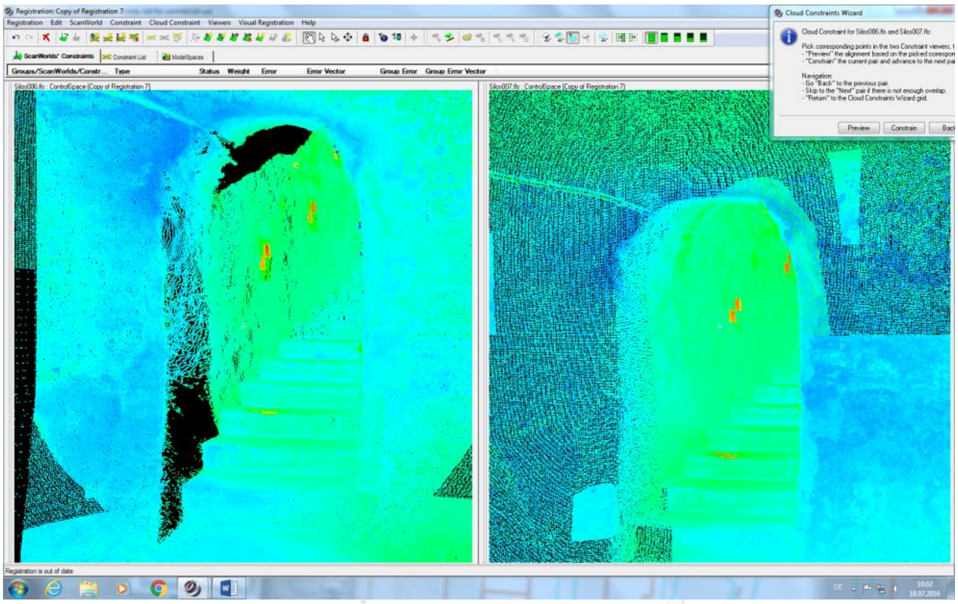


Figure 4.27. Compare scans to find common points Cyclone

7. Try to get the points well as possible. Then click on Preview in the “Cloud Constraints Wizard” window, and view the combined scans to confirm that they are aligned. If have you not picked enough points or spaced your points around enough, Cyclone will tell you with an error message. Simply add to the points that you have already picked, and click Preview again.

When you click Preview, visually check that the scans are aligned. Then close down the Model Space preview, and click “Constrain” on the Cloud Constraints Wizard. The wizard will automatically progress to the next combination of scans.

Once it has been all the scans combined, the notice that Cloud/Mesh constraints are now in the Constraints List tab. The errors will need to be calculated; Registration -> Register.

Confirm that all the errors are minimal. If not, delete the Constraint and recombine the scans again using the Cloud Constraint Wizard. If the errors are right, click: Registration -> Create Scan World / Freeze Registration, then Registration -> Create and Open Model Space.

Look at your registration file in the Cyclone Navigator. It now looks like a normal Scan World icon.

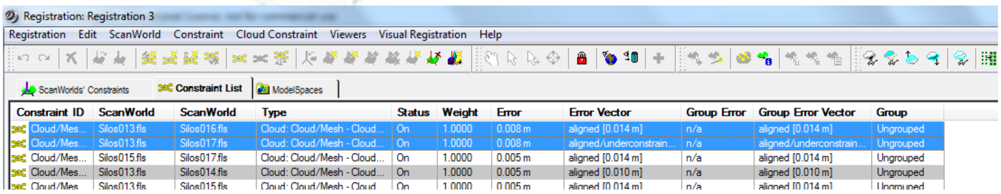


Figure 4.28. Report register Cyclone

8. And finally, it is create the model Space when you can see your result with your scans. In the next image is possible to see all the inside scans join and how Cyclone show them using the intensity of the laser, it is mean that if you see blue there are more points than the green part.

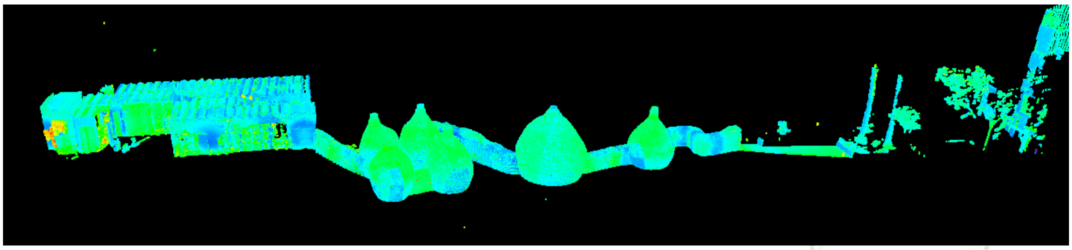


Figure 4.29. Show all scans Cyclone

In this case, the inside error is 8 mm and the period of the process is half day. And outside part has 12 cm and 2 days. It is of particular interest that has not been used all scans performed in data collection because they increased the error but it is had covered the whole area.

If it is remember the Scene and Cyclone error, is possible to know that Faro software made less error than Leica software in this case. One reason is the technique used for made the registration, in el Cyclone case it is used homolog points between scans and probably the operator chose incorrect point. Other reason could be that Scene is programming to work with Faro data and Cyclone to Leica scanner and probably make a different results.

In the next table is possible to the mean error that is produce in the difference area of the study and the time that was necessary for made the registration. Remember that we split the area in two, because was more easy made the process: inside and outside.

Table 4.1. Compare results table

	Error (m)	Time (days)
Cyclone inside	0.008	0.5
Cyclone outside	0.120	2
Cyclone All	0.140	2.5
Scene inside	0.003	0.5
Scene outside	0.007	1
Scene all	0.009	1

Note: This table is the result of registration processing.

3Dvem and compare the results

Other way to make the solution is 3Dvem. This software is programing by GIFLE a research group focusing on new advances in technology related to Photogrammetry, Computer Vision, Laser Scanning and Remote Sensing.

Figure 4.30. Gifle logo (Photogrammetry and Laser Scanning Research Group) from the UPV.

3DVEM – Register GEO is a powerful low-cost software (cost around 400€ less than other software in this area) that solves the transformation, fusion, alignment, orientation or registration of 3D data between different coordinate systems, acquired by different metric devices, either range-based (laser scanner/LiDAR, RADAR, structured light, total station, distance meter, tape, GNSS…) or image-based (photogrammetry, computer vision and Sfm).

The software 3DVEM – Register GEO is made up of two modules, 3DVEM – Register and 3DVEM – GEO, in order to provide a unified solution that facilitates the resolution of all problems related to alignment, scaling, translation, unification and 3D positioning (i.e. 3D transformation or fusion) in multiple formats, either point clouds or 3D data measured with tape, level or plumb line. The software is designed to enable the integration of simple data (for instance, based either on the arbitrary alignment of two point features, or on a measured distance and an arbitrary origin) as well as sophisticated data (for instance, LiDAR datasets). (GIFLE, 2014).

This program could substantially improve the project because it has a powerful program that is able to make better adjustments to other programs such as cyclone or Scene, according to one of its creators.

"After testing it in many projects, the results are most of the times better (up to 10 times in some cases!!). Therefore, it might be a good choice for users particularly concerned with data quality." (Lerma Garcia, Laser scanning forum, 2014)

Nowadays there are different software that is possible to use to make the registration and other post process with the point cloud but the most important think is know the difference between some of them and choose the correct when it is needed. (Lerma Garcia 3DVEM - Register GEO, 2015)

4.1.2. Geo-referencing point cloud using matlab

There are several solutions to the problem of reference the point cloud into a global system and to frame the result on its location. A possible solution would be to use the Faro software and introduce a text file witch name and coordinates of the points that are to be used for adjustment. This solution has not been tested because in the program specifications are not well indicated which method is used for adjustment.

Another possible solution would be to use the open source program called Cloud Compare. In it, the transformation could be performed using two clouds of points, having one of them in local coordinates and the other in the global correct coordinates. The problem with this method is as follows: the point cloud result is bigger than 100 GB and Cloud compare cannot handle this amount of data, so filtering should make a point cloud size to georeferencing after.

On this case, it has opted to calculate the parameters of rotation and translation, using a small software (own programming) that is explained, in the chapter 5, and inserting these parameters in Faro for so the whole point cloud (unfiltered) in the system desired. To make this calculation, it is needed to have the coordinates, of the same points, in local and global system. For this, the following process is performed:

Homologs points will be used. These points will be taken from the model generated with the UAV images and then georeferenced with error less than 5 cm. The best way to take the points is creating a mark, from the pictures and not from the point cloud in photoscan (in appendix I there is one tutorial for create a Photoscan project):

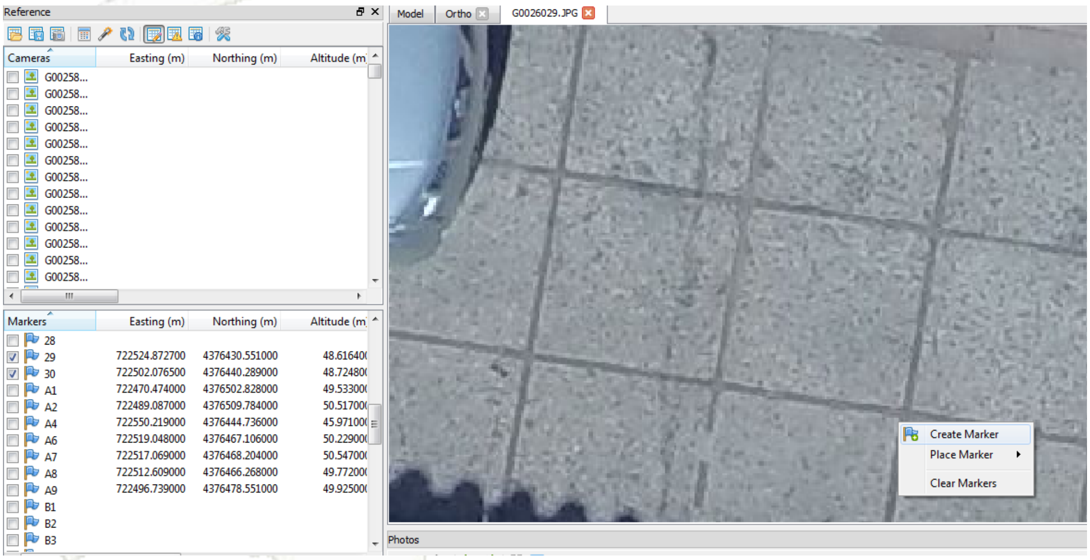


Figure 4.31. Create new marker

Once selecting point in an image, it is should find another image where it appears. The software generates a projective ray that helps to locate the same point on the other image.

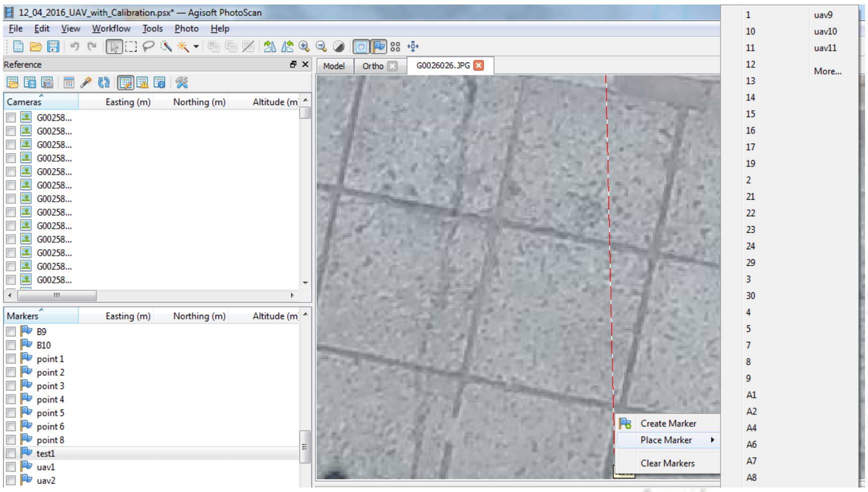


Figure 4.32. Create new marker with the same point

When it is had the same point in two images, it is possible to apply a filter and the software shows all the pictures which the point appears. Consequently, as in the previous step, we must find between 4 or 5 images and position the point.

Figure 4.33. The point in some images

Once the point is selected in multiple images, it is possible to see the accuracy of it and modify the markers to achieve the desired result.

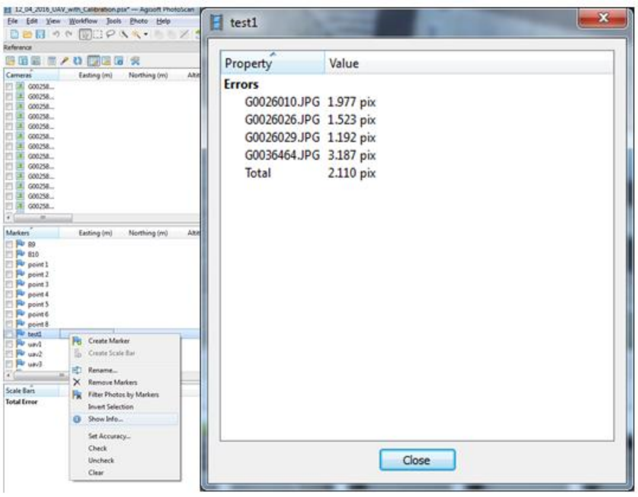


Figure 4.34. Point quality

Now it is possible to get the coordinates of the point and use in adjusting. This coordinates are from global system.

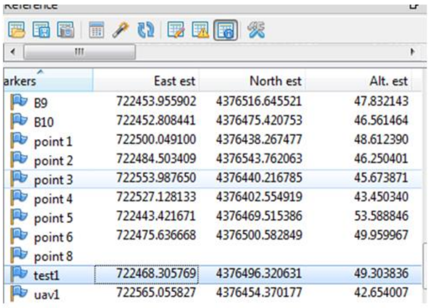


Figure 4.35. Global coordinates

After obtaining the coordinates in the global system, it is the turn of local coordinates. To do this, we can get these coordinates using Scene as follows: Open the project, go to the explorer window and create one annotation.

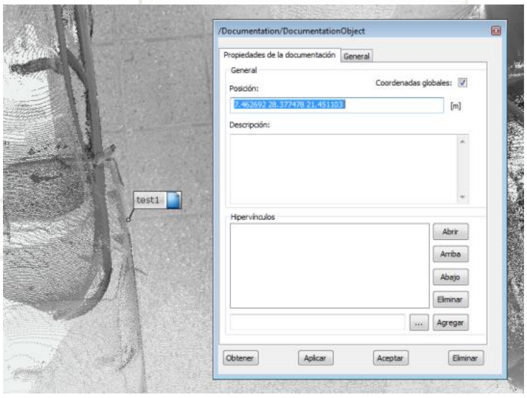


Figure 4.36. Local coordinates

Once obtained the coordinates of the same points in the two coordinate systems has preceded to calculate the transformation parameters. First it was performed using a 2D transformation method Helmet (Watson). In the next table is possible to see the coordinate in both systems: x and y in local and north and earth in global system.

Table 4.2. Coordinates for 2D transformation

Label	x_old	y_old	X_new	Y_new
uav1	101,050	-20,516	722565,052	4376454,379
uav2	86,440	-30,140	722551,203	4376443,747
uav3	78,595	-24,218	722542,971	4376449,118
uav7	3,684	44,129	722463,335	4376511,890
uav8	-1,905	64,569	722456,183	4376531,940
uav10	21,277	61,656	722479,525	4376530,694
uav12	104,805	0,614	722567,297	4376475,729

Note: List of coordinates in both systems

Using the above coordinates, you can perform a calculation of the transformation parameters in 2D. These parameters serve to verify the accuracy of the selected points and to check the fit in two dimensions.

In the follow table is possible to see that parameters that it is obtain in Helmet transformation.

Table 4.3. Parameters 2D

Scale [m]	1,001
Rotation Phi [gon]	4,573
Translation x_0 [m]	722462,756
Translation y_0 [m]	4376467,614
Error [m]	0,052

Note: 2D transformation parameters

Finally, there is the adjustment in 3D. To do this, and as has been said before, it is used a small program in matlab using the method of rigid transformation (explain it in the chapter 5) and obtaining the following results:

$$Translation = [\,Tx\;Ty\;Tz] = [722462.756\;4376467.587\;27.720] \qquad (1)$$

$$Rotation = \begin{bmatrix} Sxx & Sxy & Sxz \\ Syx & Syy & Syz \\ Szx & Szy & Szz \end{bmatrix} = \begin{bmatrix} 0.9974 & 0.0717 & -0.0026 \\ -0.0717 & 0.9974 & 0.0007 \\ 0.00256 & -0.0009 & 1.0000 \end{bmatrix} \qquad (2)$$

To verify that the results are within acceptable errors, the difference between some points of the calculated coordinates and the reference coordinates is checked, as shown in the following table:

Table 4.4. Checking 3D points

Label	X	Y	Z	x	y	z	rx	ry	rz	r
uav1	101,050	-20,516	15,194	722565,056	4376454,370	42,654	0,001	-0,017	-0,012	0,021
uav2	86,440	-30,140	18,249	722551,203	4376443,743	45,780	0,021	0,001	0,013	0,025
uav7	3,684	44,129	20,212	722463,335	4376511,890	47,880	0,019	0,005	-0,010	0,022
uav10	21,237	61,706	20,624	722479,525	4376530,694	48,254	-0,038	0,018	0,011	0,044
uav12	104,805	0,614	21,888	722567,299	4376475,730	49,333	-0,003	-0,008	-0,001	0,008

Note: 2D transformation parameters

Where:

- {X, Y, Z} is the local coordinates.
- {x, y, z} is the global coordinates.
- {rx, ry, rz} is the difference between global and new coordinates.
- r is quadratic composition of the above differences

It is seen that the maximum error is less than 5 centimeters, like the maximum error obtained in 2D transformation result. It notes that most of the error is in the high coordinate and have used a total of 7 points for made transformation.

Finally, it is apply the changes in Faro and get all the point cloud in that coordinate system. To make this step, Scene has one site when is possible to put the parameters of the transformation in meters (translation) and in grades (rotation).

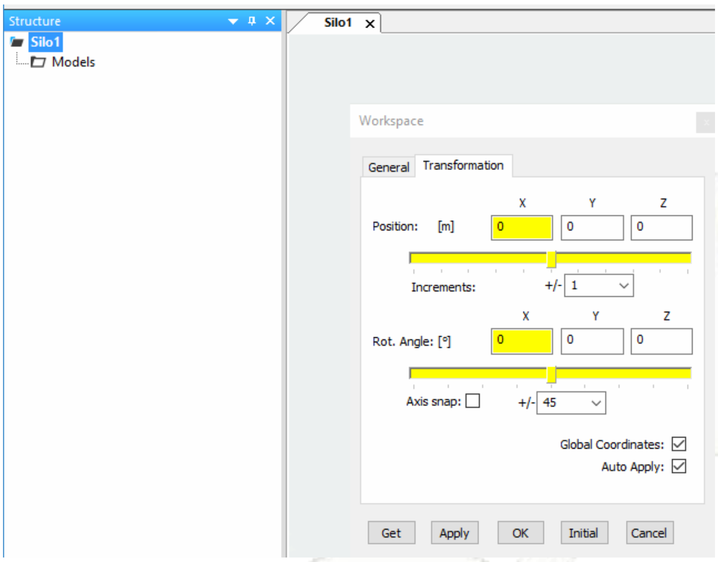


Figure 4.37. Put transformation parameters

So far, there has been the transformation of the point cloud coordinates using UAV model.

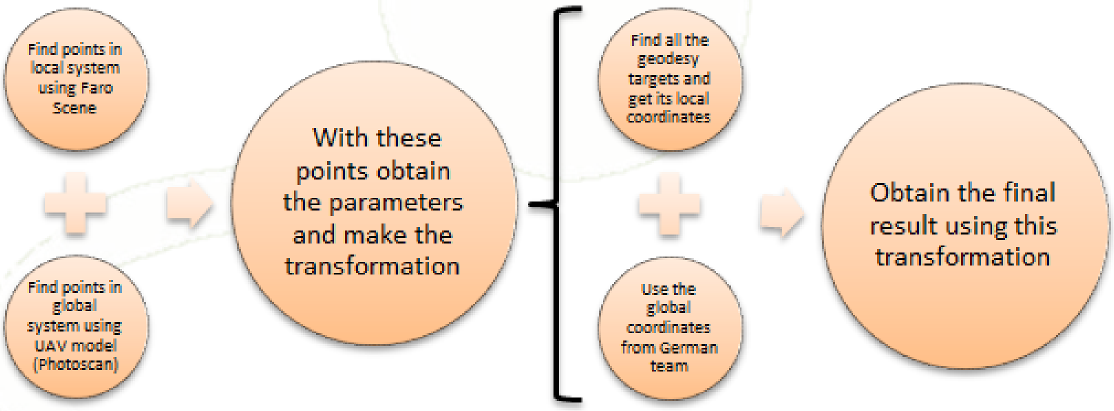


Figure 4.38. process used to achieve the result

Now you are going to use this cloud to find some of the points that have been obtained by the group of geodesy. In this way, it is had around 40 points that it is possible to compare.

Table 4.5. Error resume

	X	Y	Z	E.M.C.
Max	0,091	0,098	0,237	0,257
Min	0,013	0,025	0,000	0,045
Mean	0,038	0,053	0,083	0,118

Note: Difference between calculate coordinates and geodesy coordinates

In the las table it is possible to see that the error maximum is 25 cm. Remember that it is used 5 points for made the transformation and compare with around 40 points. Approximately 50% of these points have one error less 10 cm.

But why not use these new points to perform the calculation again?

The next step that is made is to find the local coordinates for all of this points and use them for calculate the parameters of the transformation. In the nest table is possible to check the local coordinates (from point cloud) and the global coordinates (from the German team)

Table 4.6. Local and geodesy coordinates

	Local coord.			Geodesic coord.		
2160	53,166	-65,024	18,739	722520,561	4376406,586	46,258
2105	-6,037	-10,536	20,093	722457,615	4376456,655	47,552
2101	-0,611	2,010	20,225	722462,138	4376469,524	47,686
2102	1,750	5,731	20,470	722464,226	4376473,400	47,930
2103	1,535	2,115	20,764	722464,274	4376469,782	48,225
2104	1,510	2,136	19,795	722464,247	4376469,801	47,256
2111	0,941	47,728	21,149	722460,359	4376515,232	48,627
2112	2,277	49,550	21,450	722461,553	4376517,149	48,928
2113	2,163	53,069	21,860	722461,180	4376520,649	49,338
2114	-5,665	49,301	21,950	722453,646	4376516,331	49,427
2120	5,043	58,075	21,487	722463,703	4376525,855	48,971
2121	6,130	58,049	22,194	722464,792	4376525,911	49,678
2122	9,481	58,892	21,054	722468,072	4376526,999	48,538
2123	11,840	60,674	22,151	722470,297	4376528,943	49,635
2124	14,657	63,028	21,006	722472,933	4376531,495	48,493
2125	33,318	71,854	18,655	722490,903	4376541,656	46,141
2126	30,259	74,312	18,868	722487,675	4376543,884	46,355
2007	40,435	68,215	18,515	722498,265	4376538,545	46,003
2129	17,974	70,397	20,063	722475,696	4376539,076	47,553
2130	18,468	69,283	20,136	722476,267	4376538,003	47,626
2132	23,288	66,151	20,082	722481,301	4376535,230	47,572
2008	34,068	71,425	18,639	722491,670	4376541,279	46,126
2006	42,982	68,241	18,514	722500,791	4376538,751	46,001
2005	53,151	56,434	17,886	722511,796	4376527,714	45,377
2004	56,343	53,893	17,777	722515,161	4376525,392	45,274
2002	71,136	42,011	17,113	722530,780	4376514,617	44,614
2009	45,618	48,328	19,520	722504,872	4376519,055	47,020
2012	48,875	45,088	19,334	722508,339	4376516,049	46,843
2013	48,048	44,328	18,092	722507,589	4376515,246	45,596
2014	47,545	43,857	18,635	722507,122	4376514,743	46,142
2015	57,143	42,694	17,578	722516,770	4376514,285	45,080
2016	64,023	37,170	17,334	722524,039	4376509,268	44,833
2019	49,034	43,495	18,074	722508,621	4376514,488	45,573
2020	48,140	42,638	18,497	722507,798	4376513,568	46,008
2001	84,604	31,202	16,722	722544,999	4376504,803	44,219
2142	78,510	25,622	17,102	722539,294	4376498,802	44,602
2150	22,874	40,669	24,514	722482,732	4376509,781	51,975
2152	37,387	38,667	25,186	722497,350	4376508,828	52,645

Note: Difference between calculate coordinates and geodesy coordinates

In this way, it is obtain the follow parameters:

$$Translation = [\,Tx\;Ty\;Tz] = [722462.875\;4376467.569\;27.482] \qquad (3)$$

$$Rotation\ matrix = \begin{bmatrix} Sxx & Sxy & Sxz \\ Syx & Syy & Syz \\ Szx & Szy & Szz \end{bmatrix} = \begin{bmatrix} 0.9974 & 0.0724 & -0.0026 \\ -0.0724 & 0.9974 & 0.0002 \\ 0.0026 & -0.0001 & 1.0000 \end{bmatrix} \qquad (4)$$

$$Rotation\ (gon) = \{Rx\;Ry\;Rz\} = \{\,-0.011\quad -0.0146\quad 4.150\,\} \qquad (5)$$

In this transformation it is made 3 checks. First, it is calculated the mean squared error using the same points as in the previous transformation and compare results. In the next table is possible to see that the maximum error is 5 cm and if is looked all the table, 80% of these points are fewer 3 cm the error.

Table 4.7. Error resume

	X	Y	Z	E.M.C.
Max (abs)	0,041	0,030	0,025	0,047
Min (abs)	0,000	0,001	0,000	0,009
Mean (abs)	0,009	0,010	0,013	0,021

Note: Difference between calculate coordinates and geodesy coordinates

If it is compare this result with the other the difference is like 20 cm in the error and 35 point more. The second check made is calculated the new coordinate from control points and compare the results, it is possible to see in the next table:

Label	Point clouds			Control points			Error
2	722554,041	4376440,289	45,758	722554,019	4376440,274	45,732	0,037
9	722475,583	4376500,554	49,882	722475,574	4376500,556	49,877	0,011
10	722488,377	4376508,323	50,335	722488,364	4376508,302	50,319	0,029
11	722484,670	4376543,544	46,177	722484,648	4376543,519	46,196	0,038
12	722504,476	4376531,306	45,349	722504,465	4376531,302	45,356	0,014

The difference between both is like 4 cm. These points were calculated by different method, one of them by geodesy, and not have included in the calculation, and the others after implemented the parameters of transformation, so they is a good result.

Finally, it is started from the theoretical assumption that if the transformation was perfect when trying to calculate the transformation parameters the translation and rotation should be zero using the new coordinates. And the result is:

$$Rotation = \;[0.0157\;\; -0.0102\;\; -0.0009]$$

Only few seconds is the difference between that's coordinates. So it is possible to say that it is the best solution that it is get with all the data that it is have.

4.2. Generating results and products

Just as important knows how to obtain and properly organize the data as knowing that profits can be given. In this section some of the products that can be generated with the previous three-dimensional information and explains what their usefulness and purpose for it.

4.2.1. Creating 2D results

One of the things that it is wanted to get in the next study is the dimensions of the objects studied. An easy way to interpret these measures is to generate some maps which basic data such as height or diameter of the base are identified.

As each basis silos has a different altitude, depending on the dimensions thereof, it is made two cuts: horizontal and vertical. In the next figure it is possible to see the horizontal, at a distance of 1.80 m from the base of the biggest silo.

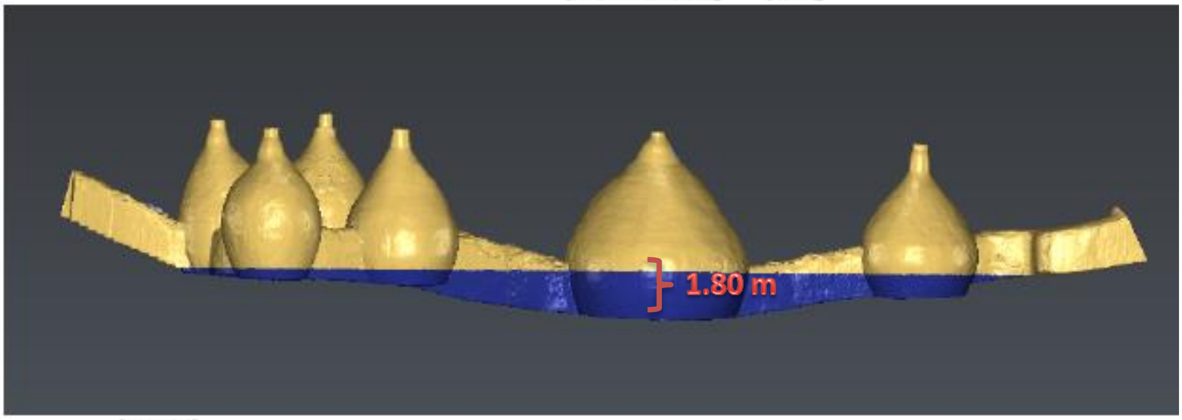


Figure 4.39. Horizontal profile

It is created some examples maps that you can see in the appendix and include this profiles. It is used some pictures and laser scanner data for create them and put in the same product.

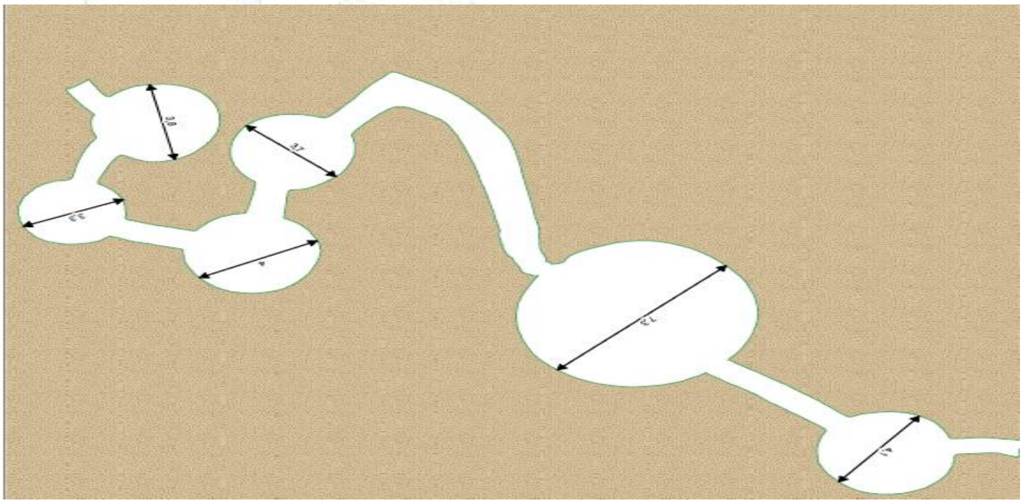


Figure 4.40. Silos Projection

Also, it can be interesting to know the capacity, although today it is not used and in its golden age food supplied the city of Valencia and was a strategic point for enemy attacks. The real dimension of the silos had been modify during years because originally the tunnels were not and nowaday are used to access the inside of the silos and communicate with each other.

In the next image it is showed how the silos are split one to one and in the below table is exposed volumes from silos.

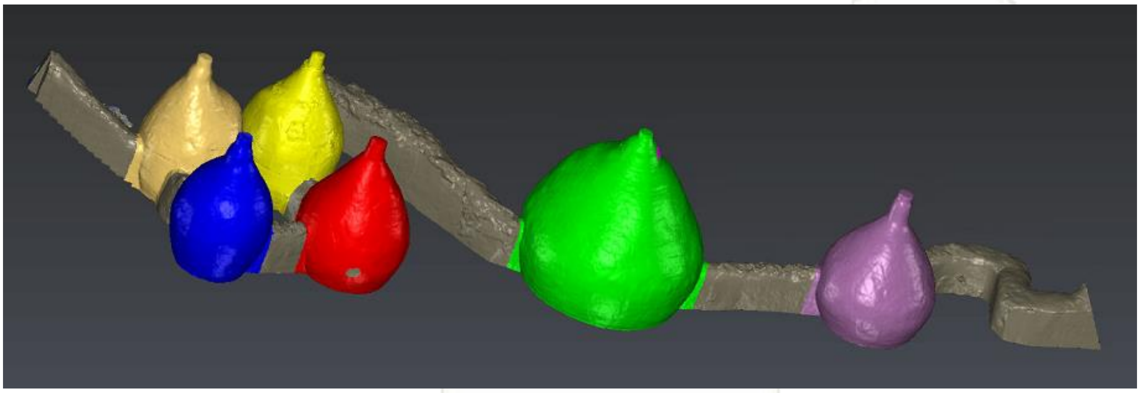


Figure 4.41. Split Silos

In this table is possible to see three different measurements of volume. In the first column are volumetric units in the international system, in the second are Cahices. These units were used in the past in this region and 100 cahices equals 66.5 m^3. And in the last column are one data obtained in historic documents (Ana vals at al., 2014).

Table 4.8. Calculating the silo's volume

	M^3	Cahices	Historic
1	170	256	260
2	760	1142	1140
3	160	240	240
4	166	250	250
5	130	196	200
6	160	240	240

Note: This table is obtained with 3Dreshaper, silo to silo.

It can see that 4 of the 6 have similar capacity, but nevertheless there are two disparities. One of them is the smallest with a capacity of approximately 160 m^3 and the other is the biggest with a capacity of 760 m^3 approximately.

4.2.2. Generate 3D data

Everyone's now aware of 3D printing — they have read about it in the papers, on blogs or seen it on TV. Now, the mentality tend to be, in the future, we will be able to download our products or make them ourselves with CAD programs, apps and 3D scanners, then just print them out, either at home, or localised print shops.

But well, today still is not as easy to get a good model. Therefore, it is explained how created a proper mesh back 3D printing, it is necessary make a filtering processes and generating triangles, which will be described below.

Create a model of the entire study area can be an expensive job, for this reason it is selected a particular area, in this case, the area where the silos and top.

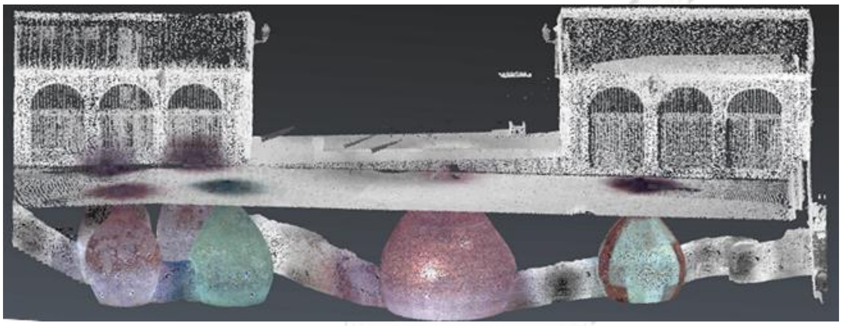


Figure 4.42. Point cloud for meshing

There are many tools available to perform filtered point cloud. However, it has taken special attention because some of them don't remove all the noise and others, on the contrary, could eliminate interesting areas, such as doorknobs or window frames.

In the next image it is possible to see an automatic adjustment which all those points that are more than 1 cm than another are eliminated, thus generating a more uniform walls.

However, there are some areas that are not interesting for the final model or simply noise caused by crystal surfaces that should not be included in the mesh. To eliminate these unwanted items, it is needed to apply a manual filtering which those areas should be selected and subsequently be eliminated them.

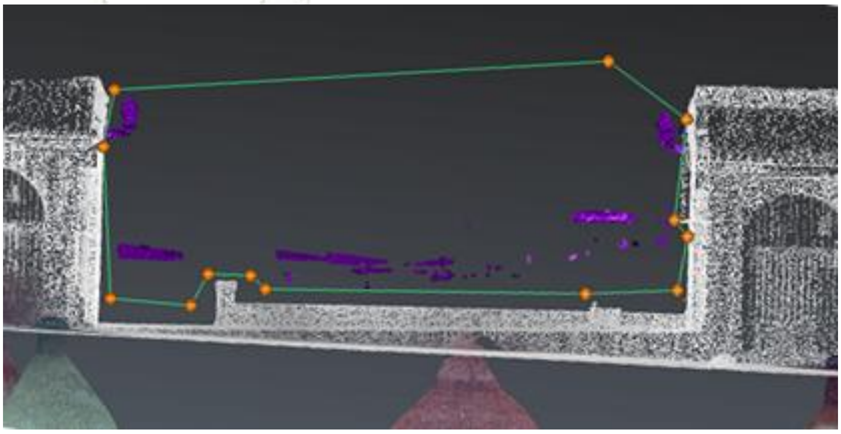


Figure 4.43. Manual filter

Then, it is continued to made iterations until the outliers remain eliminate and keep only the important points. In addition, it is remembered that the data collection was carried out inside the silos, and consequently, there were many elements that must be eliminated.

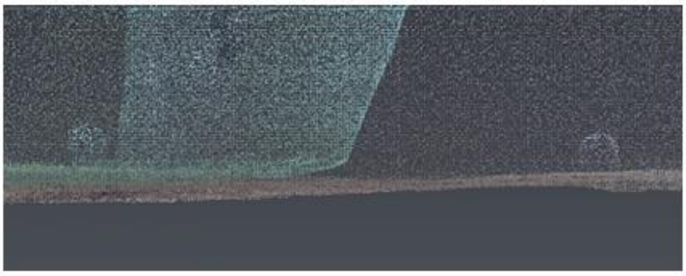


Figure 4.44. vision of the spheres in the point cloud

All these unwanted elements can be removed before or after the generation of the triangles. In this case, the filtrate is made after the generation of the mesh.

Now, it is possible to start with the generation of triangles. There are two aspects to consider: one of them is the distance between points for the generation of triangles. Another is the maximum size to close holes and try to leave a tight mesh. In this project 5 cm and 15 cm is used respectively in the first iteration.

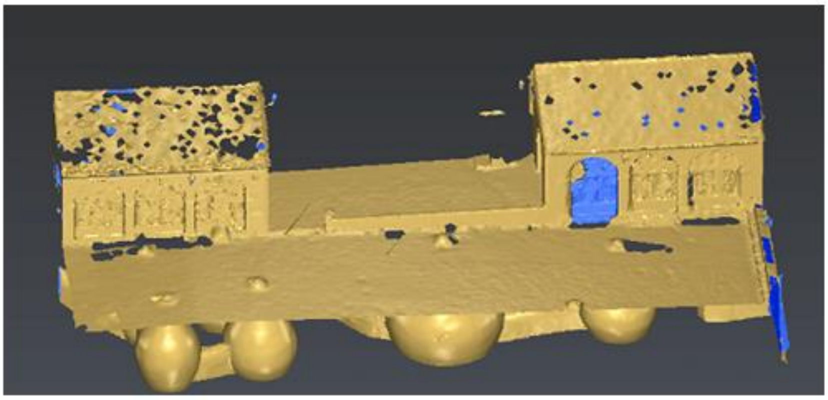


Figure 4.45. First mesh

As it is could see in this first meshing, the task of creating triangles is not as simple as giving a button and wait. There needs to be a review of the entire model performing the following tasks:

- Filling holes

In 3DReshaper, there is a tool to find the holes and cover them trying to adapt to the new existing surface. However, it does not always work properly and must go checking it to fit perfectly.

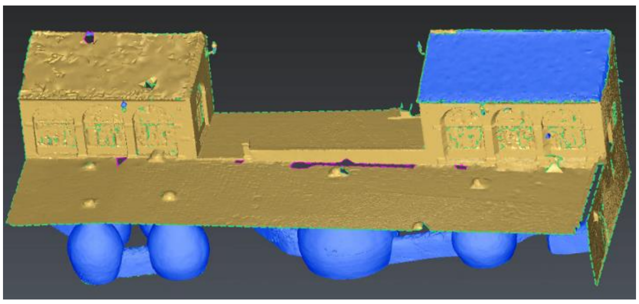


Figure 4.46. Filling holes

- Smoothing

Building outside, it is found large windows that give natural light to the interior. This can be problematic when a laser making is performed and thus a smoothing performed.

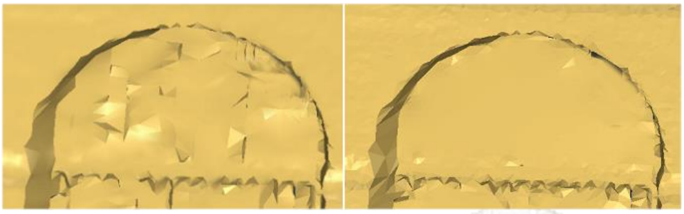


Figure 4.45. Smoothing windows

- Generation of new parts

The idea is to get a model simulating reality. It is not intended to model the entire square otherwise the area where the silos are, incorporate planes to generate a watertight mesh serve later for printing.

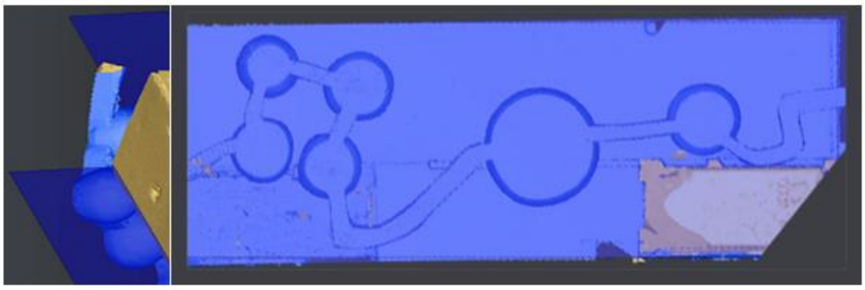


Figure 4.47. Create new planes

The process used is as follows: planes are generated using grid points as anchor points, these planes are transformed in point cloud and then meshing. Finally it is reviewed all edges and fill holes.

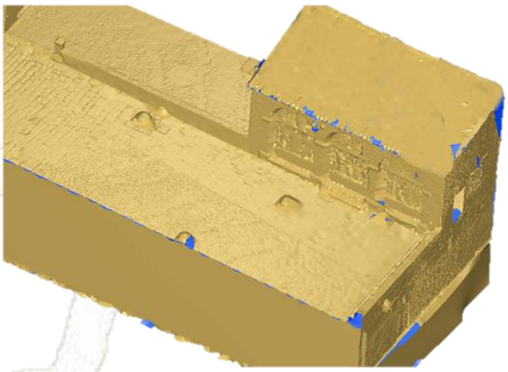


Figure 4.48. Before fill holes

- Removing unwanted elements.

When the data is taken, probably, are a lot of elements that is not wanted to include in the final result, for this reason is important to check all the mesh and delete these elements left over. In this case were inside the silo only lights an cables in the top and wallet but outside there were a lot of objects that will be disturb the final result. In the follow images is possible to see some of them.

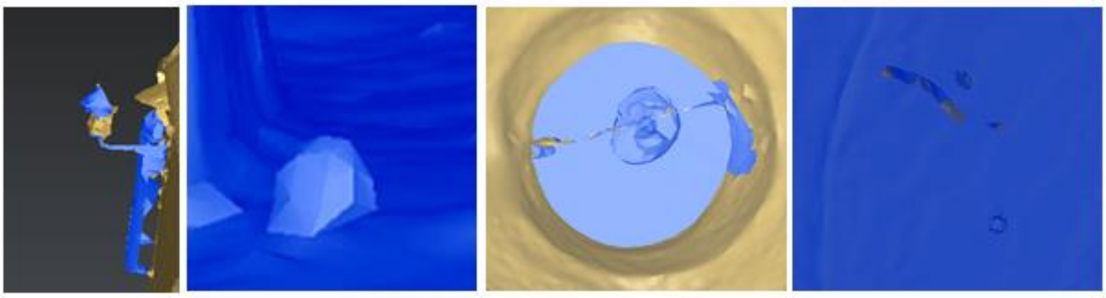


Figure 4.49. Unwanted elements. From left to right: Streetlight, spheres, lamps and other

Using the process explained above is achieved to generate a mesh representing a degree of similarity with reality. We have also generated two very visual products that are explained below: KMZ file and print 3D.

Printing 3D model

For print in 3D and create a kmz file is used only the inside data, because the external had enough problems, besides that in the case of KMZ file greatly improves their visual interpretation.

In order to make a 3D impression, first it is performed the selection of the area to be printed. In addition, in the example shown, it is to make a negative impression from the inside of the silos, so it can see their structure and composition from the outer face print.

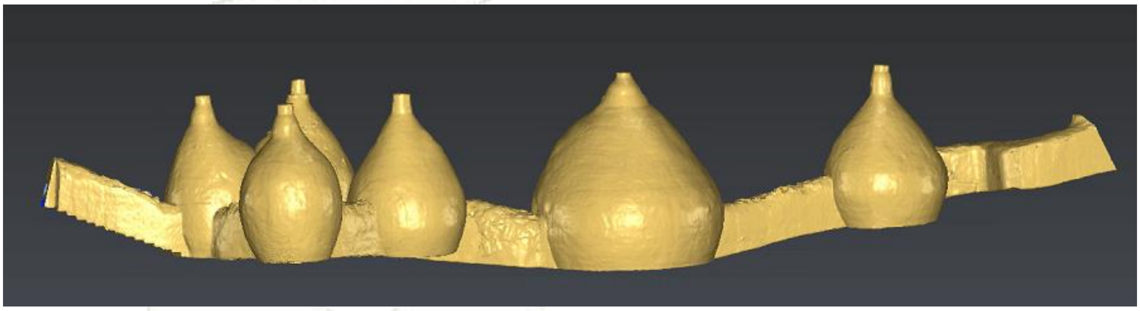


Figure 4.50. Negative mesh

In this example, it is covered the entrance gates to generate a watertight and close mesh.

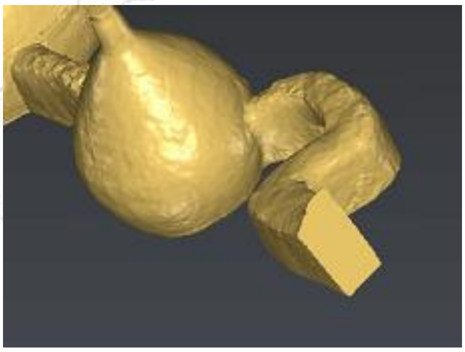


Figure 4.51. Close the door

Once generated the mesh watertight, it is proceeded to use their 3D printer software. In this project is tried to use to printers: BQ Witbox and printer created by FabLab Company.

For use the first printer, there is a software from BQ company call Cura. It has been engineered to make the most of your Ultimaker 3D printer and BQ materials. When Cura is combined with them both, you have one of most reliable and seamless 3D printing experiences on the market today. In this case, it is used BQ witbox 3D printer and BQ PLA filament.

Figure 4.52. 3D Printer

With this software is possible to import the 3D model from 3Dreshaper and change scale and orientation to create an impression of the desired size and fit on the printer dock.

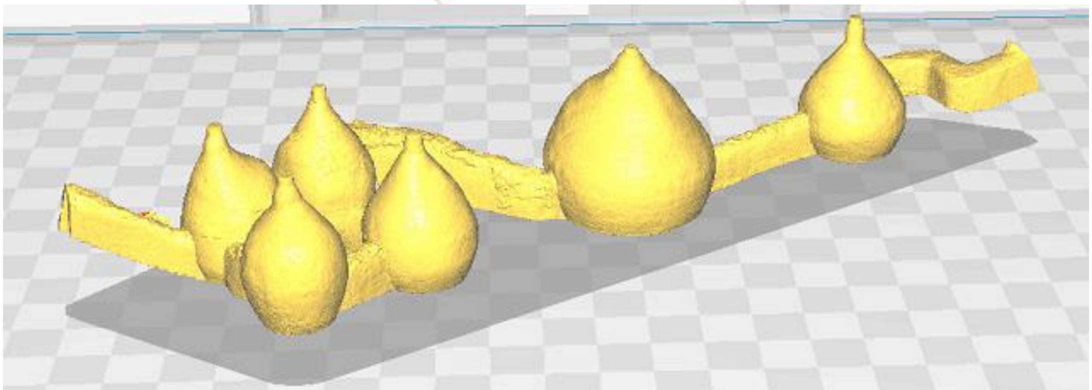


Figure 4.53. Cura software

In Fablab company using one printer that they made and the software was Blender. The difference between BQ is the price for the printers and the type of materials that it can be used. For example Witbox can print in PLA (polylactic acid) and ABS (acrylonitrile butadiene styrene) and the other printer uso only PLA. In the follow sentences is explaining a little bite the difference between this both materials.

Table 4.9. Calculating the silo's volume

	Advantages	Disadvantages
PLA	Easy printing The print's bed shloud not be hot More faster printing than others Ecologic material	It deforms at temperatures above 60 ºC More fragile than others Humidity sensitive
ABS	Stable at high temperatures It can be sanded Resist chemical attack Harder than other materials	Difficult printing (high temperatures) It could be produce Warping effect Creaks faster than others

Note: This information is obtained in Impresoras3D (Impresoras3D, 2016).

Sometimes, there are some mechanical problems with the printer and other problems generated mesh. Below there are some problems that it is going to explain in the next lines:

- Mechanical problems

A 3D printer has two motors that move the nozzle for 3D printing. The calibration of these engines or printer dock sometimes can fail and must be recalibrated.

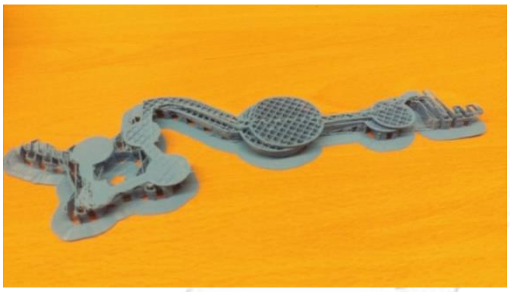


Figure 4.54. Mechanical problems

- Choose incorrect parameters

How can it be logical to think, these instrumentals can have many parameters that only an expert can know. In this case, the technique "trial and error" is the best help to get that experience.

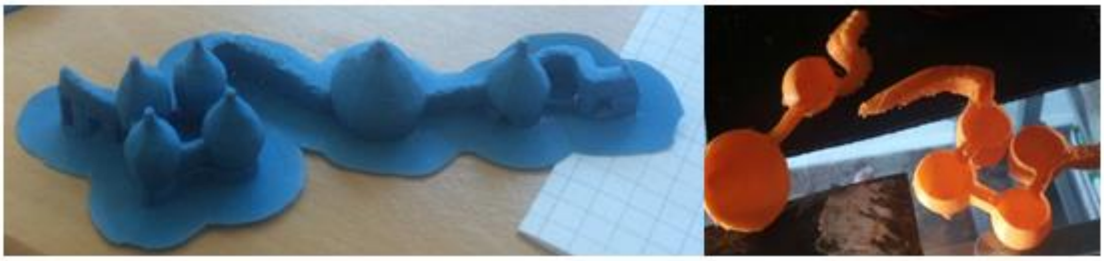


Figure 4.55. Wrong scale (left) and Wrong wall thickness (right)

In the previous two pictures you can see how the 3D model is destroyed. For example, in the right picture it was not put packing density and had chosen bad the wall thickness. In the left example, the model may look acceptable but when it is seen in reality is too small.

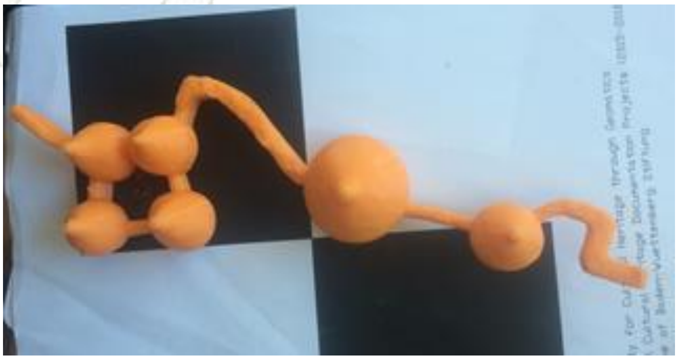


Figure 4.56. 3D printer for the silos

In the next picture it is possible to see several impression tries. Designing them from top to low are: First is a 3D printing scale 1:185. It is followed, an impression whose final status is not right that the walls are rough. Thirdly, there is an impression which had a problem keeping the printer and last is one small printer at 1: 500.

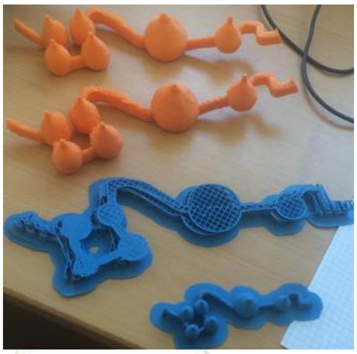


Figure 4.57. 3D printer for the silos

KMZ file

As the 3d model is available in .obj format extracted from 3DReshaper, a new file is generated in .stl format. This format is more common among open source programs such as that to be used below, MeshLab.

In this software, it is purport to transform the format .stl to .dxf and reduce the number of triangles and vertices that the mesh has. As it is tried to generate a .KMZ file so that it can be displayed on google earth, it is not necessary to maintain the resolution and google earth cannot load more than 64,000 vertices too.

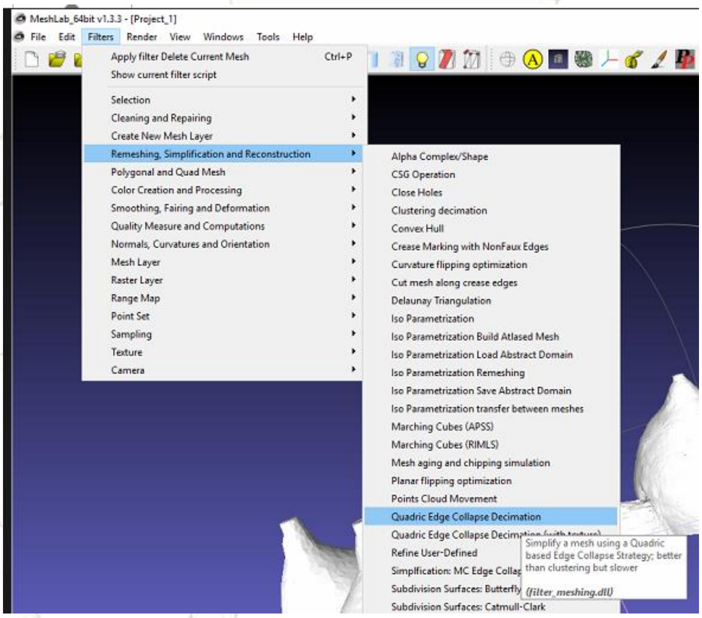


Figure 4.58. Meshlab filter

Then, it is made a filter using meshlab and get yourself downsize from 8.000 to 2.000 kb, approximately. In the next image, it is possible to see how much was reducing the mesh. The original mesh had 300.000 vertex and 648.000 faces and the final mesh has 20.000 vertex and 40.000 faces, It has been reduced approximately 15 times the size.

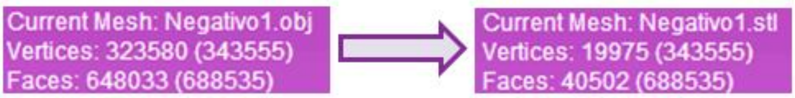


Figure 4.59. Reduce size

Before, the new dxf file is imported in SketchUp, another free program code to generate modelled fairly intuitive. In skecthup the only task that must be done it is georeferenced exactly where it is wanted to place the mesh. There is a disparity between the coordinates and the projection model that uses google earth. To this end, this program has a plugin that helps the final positioning of the mesh.

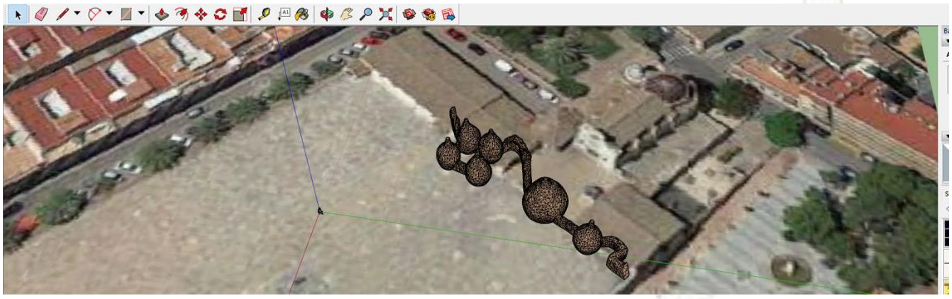


Figure 4.60. SkecthUp georeferencing

Finally, the only thing that it is needed is to open the .kmz file in google earth and show the result.

Figure 4.61. Google earth with kmz file

5. Programming

In this chapter is explained some programming projects that have been carried out in making the thesis. Nowadays is important to know how is possible to create our software and improve it every days. Probably, in the first time, it may seem difficult and expensive but over time the tool that is created can greatly facilitate the tasks.

5.1. Calculate transformation between local and global coordinate system with Matlab.

In this first software that was made, it is possible to calculate the parameters of the transformation between coordinate systems. To make this, it is needed to introduce two matrixes with the coordinates of the same points in both systems and the software gifts the rotation an translation parameters.

5.1.1. Concepts

In the follow lines is explain briefly the theory of 3D transformation, and after show how is implemented in the line code.

3d transformations are extensions of two-dimensional therefore we assume that in the case of 2D has the following equation (Universidad de Las Palmas de Gran Canaria, 2010):

$$(x', y') = (x, y) \cdot \begin{pmatrix} a_1 & a_2 \\ b_1 & b_2 \end{pmatrix} \rightarrow x' = ax + by \tag{6}$$

Therefore it is passed 3x3 matrices using homogeneous coordinates:

$$(x', y', 1) = (x, y, 1) \cdot \begin{pmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{pmatrix} \rightarrow x' = ax + by + c \tag{7}$$

Following the same method as in the 2D case, pass the 3D matrix to a size of 4x4:

$$(x', y', z', 1) = (x, y, z, 1) \cdot \begin{pmatrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4 \\ c_1 & c_2 & c_3 & c_4 \\ d_1 & d_2 & d_3 & d_4 \end{pmatrix} \rightarrow x' = ax + by + cz + d \tag{8}$$

Translation

To calculate the translation parameters must calculate the difference between coordinates, so that:

$$\begin{cases} x' = x + t_x \\ y' = y + t_y \\ z' = z + t_z \end{cases} \rightarrow (x', y', z') = (x, y, z) \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} + \begin{pmatrix} t_x \\ t_y \\ t_z \end{pmatrix} \tag{9}$$

Scale

The scaling factor is obtained by multiplying the position of the point by a constant dependent on the coordinate, such that:

$$\begin{cases} x' = xs_x \\ y' = ys_y \\ z' = zs_z \end{cases} \rightarrow (x', y', z') = (x, y, z) \cdot \begin{pmatrix} \delta_x & 0 & 0 \\ 0 & \delta_y & 0 \\ 0 & 0 & \delta_z \end{pmatrix} \quad (10)$$

Rotation

Obtaining rotation angles, it is a bit more tedious than the previous process. To this end, it should be noted that the rotation must be applied to each axis separates (x, y, z). One way is to obtain the rotation matrix:

$$R = \begin{Bmatrix} Cos(\theta) + u_x^2(1 - Cos(\theta)) & u_x u_y(1 - Cos(\theta)) - u_z Sin(\theta) & u_x u_z(1 - Cos(\theta)) - u_y Sin(\theta) \\ u_x u_y(1 - Cos(\theta)) - u_z Sin(\theta) & Cos(\theta) + u_y^2(1 - Cos(\theta)) & u_y u_z(1 - Cos(\theta)) - u_x Sin(\theta) \\ u_x u_z(1 - Cos(\theta)) - u_y & u_y u_z(1 - Cos(\theta)) - u_x & Cos(\theta) + u_z^2(1 - Cos(\theta)) \end{Bmatrix} \quad (11)$$

Obtaining the Euler angles as follows:

$$R = \begin{Bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{Bmatrix} \rightarrow \begin{cases} \theta_x = atan2(r_{32}, r_{33}) \\ \theta_y = atan2(-r_{31}, \sqrt{r_{32}^2 + r_{33}^2}) \\ \theta_z = atan2(r_{21}, r_{11}) \end{cases} \quad (12)$$

Here atan2 is the same arc tangent function, with quadrant checking, you typically find in C or Matlab. The Euler angles returned when doing decomposition will be in the following ranges:

$$\begin{cases} \theta_x \rightarrow (-\pi, \pi) \\ \theta_y \rightarrow (-\frac{\pi}{2}, \frac{\pi}{2}) \\ \theta_z \rightarrow (-\pi, \pi) \end{cases} \quad (13)$$

Errors

It is calculated the difference between the new and the old coordinate and call them (rx, ry, rz). And finally, obtain the global error following this norm:

The Frobenius norm, sometimes also called the Euclidean norm (a term unfortunately also used for the vector L^2-norm), is matrix norm of an m×n matrix A defined as the square root of the sum of the absolute squares of its elements.

$$Error = \sqrt{\sum r_x^2 + r_y^2 + r_z^2} \quad (14)$$

The Frobenius norm of a matrix m is implemented as Norm[m, "Frobenius"] and of a vector v as Norm[v, "Frobenius"].

5.1.2. Explanation of the software develop

Matlab is a sophisticated software and interactive environment that is used by millions of developers and scientists worldwide. In this environment you can develop and present your ideas and also work across disciplines. This includes signal and image processing, communications, control systems and financial mathematical operations.

In this case, it is used to create a simple program that it calculates the transformation matrices: Rotation and Translation. In other words, this function finds the optimal Rigid/Euclidean transform in 3D space. It takes as input an Nx3 matrix of 3D points and returns R, t. It is showed in the chapter 4.1.2. Geo-referencing.

```
function [R,T,Yf,dY,Err] = rot3dfit(X,Y)
    error(nargchk(2,2,nargin));
    if size(X,2) ~= 3, error('X must be N x 3'); end;
    if size(Y,2) ~= 3, error('Y must be N x 3'); end;
    if size(X,1) ~= size(Y,1), error('X and Y same size'); end;
    % mean correct
    Xm = mean(X,1);
    X1 = X - ones(size(X,1),1)*Xm;
    Ym = mean(Y,1);
    Y1 = Y - ones(size(Y,1),1)*Ym;
    % calculate best rotation using algorithm 12.4.1 from
    % G. H. Golub and C. F. van Loan, "Matrix Computations"
    % 2nd Edition, Baltimore: Johns Hopkins, 1989, p. 582.
    XtY = (X1')*Y1;
    [U,S,V] = svd(XtY);
    R = U*(V');
    %Euler angles
    Euler=[atan2(R(2,3),R(3,3)) atan2(-R(1,3),sqrt(R(2,3)^2+R(3,3)^2))
    atan2(R(1,2),R(1,1))];
    Euler_gon=Euler*180/pi;
    % solve for the translation vector
    T = Ym - Xm*R;
    % calculate fit points
    Yf = X*R + ones(size(X,1),1)*T;
    % calculate the error
    dY = Y - Yf;
    Err = norm(dY,'fro'); % must use Frobenius norm
```

In this code lines, it is showed one function that has 3 parts that it is explain now. The first lines check if the matrices have 3 columns (x,y,z) and if both them have the same number of points. Then, the coordinates of the midpoints are calculated. Followed by obtaining the matrices of rotation and translation and finally the new coordinates with them error.

All the theoretical explanation of these functions has been obtained in the article “Closed-Form Solution of Absolute Orientation Using Orthonormal Matrices” (Berthold at al).

The only thing missing is entering coordinate matrices, in this case it is generated and txt file to show the result more easily and open it in excel or something like this to understand better.

In these lines it is made some steps: first clear all to delete all the variables that matlab has and put the sentence “format short” to obtain the result in scientific number. After is create the txt file and introduce the first line, in this line appear what is all the columns. Then stay the two matrix A and B for put the coordinates, old and new coordinates. And finally, call the function rot3fit and put all the data in the txt file.

```
clear all
clc
format short
fid2=fopen('register2.txt','w');
fprintf(fid2,'X\tY\tZ\tx\ty\tz\trx\try\trz\tr\n');
%Tables with x, y and z. In this matrix (A,B)it is put the
%coord. A=old coord. B= new coord.
A=[]
B=[];
[R2,t2,Yf,dY,Err] = rot3dfit(A,B);
C=[];
D=[];
for n=1:1:size(A,1)
    xx=Yf(n,1);
    yy=Yf(n,2);
    zz=Yf(n,3);
    rxx=B(n,1)-xx;
    ryy=B(n,2)-yy;
    rzz=B(n,3)-zz;
    D(n,4)=xx;
    D(n,5)=yy;
    D(n,6)=zz;
    D(n,1)=B(n,1);
    D(n,2)=B(n,2);
    D(n,3)=B(n,3);
    D(n,7)=rxx;
    D(n,8)=ryy;
    D(n,9)=rzz;
    D(n,10)=sqrt(rxx^2+ryy^2+rzz^2);
fprintf(fid2,'%f\t%f\t%f\t%f\t%f\t%f\t%f\t%f\t%f\t%f\n',B(n,1),
B(n,2),B(n,3),xx,yy,zz,rxx,ryy,rzz,sqrt(rxx^2+ryy^2+rzz^2));
end
fclose(fid2);
```

All this code has been generated with the help of Greek students and information obtained Matlab forum (Gutierrez, 2005).

To verify that the program works correctly it is used Geomagic. Geomagic is a comprehensive 3D CAD tools for design, engineering and preparation for manufacturing, Geomagic Design empowers rapid, accurate product development in an easy-to-use environment. So, it is executed the following phases:

- Creating some points in Geomagic.

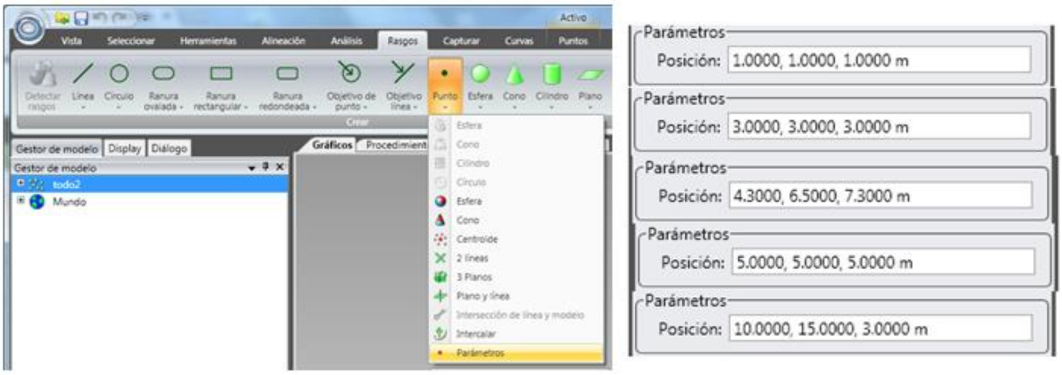


Figure 5.1. Creating points in Geomatics

- Apply rotation and translation and obtain the new coordinates

Figure 5.2. Transformation in Geomatics

- Using the old and new coordinates in this code and obtain the matrices (rotation and translation)

$$R = \begin{Bmatrix} -0{,}98472 \\ -2{,}3064 \\ -0{,}39014 \end{Bmatrix} \quad T = \begin{Bmatrix} 12{,}999 \\ 16{,}000 \\ 20{,}000 \end{Bmatrix} \quad \text{Error} = 0{,}0001 \qquad (15)$$

As shown in this example, the translation of these 5 points is nearly perfect, but in the rotation there are some seconds of difference between the original and the calculation angles. This is produce because they are rounded numbers to 4 decimal and this fact generates these angular differences are created.

5.2. Create a simple viewer for show the 3D model in Python

In this second part of programing, it is wanted to create software to show the 3D model. For do it, it is worked with Python in Ubuntu.

5.2.1. Concepts

- **Ubuntu**

Ubuntu is a Debian-based Linux operating system and distribution for personal computers, smartphones and network servers. It uses Unity as its default user interface. It is based on free software and named after the Southern African philosophy of Ubuntu (literally, "human-ness"), which often is translated as "humanity towards others" or "the belief in a universal bond of sharing that connects all humanity"

We use the last stable version called Ubuntu 14.04.4 LTS (Large-scale deployments).

Figure 5.3. Logo Ubuntu

- **Python**

Python is a widely used high-level, general-purpose, interpreted, dynamic programming language. Its design philosophy emphasizes code readability, and its syntax allows programmers to express concepts in fewer lines of code than would be possible in languages such as C++ or Java. The language provides constructs intended to enable clear programs on both a small and large scale.

- **Liclipse**

It is an Eclipse based IDE that includes the PyDev plugin to program in Python or Django, it also supports other languages (15) like html, css or js.

Figure 5.4. Logo Liclipse

The main objective in this part is show the 3D model in one free viewer and tries to put in the good place in the word.

Figure 5.5. Python visor

5.2.2. Code

In the following lines it is explained the python files. There are two: Functions are in one of them and the main code in the other. Now, it is shoed and explained functions.

```
class OBJ:
    def __init__(self, filename, swapyz=False):
        """Loads a Wavefront OBJ file. """
        self.vertices = []
        self.normals = []
        self.texcoords = []
        self.faces = []
        material = None
        for line in open(filename, "r"):
            if line.startswith('#'): continue
            values = line.split()
            if not values: continue
            if values[0] == 'v':
                v = map(float, values[1:4])
                if swapyz:
                    v = v[0], v[2], v[1]
                self.vertices.append(v)
            elif values[0] == 'vn':
                v = map(float, values[1:4])
                if swapyz:
                    v = v[0], v[2], v[1]
                self.normals.append(v)
            elif values[0] == 'vt':
                self.texcoords.append(map(float, values[1:3]))
            elif values[0] in ('usemtl', 'usemat'):
                material = values[1]
            elif values[0] == 'mtllib':
                self.mtl = MTL(values[1])
            elif values[0] == 'f':
                face = []
                texcoords = []
                norms = []
                for v in values[1:]:
                    w = v.split('/')
                    face.append(int(w[0]))
                    if len(w) >= 2 and len(w[1]) > 0:
                        texcoords.append(int(w[1]))
                    else:
                        texcoords.append(0)
                    if len(w) >= 3 and len(w[2]) > 0:
                        norms.append(int(w[2]))
                    else:
                        norms.append(0)
                self.faces.append((face, norms, texcoords,
material))
```

The code that has been shown is to upload a file obj. To do this, the program reads line by line the file using iterators and extracted from it the basic object information: The faces of the item, the surface normal vectors, texture and coordinates of each triangle.

The next part of the code is used to load the mtl file. This file is important because in it appear the texture information like colour, transparencies or brightness. This function is call for the last function and helps to make a good visualization of the 3d model.

```
def MTL(filename):
    contents = {}
    mtl = None
    for line in open(filename, "r"):
        if line.startswith('#'): continue
        values = line.split()
        if not values: continue
        if values[0] == 'newmtl':
            mtl = contents[values[1]] = {}
        elif mtl is None:
            raise ValueError, "mtl file doesn't start with
newmtl stmt"
        elif values[0] == 'map_Kd':
            # load the texture referred to by this declaration
            mtl[values[0]] = values[1]
            surf = pygame.image.load(mtl['map_Kd'])
            image = pygame.image.tostring(surf, 'RGBA', 1)
            ix, iy = surf.get_rect().size
            texid = mtl['texture_Kd'] = glGenTextures(1)
            glBindTexture(GL_TEXTURE_2D, texid)
            glTexParameteri(GL_TEXTURE_2D,
GL_TEXTURE_MIN_FILTER,
                GL_LINEAR)
            glTexParameteri(GL_TEXTURE_2D,
GL_TEXTURE_MAG_FILTER,
                GL_LINEAR)
            glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA, ix, iy, 0,
GL_RGBA,
                  GL_UNSIGNED_BYTE, image)
        else:
            mtl[values[0]] = map(float, values[1:])
    return contents
```

Now, it is going to explain the main part. The first think that it is done is import some libraries. Library is a collection of non-volatile resources used by develop software and it makes it easier to generate programs, one of the good things about working in open source.

```
% IMPORT LIBRARIES
import sys, pygame
from pygame.locals import *
from pygame.constants import *
from OpenGL.GL import *
from OpenGL.GLU import *
 % IMPORT OBJECT LOADER
from objloader import *
```

```
pygame.init()
viewport = (800,600)
hx = viewport[0]/2
hy = viewport[1]/2
srf = pygame.display.set_mode(viewport, OPENGL | DOUBLEBUF)
…
# LOAD OBJECT AFTER PYGAME INIT
#obj = OBJ(sys.argv[1], swapyz=True)
obj = OBJ("Silo1.obj", swapyz=True)
clock = pygame.time.Clock()
glMatrixMode(GL_PROJECTION)
glLoadIdentity()
width, height = viewport
gluPerspective(90.0, width/float(height), 1, 100.0)
glEnable(GL_DEPTH_TEST)
glMatrixMode(GL_MODELVIEW)
rx, ry = (0,0)
tx, ty = (0,0)
zpos = 5
rotate = move = False
while 1:
    clock.tick(30)
    for e in pygame.event.get():
        if e.type == QUIT:
            sys.exit()
        elif e.type == KEYDOWN and e.key == K_ESCAPE:
            sys.exit()
        elif e.type == MOUSEBUTTONDOWN:
            if e.button == 4: zpos = max(1, zpos-1)
            elif e.button == 5: zpos += 1
            elif e.button == 1: rotate = True
            elif e.button == 3: move = True
        elif e.type == MOUSEBUTTONUP:
            if e.button == 1: rotate = False
            elif e.button == 3: move = False
        elif e.type == MOUSEMOTION:
            i, j = e.rel
            if rotate:
                rx += i
                ry += j
            if move:
                tx += i
                ty -= j
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT)
    glLoadIdentity()
    # RENDER OBJECT
    glTranslate(tx/20., ty/20., - zpos)
    glRotate(ry, 1, 0, 0)
    glRotate(rx, 0, 1, 0)
    glCallList(obj.gl_list)
    pygame.display.flip()
```

Even though there are many lines of code that are basic configuration for pygame object, there are three parts that can be distinguished are:

- One pygame object begins setting the basic functions such as mouse actions: rotations, translations and scaling.
- The object file is loaded using the functions explained above it and putting it in the pygame object.
- And finally, the textured pattern is generated and displayed in the graph window.

Figure 5.6. Python viewer

5.3. Generate HTML file where is possible to show the point cloud

In the las part of this chapter is wanted to show how is possible to generate a html file and showing your point cloud data. Nowadays, there are a lot of forums or web sites when one develop man can put his projects and share with the others, like github. This is one of the ideas that open source has and helps the development of new applications.

In this case, it is used one of this repositories call "Potree" that is possible to find in github. They create some examples to show the point clouds and it is used this examples to create the viewer that is use in this project.

They provided one batch that it is possible to introduce one las file and obtain the html. So in the first place it is neede the point cloud in las file. Furthermore, as the cloud of points obtained with the laser there is no data rgb in all points, will join the point cloud generated by UAV. So it is get a point cloud data with land and air.

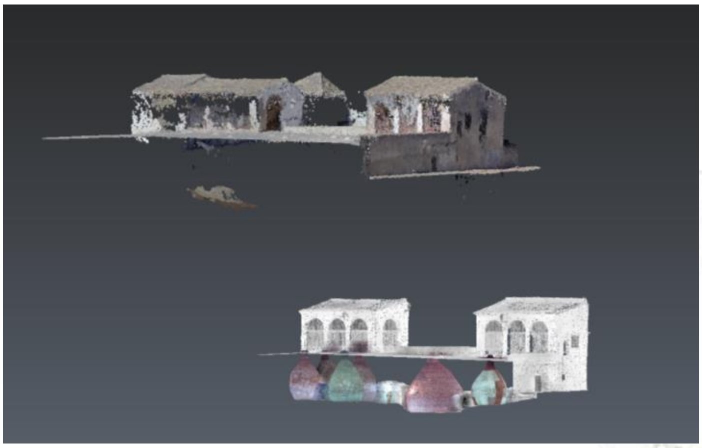


Figure 5.7. Difference between UAV model and laser model

In the next image is possible to see that the top of the square has colour (from UAV) and the wall has not (from the laser scanner).

Figure 5.8. Difference between uav model and laser model.

When the programs finish, it is needed to copy all the files that generates in one server because this html file uses java libraries that only work when is put in server. It is mean that if it is tried to open in local, it is not show anything. So, in this case, it is put in the student server from Hochschule Karlsruhe and is possible to see in the next url: http://www.home.hs-karlsruhe.de/~moda1021/potree_converted/pageName.html.

This viewer has a lot of tools that which can be very useful. Below we will explain some of them:

- Appearance:

In this part it is possible to change the number and size of points that is wanted to show. It is possible to change the background to and put sky. And modify the opacity of the points and the distance between point cloud and point of view.

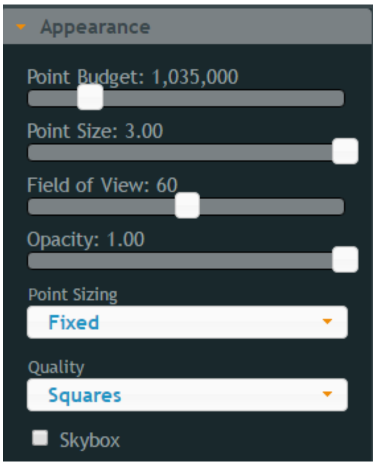


Figure 5.9. Appearance in the viewer

- Tools and measurements:

It is possible to take distinct measurements with this viewer. For example, in the next image, it is possible to see the distance between points.

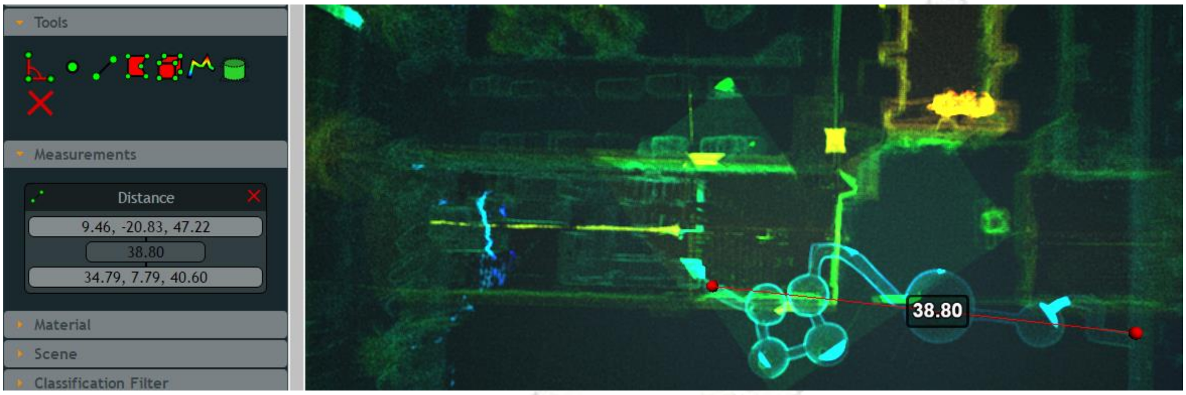


Figure 5.10. Take the distance in the viewer

It is possible to change the representation. In the next image is possible to see RGB data and elevation data. This tools is really interesting because if it is wanted to study the geometry is better to use height or intensity and if it is wanted to showed the place is better use RGB data.

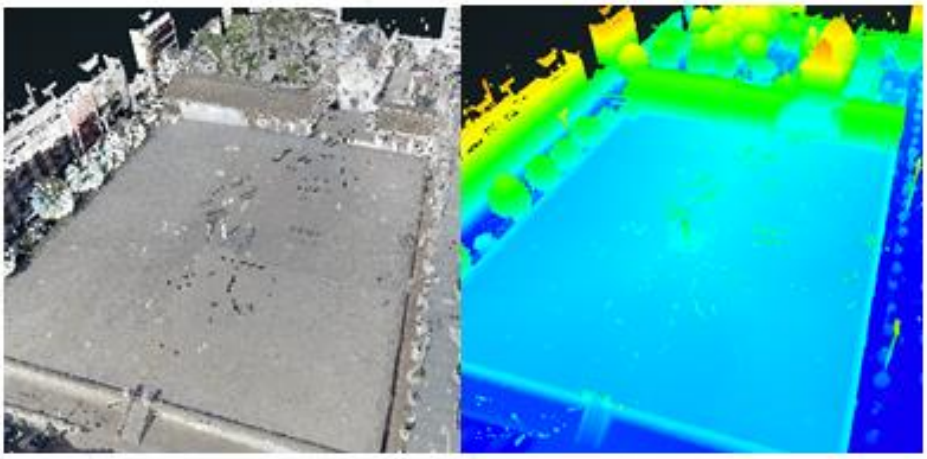


Figure 5.11. Take the distance in the viewer

The usefulness of this tool is that it is can to visualize the point cloud on a website without need for a treatment for mesh generation. While, it is true that the point cloud cannot make take-offs studies or other studies, this representation of reality can be very useful for projects that are not available too long.

6. Compare with other projects

In this part of the project it is gone to explain other projects like this and after compare the results. Divide this step in two parts, in the first part speak about laser scanning and join with other technologies like Thermography and photogrammetry and in the second part show the difference.

6.1. Cultural heritage projects

In this chapter, it is tried to show some work in which you try to integrate more than one technique for documentation of heritage, as in the case of this project. Mainly laser scanning techniques and photogrammetry for the generation of these products are used and not taken into account other as GPR or thermography. It is not the case of this thesis but it is the case of the collaborative project between universities.

6.1.1. Project 1: Architectural recording

In the first place, it is gone to show one interesting project. It is "*INTEGRATION OF 3D LASER SCANNING, PHOTOGRAMMETRY AND THERMOGRAPHY TO RECORD ARCHITECTURAL MONUMENTS*". This project was made by Photogrammetry & Laser Scanning Research Group (GIFLE) from the Universidad Politécnica de Valencia in October, 2009.

They was been focused in Djin Blocks are three-dimensional stone-carved funerary structures that resemble towers and are spread throughout the site of Nabataean Petra on white Ordovician sandstone. All the Djin Blocks are on the list of the park's archaeological monuments of Petra, which has been a world heritage site since 1985. Petra was listed twice on the World Monuments Watch List of the One Hundred Most Endangered Sites

They present a methodology to record accurately and exhaustively a World Heritage Monument by means of terrestrial laser scanning, close range photogrammetry and thermal imagery.

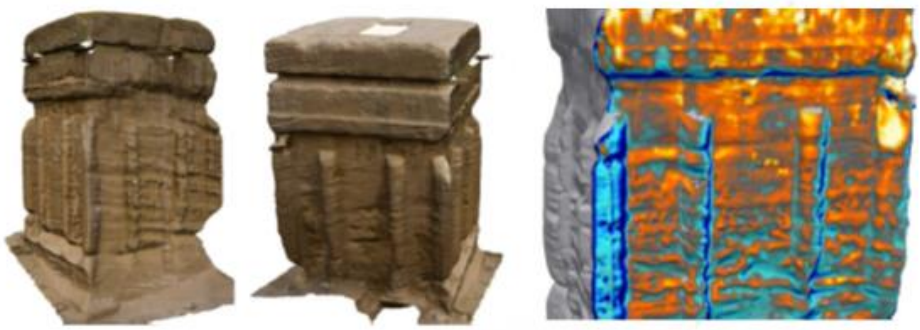


Figure 6.1. Project GIFLE (GIFLE)

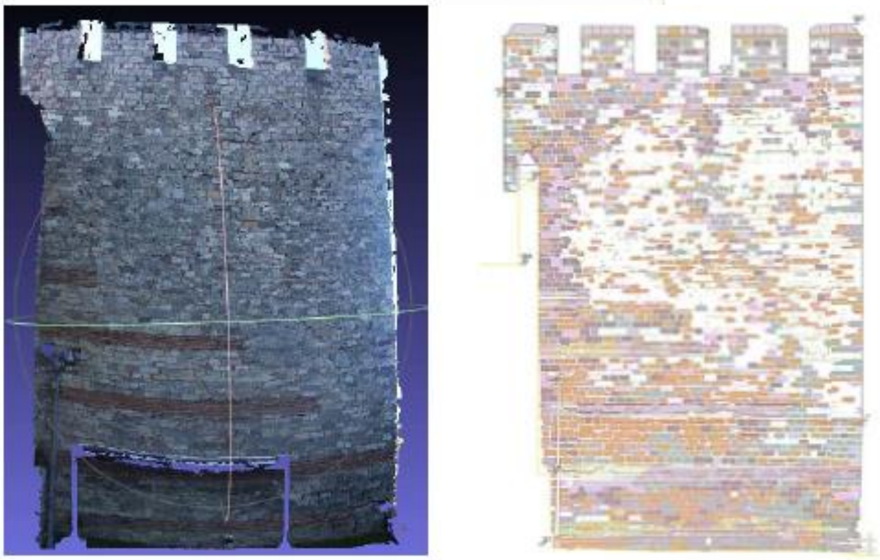
And they concluded that Images combined from the visible and thermal infrared parts of the electromagnetic spectrum are very effective for determining features, alterations or damage, otherwise very difficult to characterise by traditional means. Furthermore, the integration of the imagery to yield 3D photomodels allows comprehensive analyses far beyond traditional 2D imagery. This study also demonstrates the benefit of using thermography to detect otherwise invisible patterns of no longer existing attachments onto the eastern facade.

6.1.2. Project 2: Monument recording

In the other hand, show you "*COMPARISON OF LASER SCANNING AND PHOTOGRAMMETRY AND THEIR USE FOR DIGITAL RECORDING OF CULTURAL MONUMENT CASE STUDY: BYZANTINE LAND WALLS-ISTANBUL*". It was made by Department of Geomatic Engineering, Division of Photogrammetry, Davutpasa Campus (Istambul).

This project was in "The Byzantine Land Walls of Istanbul are located at Topkapı region of Istanbul. Dating back to the reign of Theodosius II (408-450 AD), the "Land Walls" enclose the land boundaries of the Byzantine settlement. Due to their multiple defense systems consisting of a moat (taphros), outer terrace (parateichion), outer wall (mikron teichos), inner terrace (peribolos), and inner wall (mega teichos), the Land Walls are considered to be one of the greatest achievements of ancient military architecture. With UNESCO's inclusion of the monument and its surroundings on the World Heritage List in 1985, the remarkable significance of the Land Walls was internationally acknowledged" (Çorakbaş, et al., 2014).

They create a 3d model of one wall using photogrammetry and laser scanning and finally compare the results.



6-1. Projec images (B.Bayrama)

Three different measurement techniques have been applied and the results compare. There are TLS, and photogrammetry. They develop one method and based on automatic point cloud generation from stereo photographs.

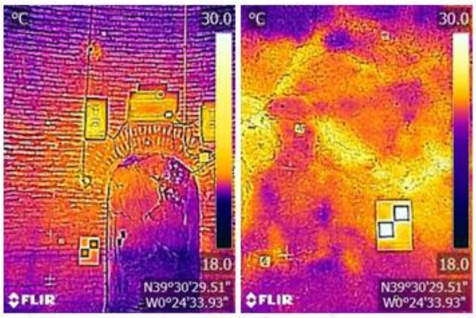
6.1.3. Compare and enhancements

If compare this project with the first, it is possible to see some difference and some similitudes between both. For example, in both project it was used laser scanner, photogrammetry and thermography trying to find pathologies and other affections.

In the other hand, one difference is that they didn't use UAV to take the top of the monument and in this thesis is used. The advantage of using the UAV is that you can get more information from inaccessible areas on foot. However this means more work, either by placing more field or looking homolog points to join the data.

6.2. Mr. Berner taking the UAV (Ana Valls, 2016)

If it is compared with the second project, the first thing that is possible to see is that they didn't use thermography, and the team in the international project that works in this area explained important to take this information because there are some pathologies or materials that that the eye cannot see and is easy to obtain with temperature values.



6.3. Thermic Photography (Carbonell rivera, 2016)

Below it is showed a table in which some important aspects of these projects are compared and can be used as or improved in this project.

Table 6.1. Compare results table

	Photogrammetry	Laser scanner	Thermography	UAV
Fisrt	Take pictures around the object	Standard deviation of about 2-4 mm	Take pictures in sun and shadow	Don't use
Second	Take pictures only in one face	Around 3mm.	Don' take	Don't use
This project	Take pictures outside and inside	Aprox. 2mm	Photo taken twice daily	Use for the Top

Note: This table is the result of registration processing.

7. Conclusions and future work

In this final part of this thesis, it is tried to explain all the conclusions that is obtain during the entire master thesis. In spite of had a hard and costly way, it is been discussed many topics related to 3D design, modelling reality in digital and generating useful products for society, for scientists and for all those who want to enter this world.

7.1. Conclusions

During the whole project it has focused special attention in making data from the laser scanner and the products that can be derived from it, providing valuable information and useful to studies of patrimonial documentation. Not only for the ability to collect large amount of information in a short time, also by the quality of them.

The search for prior information to the project and work planning are two fundamental aspects to obtain satisfactory results and useful to the user. This together with the combination of various techniques makes the project a comprehensive study of the area.

First, it is noteworthy that is very useful prior information search, because it is could not access the inside of the silos before the work week. Fortunately, there is much documentation on the Internet that helps to get an idea of the dimensions of the project.

One example of this is the doctoral thesis of Ana Valls that has a lot of graphical documentation greatly facilitated the task of preparing the project.

During the fieldwork, there were some problems like instrumental problem ore the time of acquisition of the material was not enough. If it is had more time, probably it was possible to take pictures in the scans and after put RGB date in the point cloud. This simple fact would have greatly facilitated the visual interpretation in office work.

But nevertheless, it was used a fast laser scanner and was able to obtain a total of 70 scans in a day. Likewise, it was enough time to put the targets in a clear and orderly manner, creating a good geometry for join the scans after.

Use spheres outside can be really problematic because they are easier to move (by the wind, people ...) that targets on paper, and after generate problems in the register.

To register the point cloud, it is used two of the most popular programs in this world: Cyclone (Leica) and Scene (Faro). The biggest difference between them is that one of them (Scene) can find the targets and spheres, and the other cannot (Cyclone), because it had not been used Leica's targets. In the next table is possible to see the error was made in both software and the time that was needed for make the register.

Table 7.1. Results

	Error (m)	Time (days)
Cyclone	0.140	2.5
Scene	0.009	1

Note: This table is the result of registration processing.

With Faro is done in a very easy and intuitive way the program registration, and to implement an automatic iterative code to find the common elements between point clouds and if there is enough overlap between the clouds can also perform manual search.

One of the biggest problem that is had in this project was to try join the inside part and the outside part because in one of the entry the door was close and there were not enough targets to made the registration. On the other site, the hardware is really important when you try to do one project like this because need a lot of space and good computer to make all. In this case the date are more than 200GB and sometimes the computer could not work with this.

Try to combine all the available information in a single product makes it possible to be obtained as a final result a cloud of georeferenced points. On this occasion, it was had problems with obtaining coordinates based on the geodesic network, but with the help of information from UAVs and laser scanner has been able to generate a product with a centimetres accuracy.

It is create software to obtain the parameters of the transformation and after put these in faro Scene. In this way, when you export all the point cloud, it is referenced in the wanted coordinate system. If it is wanted to created software, remember to test it several times and certifies that works well.

Once registration is complete, and obtained the referenced point cloud, it is can generate some products, in two and three dimensions. For many years, generation and printing of plans to been the most common to provide information buildings and monuments way. but today, this trend is changing.

In the one hand, planes have been made to countersign the dimension of silos, it could have improved the representation by scanning the outside. However, it is easy to interpret and is not needed one computer to show it.

In the other hand, it is tried to generated a digital model that everyone can see at home. In this case there are two products: first generate a viewer where it is possible to take measurements and show all the points and second generation a digital model with low resolution that any user can see in them computer using google earth.

The generation of 3D printing is another novelty that happens in this days. It is not an easy task, because you can have a lot of problems, not only in the generation of digital model also are problems in the printers. However, knowing perform these model provides a point of innovation in the projects.

Finally, there is a variety of information available that facilitate the tutoring of new programming languages. Search for innovation and create small programs that meet our needs is something that everyone should try because with the passage of time is saved.

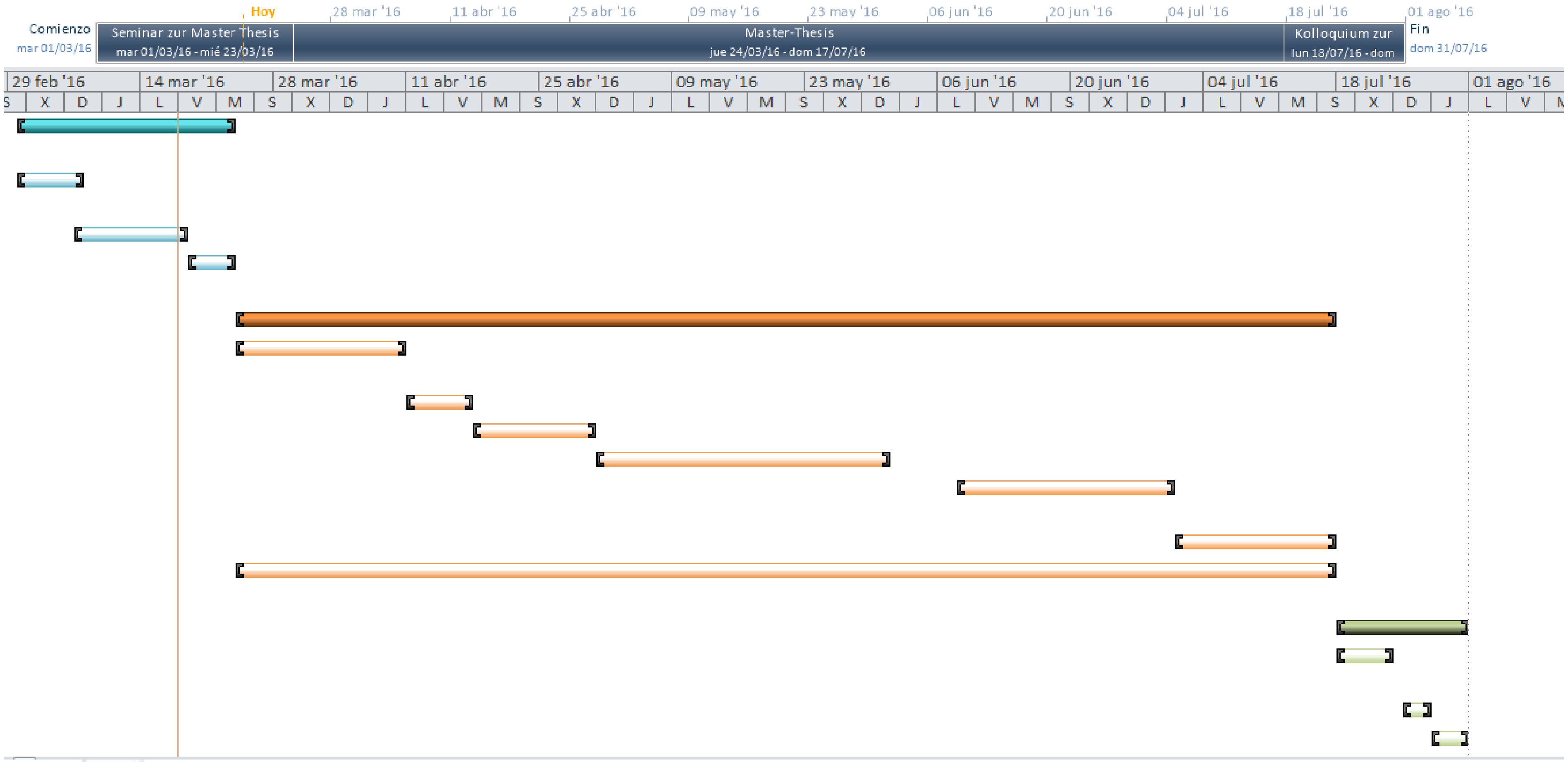
7.2. Future works

Currently, the technology is constantly advancing and more research in the fields of 3D data processing or implementation UAV in data acquisition tasks. Therefore, complex task becomes define future work. However, below are listed some of them.

- Automating the generation of products in two dimensions as the generation of planes from one model to different heights or the generation of a report with basic information as dimensions and cubing.
- Generate a 3D impression of the entire study area including the outer area and the inner area of the silos.
- Use a decent server to facilitate the transmission of data between computer components.
- Join all the techniques used in the international project, trying to create a single product in which can see and compare all the technologies used.
- To publicize this type of work to society through awareness campaigns of cultural heritage and encourage Geomatics.

Appendix I: written documentation

I. Planning



0-1. Picture of the planing

II. Faro 5.5 Tutorial (Silos Inside)

Faro Scene and indirect registration technique: target to target constraints

In this part of the thesis, it is wanted to show step by step, how to perform a target to target registration in FARO Scene and how to have a point-cloud-based registration combining all scans into a coherent point cloud.

For instance, it is use a data from the silos, which stretches over 2 sites (inside and outside). It is used a laser scanner data, reference spheres and other targets. For this registration method, the overlapping area between scans not is so important because use for the join some points but if you have overlapped of areas the result could become better.

Based on photogrammetry, an overlap of at least 30% is necessary – the more identical points are available. For example, if it wanted to get the smaller error in the registration, it would be simply scan the targets. In this case, it is used 6 targets between one scan and the next, thus avoiding collinearity there among targets.

Below it is written a small tutorial on how it has worked. First, start FARO scene (it is worked with the current version of FARO scene 5.5.3) and create a new project.

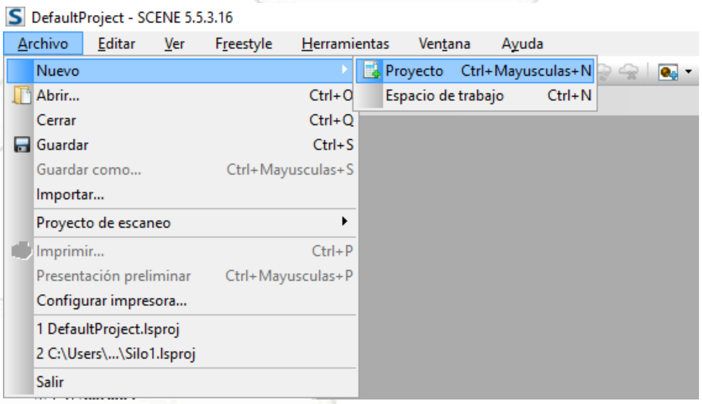


Figure 0.1. Open new project Scene

The difference between a project and a workspace is the data storage and structure. In a workspace, the data such as the scans and the color images are stored in a folder. Any change forces direct modification of the data.

In one project, a database is written and can be traced to the changes. It creates a history and only the changes are saved. So the user has the option to retrieve older version and to make the changes. Of course, if you need more space for a project, it can be adjusted at the end and the project is therefore compressed.

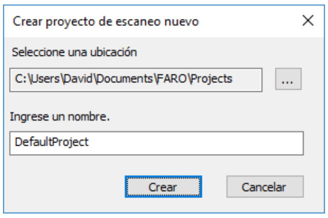


Figure 0.2. Select workspace new project Scene

The scans can be drawn into the FARO Scene project either directly from the SD card or from another location, simply via drag & drop. In the tree view, a folder named scans will be created immediately below the workspace, where all scans land automatically.

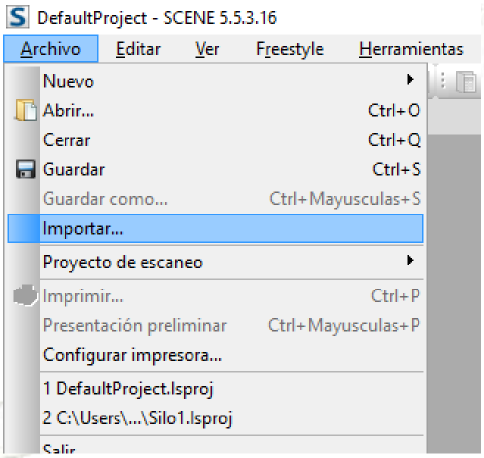


Figure 0.3. Import scans Scene

When it is saved the project, the FARO Scene typical folder structure is created and the scan data is stored in the database. This first operation takes a bit longer, but it is only a one-time process.

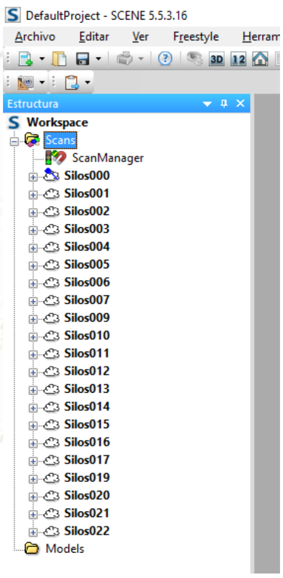


Figure 0.4. Show all the inside scans Scene

After successfully creating the project structure, one message is appears and specifying that all the data is stored in the first version. We confirm the information with OK.

Now the registration process will be started. Firstly, it is necessary to find all the targets and spheres that appear in the scans, for make it click right button and select operation and find objects.

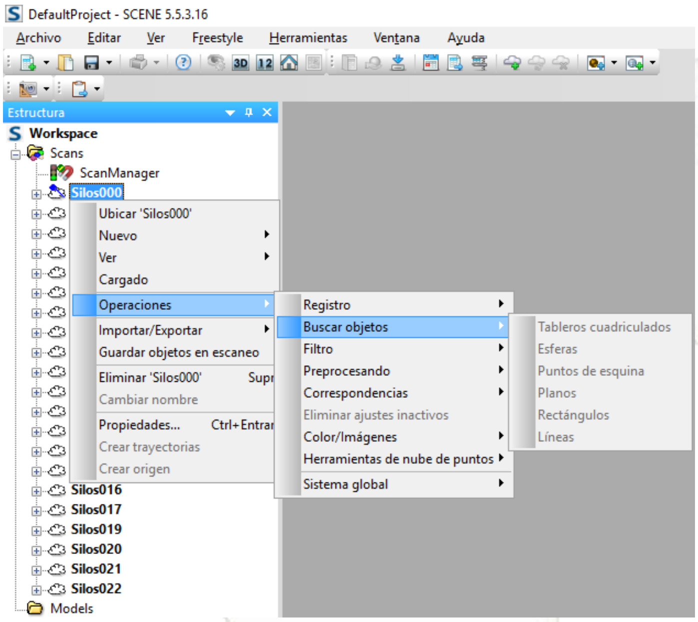


Figure 0.5. Finding tarjets Scene

In this case, it is found spheres and targets because it was used it when work in the silos site.

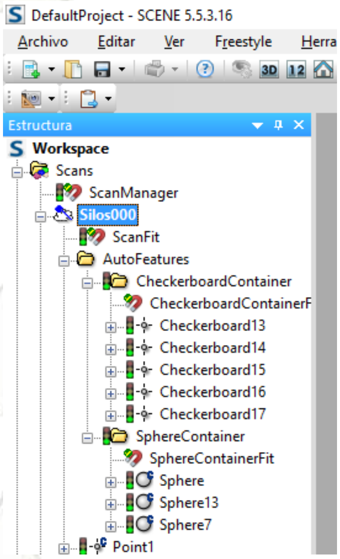


Figure 0.6. Showing spheres and checkerboard Scene

It is open with a right mouse click under menu the folder scans operation and select operation of the registration of the scans command station from (RMK site-> operations-> deployment-> scans station).

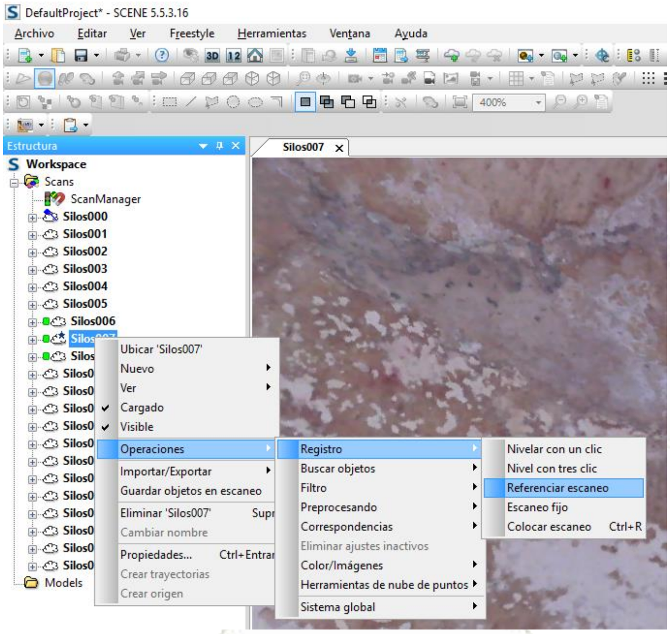


Figure 0.7. Reference scans Scene

The registration menu appears and the type of registration is selected. Then, it is had scanned with targets, it is selected the top view-based type of the registration. The top view-based registration tool is used to obtain the first approximate coordinates.

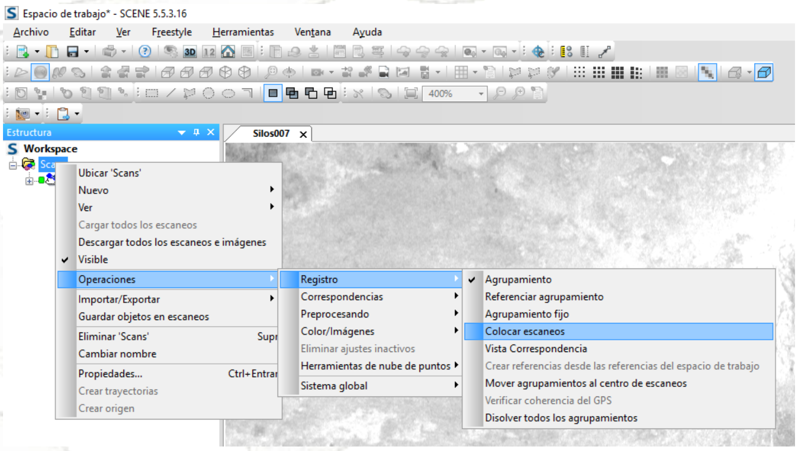


Figure 0.8. Create new register Scene

It is gone to the General tab and activates the sensors that we need. The inclinometer and the compass are important sensors, as these two first coordinates determine the location of the scanner (rough guide). In addition, GPS and altimeters may be needed depending on the project.

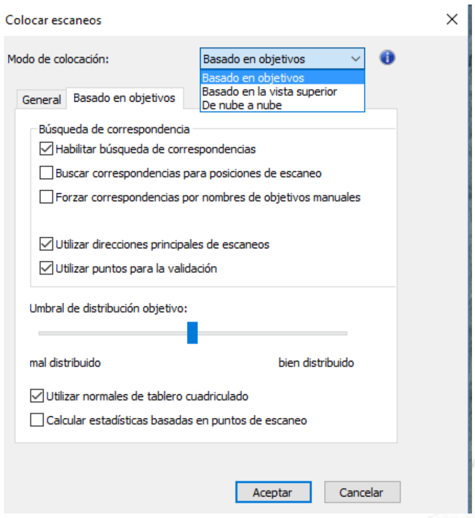


Figure 0.9. Select method to register Scene

The option of the auto-clustering allows the software, after defining distance separation, create clusters. The auto-clustering is disabled. Experience has shown that manual clustering makes more sense because the scans can be divided in the respective project areas. After this phase, it is known best how can performed the scanning.

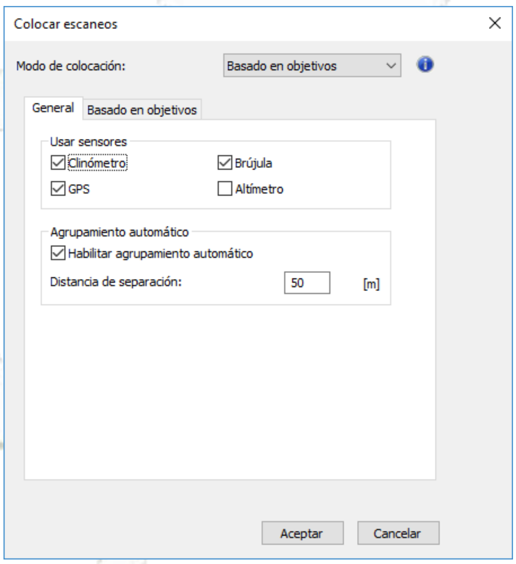


Figure 0.10. Register options Scene I

Now, it is gone to the tab plan based view. There are two sliders and an input field for where the average point distance should be set.

The first slider is the subsample, which is connected to the input field for the average point spacing. The subsampling describes the sampling ratio of the point cloud. The denser the sampling ratio, the most of time is needed for the calculation step: 5 cm for architecture and 2 cm. For example, plant design can be used as orientation values. Because the top view-based way of registration only serves as an approximate placement, these orientation values are sufficient.

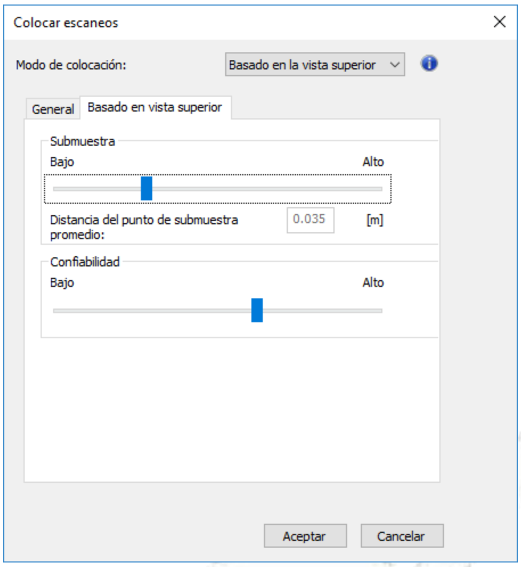


Figure 0.11. Select options register Scene II

The reliability depend on the noise behavior of the point cloud. In areas with a lot of stainless steel, glass or mirror surfaces, the reliability is low. In an apartment, the reliability is quite high. It is confirmed the settings with OK and start the calculation. As a result of the registration the Scan Manger appears with a green light.

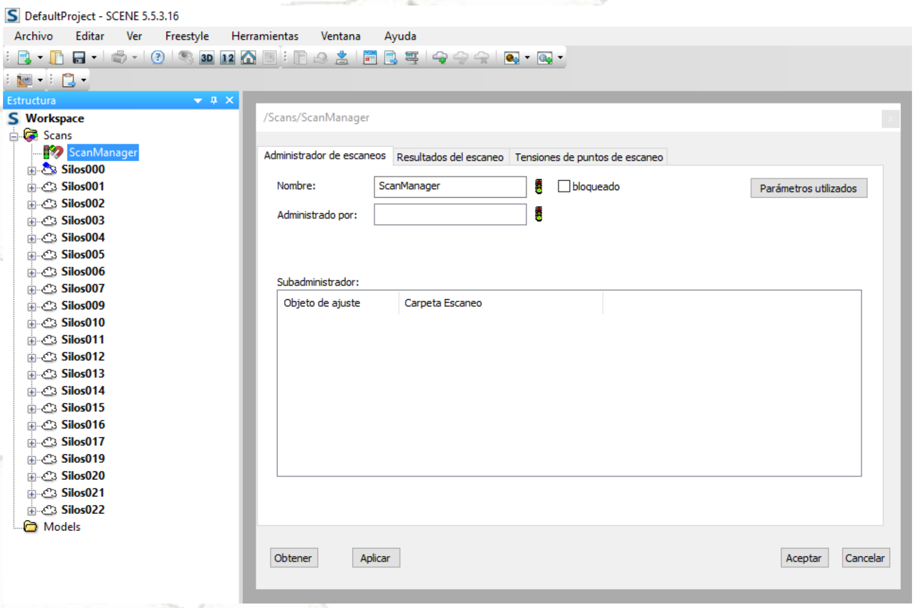


Figure 0.12. Green light Scene

Let’s look at the results in more detail. Under the tab scan point tension, we get an overview of the overall statistics and the various tensions and overlap zones between the scans. This is the first approximately:

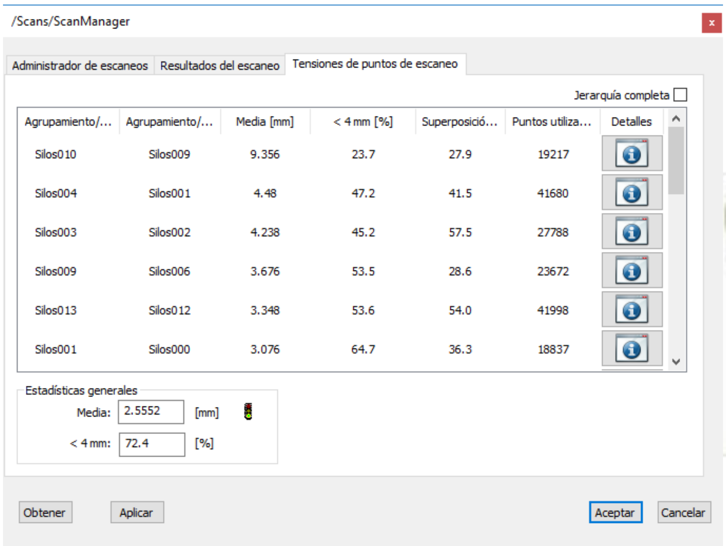


Figure 0.13. Show error Scene

Other way to make is using the point cloud-based registration. Because you have now Scan Manager, we must simply update it. Right- click menu on the Scan Manager, is the scanning feature update available. (Update RMK-> scans update)

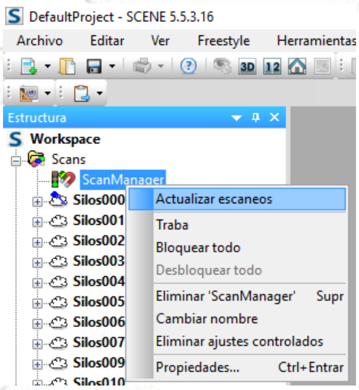


Figure 0.14. Reload scans Scene

In this part of the software, it is possible to choose the point cloud registration as new calculation. The settings under the general tab are applied, likewise, the setting for the subsample. New additions are the settings for the maximum passes and the maximum search distance.

It is determined the maximum number of runs through the computation passes – how often we attempt to align the point clouds together. The maximum search distance is the Radius, starting from the scanner position in which area identical point clouds are sought. 10 meter is sufficient for indoors — a greater value would be appropriate for an outdoor area, depending on how close and what resolution was scanned.

But it is made the cloud to cloud registration with other program and explains it in the following paraphrase. It is gone to study the first result.

The overall statistics give an average value of 2.5 mm and during assortment after the overlap area; the registry must be satisfied the objectives.

Of course, it is wanted a visual inspection too. It is loaded all the scans with reduced resolution. More options are available to us under the main menu under Extras. Under the tab, scan data can be adjusted and loaded to the size of the individual scans. Once you deselect, we can enter a manual value. Now we load each scan with unlimited scan points.

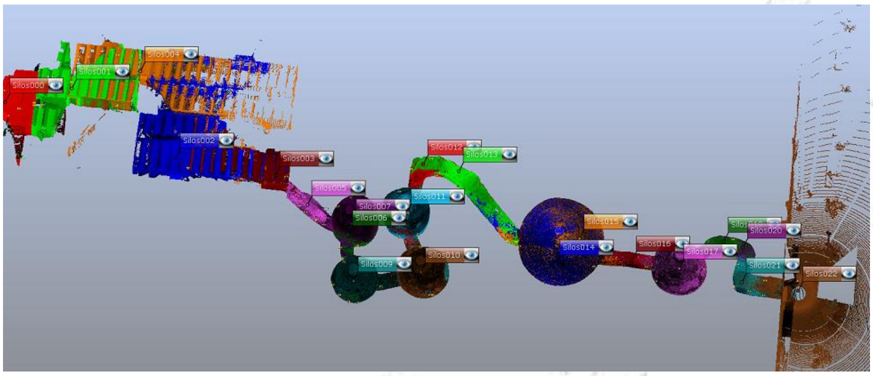


Figure 0.15. All inside scans

It is can load all the scans with the right click menu on the folder scans (Download RMK-> all scans). A look at the 3D view shows us a coherent point cloud.

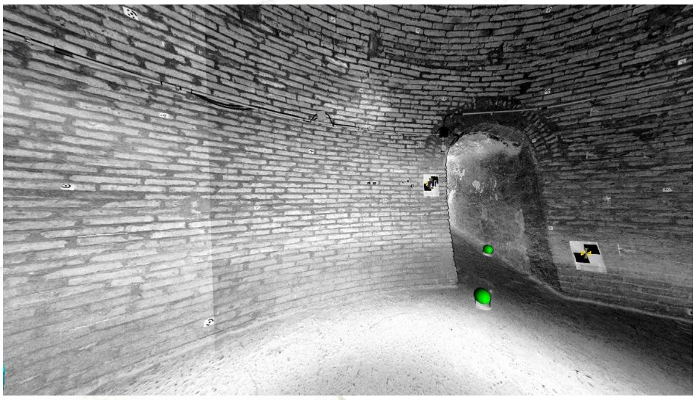


Figure 0.16. Show intensity from one scan Scene

Using the tool bar, it is marked an area of the window, which was visible from the scan from the top floor, as well as from the down floor using the tool bar. This section it is loaded in a spatial view, on the right click menu on the selected area. (RMK-> view-> spatial view)

The highlighted area will open in a new tab in the 3D view.

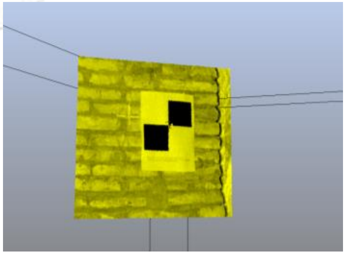


Figure 0.17. Open area selected Scene

With this help, it is easier to find corners and other easy points to identify for registration without targets.

Figure 0.18. Find real points Scene

Above the right click menu of the previously opened 3D views, we can add the newly selected scan points.

Now, the areas can be controlled. In order to better distinguish which points are from what scan, the points appear yellow, which are the active scans. This must be done by right clicking on the respective scan.

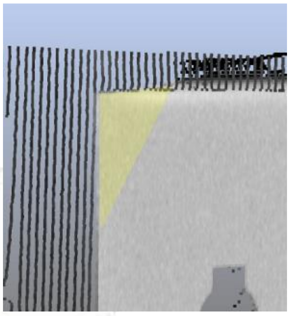


Figure 0.19. Find corner Scene

This is now a small, manageable project. For larger size projects it makes sense to define areas. In a building a separation area is close to the floors. Registered scan clusters are created for each floor, after being registered individually scanned are joined to create a point cloud.

It is necessary to keep in mind those 2 important things: the error and the time. In this case the error is 2.5mm (only the scans with inside part) and need half day for make the registration approximately. We speak about this in the end of this chapter.

On the other hand, the Greeks students are made the outside part and they need 2.5 days for join all the scans and have 20 cm approximately the error. It is know that this error is too large so it is should review the whole process to find the maximum errors and try to correct them.

III. Faro report (An example)

```
**********************

* Registration Report *

**********************

General Information

----------------------------

Scan Quantity             : 70

Participating Scans       : Silos000, Silos001, Silos002, Silos003, Silos004, Silos005,
Silos006, Silos007, Silos009, Silos010, Silos011, Silos012, Silos013, Silos014, Silos015,
Silos016, Silos017, Silos019, Silos020, Silos021, Silos022, Silos0023, Silos024, Silos025,
Silos026, Silos027, Silos028, Silos029, Silos030, Silos031, Silos032, Silos033, Silos034
Silos035, Silos036, Silos037, Silos038, Silos039, Silos040, Silos041, Silos042, Silos043,
Silos044, Silos045, Silos046, Silos047, Silos048, Silos049, Silos050, Silos051, Silos052,
Silos053, Silos054, Silos055, Silos056, Silos057, Silos059, Silos060, Silos061, Silos062,
Silos063, Silos064, Silos065, Silos066, Silos067, Silos068, Silos069, Silos070, Silos071,
Silos072

Total Correspondences     : 1420

Scan

----------------------------

Scan Name                 : Silos000

Inclinometer Usage        : yes

Position [m]              : 0.000000 0.000000 20.250546

Orientation Axis          : 0.0482300686 -0.0187284510 -0.9986606559

Angle [°]                 : 34.503846

Point Distance [mm]       : 0.000000

Number of Correspondences : 20

Correspondences

| Scan 1 || Scan 2 || Tension |

/Scans/Silos000:Inclinometer /Scans/Silos001:Inclinometer 2.2924

/Scans/Silos000:Inclinometer /Scans/Silos005:Inclinometer 2.0973

/Scans/Silos000:Inclinometer /Scans/Silos011:Inclinometer 6.2137

/Scans/Silos000:Inclinometer /Scans/Silos016:Inclinometer 1.9062

/Scans/Silos000:Inclinometer /Scans/Silos021:Inclinometer 2.0334

/Scans/Silos000:Inclinometer /Scans/Silos004:Inclinometer 1.4550

/Scans/Silos000:Inclinometer /Scans/Silos014:Inclinometer 2.0920
```

```
/Scans/Silos000:Inclinometer /Scans/Silos006:Inclinometer 1.9959

/Scans/Silos000:Inclinometer /Scans/Silos002:Inclinometer 2.0896

/Scans/Silos000:Inclinometer /Scans/Silos013:Inclinometer 0.0285

/Scans/Silos000:Inclinometer /Scans/Silos020:Inclinometer 0.1694

/Scans/Silos000:Inclinometer /Scans/Silos007:Inclinometer 2.1130

/Scans/Silos000:Inclinometer /Scans/Silos012:Inclinometer 5.7258

/Scans/Silos000:Inclinometer /Scans/Silos009:Inclinometer 1.6750

/Scans/Silos000:Inclinometer /Scans/Silos019:Inclinometer 2.8459

/Scans/Silos000:Inclinometer /Scans/Silos017:Inclinometer 3.2837

/Scans/Silos000:Inclinometer /Scans/Silos022:Inclinometer 1.5909

/Scans/Silos000:Inclinometer /Scans/Silos010:Inclinometer 5.7682

/Scans/Silos000:Inclinometer /Scans/Silos003:Inclinometer 1.5404

/Scans/Silos000:Inclinometer /Scans/Silos015:Inclinometer 3.5907


Matched Objects

| Target || Distance [mm] || Longitudinal [mm] || Angular [°] || Orthogonal [mm] |



…


(continue with all the scans -72-)
```

IV. Cyclone report (Silos inside)

```
Status: VALID Registration

Mean Absolute Error:

   for Enabled Constraints = 0.002 m

   for Disabled Constraints = 0.000 m

Date: 2016.07.18 10:26:12

Database name : Silos

ScanWorlds

Silos000.fls

(…)

Silos021.fls


Constraints

Constraint ID  ScanWorld     ScanWorld     Type                            Status   Weight
Error     Error Vector                                                HorzVert

Cloud/Mesh 1   Silos000.fls  Silos001.fls  Cloud: Cloud/Mesh - Cloud/Mesh  On       1.0000
0.000 m                  aligned [0.016 m]

(…)

Cloud/Mesh 36  Silos019.fls  Silos021.fls  Cloud: Cloud/Mesh - Cloud/Mesh  On       1.0000
0.004 m                  aligned [0.010 m]

Cloud/Mesh 1  [Silos000.fls : Silos001.fls]

    Objective Function Value: 3.49283e-005 sq m

    Iterations: 13

    Overlap Point Count: 30866

    Overlap Error Statistics

      RMS: 0.0163338 m

      AVG: 0.00716276 m

      MIN: 1.79634e-006 m

      MAX: 0.0867739 m

    Overlap Center: (-2.009, 6.871, -0.555) m

    Error after global registration: 1.23096e-007 sq m

    Translation: (-1.707, 5.433, -0.139) m

    Rotation: (-0.0335, -0.0270, -0.9991):70.263 deg
```

```
(…)
Cloud/Mesh 36  [Silos019.fls : Silos021.fls]
    Objective Function Value: 3.33313e-005 sq m
    Iterations: 39
    Overlap Point Count: 8133
    Overlap Error Statistics
      RMS: 0.00965452 m
      AVG: 0.00536894 m
      MIN: 7.46591e-005 m
      MAX: 0.0604461 m
    Overlap Center: (-2.320, 0.013, 0.001) m
    Error after global registration: 6.39889e-006 sq m
    Translation: (-3.062, 2.483, 0.418) m
    Rotation: (-0.0073, -0.0118, -0.9999):-132.512 deg

ScanWorld Transformations
Silos000.fls
translation: (0.000, 0.000, 0.000) m
rotation: (0.0000, 1.0000, 0.0000):0.000 deg
(…)
Silos021.fls
translation: (9.259, 62.607, -3.906) m
rotation: (-0.0323, 0.0134, 0.9994):19.350 deg


Unused ControlSpace Objects : none
```

V. Photoscan Tutorial and control points

PhotoScan Process

Processing of images with PhotoScan includes the following main steps:

- Creating Chunk PhotoScan;

To create new chunk click on the Add Chunk toolbar button on the Workspace pane or select Add Chunk command from the Workspace context menu (available by right-clicking on the root element on the Workspace pane).

After the chunk is created you may make the next process. The models in the chunks are not linked with each other. The list of all the chunks created in the current project is displayed in the Workspace pane along with flags reflecting their status.

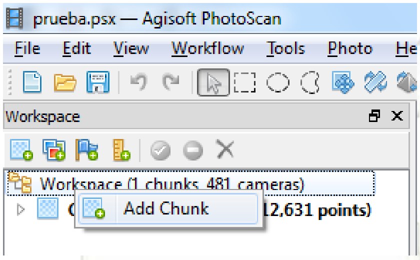


Figure 0.20. Add chunk

- loading photos into PhotoScan;

Before starting any operation it is necessary to point out what photos will be used as a source for 3D reconstruction. In fact, photographs themselves are not loaded into PhotoScan until they are needed. So, when you "load photos" you only indicate photographs that will be used for further processing. To load a set of photos:

1. Select Add Photos... command from the Workflow menu or click Add Photos toolbar button on the Workspace pane.
2. In the Add Photos dialog box browse to the folder containing the images and select files to be processed. Then click Open button.
3. 3. Selected photos will appear on the Workspace pane.

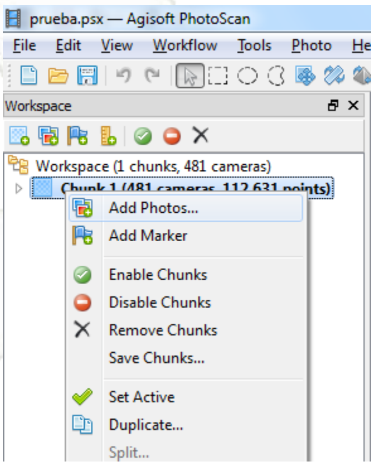


Figure 0.21. Add photos

- inspecting loaded images, removing unnecessary images;

Loaded photos are displayed on the Workspace pane along with flags reflecting their status.

Figure 0.22. Check photos

- aligning photos;

Once photos are loaded into PhotoScan, they need to be aligned. At this stage PhotoScan finds the camera position and orientation for each photo and builds a sparse point cloud model. To align a set of photos:

1. Select Align Photos... command from the Workflow menu.
2. In the Align Photos dialog box select the desired alignment options. Click OK button when done.
3. The progress dialog box will appear displaying the current processing status. To cancel processing click Cancel button.

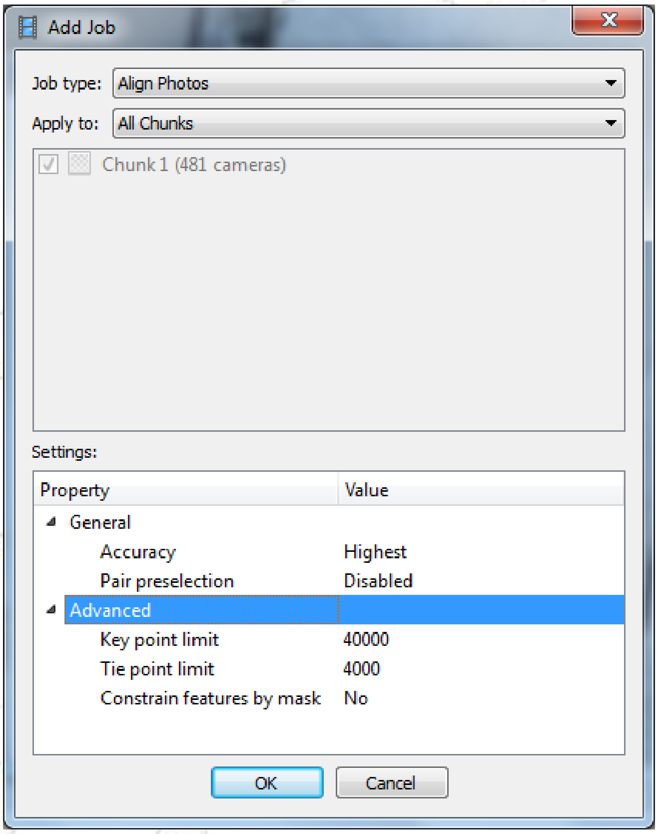


Figure 0.23. Align photos

Alignment having been completed, computed camera positions and a sparse point cloud will be displayed. You can inspect alignment results and remove incorrectly positioned photos, if any. To see the matches between any two photos use View Matches... command from a photo context menu in the Photos pane. Incorrectly positioned photos can be realigned.

- building dense point cloud;

PhotoScan allows to generate and visualize a dense point cloud model. Based on the estimated camera positions the program calculates depth information for each camera to be combined into a single dense point cloud. PhotoScan tends to produce extra dense point clouds, which are of almost the same density, if not denser, as LIDAR point clouds. A dense point cloud can be edited and classified within PhotoScan environment or exported to an external tool for further analysis. To build a dense point cloud:

1. Check the reconstruction volume bounding box. To adjust the bounding box use the Resize Region and Rotate Region toolbar buttons. Rotate the bounding box and then drag corners of the box to the desired positions.
2. Select the Build Dense Cloud... command from the Workflow menu.
3. In the Build Dense Cloud dialog box select the desired reconstruction parameters. Click OK button when done.
4. The progress dialog box will appear displaying the current processing status. To cancel processing click Cancel button.

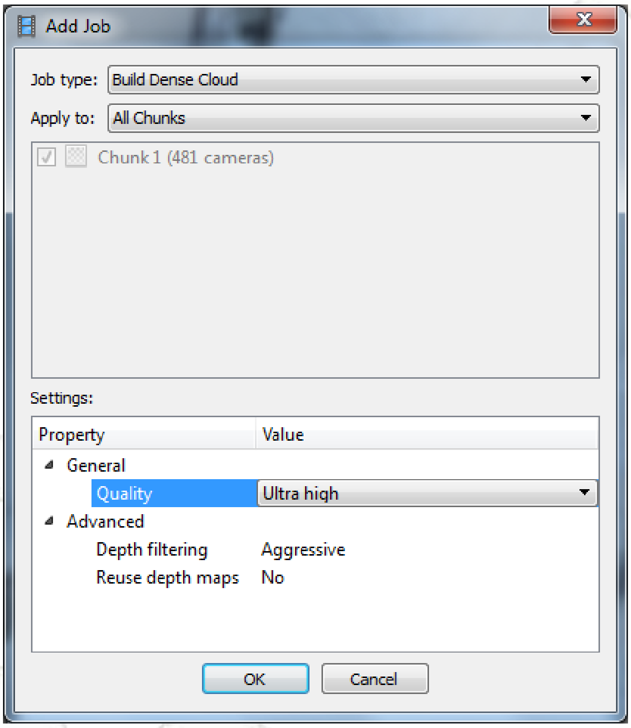


Figure 0.24. Buildin point cloud

- building mesh (3D polygonal model);

To build a mesh:

1. Check the reconstruction volume bounding box. If the model has already been referenced, the bounding box will be properly positioned automatically. Otherwise, it is important to control its position manually.
2. In the Build Mesh dialog box select the desired reconstruction parameters. Click OK button when done.
3. The progress dialog box will appear displaying the current processing status. To cancel processing click Cancel button.

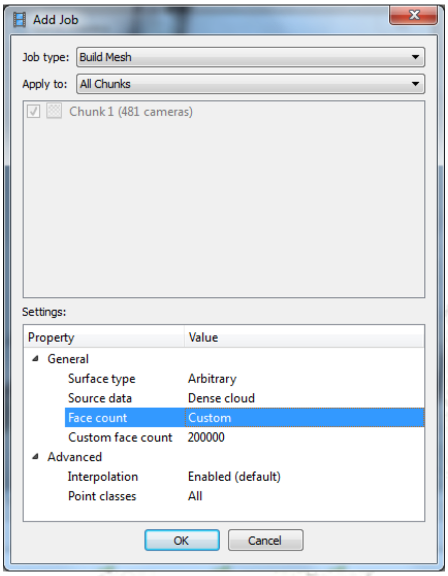


Figure 0.25. Building mesh

- generating texture;

To generate 3D model texture:

1. Select Build Texture... command from the Workflow menu.
2. Select the desired texture generation parameters in the Build Texture dialog box. Click OK button when done.
3. 3. The progress dialog box will appear displaying the current processing status. To cancel processing click Cancel button.

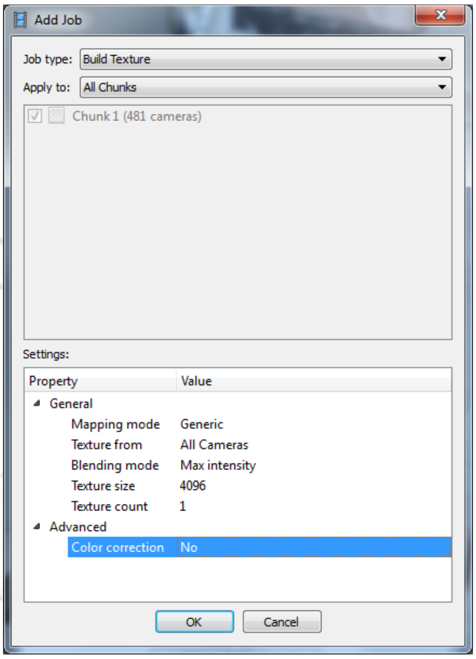


Figure 0.26. Generate texture

- building tiled model;

Hierarchical tiles format is a good solution for city scale modeling. It allows for responsive visualisation of large area 3D models in high resolution, a tiled model being opened with Agisoft Viewer - a complementary tool included in PhotoScan installer package.

Tiled model is build based on dense point cloud data. Hierarchical tiles are textured from the source imagery. To build a tiled model:

1. Check the reconstruction volume bounding box - tiled model will be generated for the area within bounding box only. To adjust the bounding box use the Resize Region and Rotate Region toolbar buttons. Rotate the bounding box and then drag corners of the box to the desired positions.
2. Select the Build Tiled Model... command from the Workflow menu.
3. In the Build Tiled model dialog box select the desired reconstruction parameters. Click OK button when done.
4. The progress dialog box will appear displaying the current processing status. To cancel processing click Cancel button.

- building digital elevation model;

PhotoScan allows to generate and visualize a digital elevation model (DEM). A DEM represents a surface model as a regular grid of height values. DEM can be rasterized from a dense point cloud, a sparse point cloud or a mesh. Most accurate results are calculated based on dense point cloud data. PhotoScan enables to perform DEM-based point, distance, area, volume measurements as well as generate cross-sections for a part of the scene selected by the user. Additionally, contour lines can be calculated for the model and depicted either over DEM or Orthomosaic in Ortho view within PhotoScan environment. More information on measurement functionality can be found in Performing measurements on DEM section. To build DEM:

1. Select the Build DEM... command from the Workflow menu.
2. In the Build DEM dialog box set Coordinate system for the DEM.
3. Select source data for DEM rasterization.
4. Click OK button when done.
5. The progress dialog box will appear displaying the current processing status. To cancel processing click Cancel button.

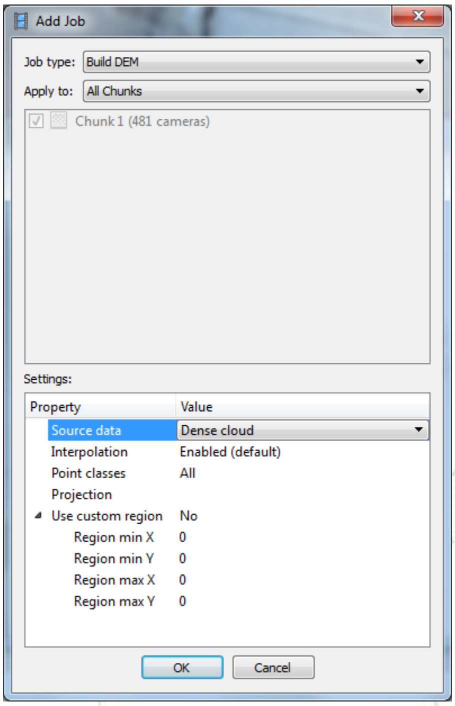


Figure 0.27. Building DEM

- building orthomosaic;

Orthomosaic export is normally used for generation of high resolution imagery based on the source photos and reconstructed model. The most common application is aerial photographic survey data processing, but it may be also useful when a detailed view of the object is required. PhotoScan enables to perform orthomosaic seamline editing for better visual results (see Orthomosaic seamlines editing section of the manual).

For multispectral imagery processing workflow Ortho view tab presents Raster Calculator tool for NDVI and other vegetation indices calculation to analyze crop problems and generate prescriptions for variable rate farming equipment. More information on NDVI calculation functionality can be found in Performing measurements on mesh section. To build Orthomosaic:

1. Select the Build Orthomosaic... command from the Workflow menu.
2. In the Build Orthomosaic dialog box set Coordinate system for the Orthomosaic referencing.
3. Select type of surface data for orthorectified imagery to be projected onto.
4. Click OK button when done.
5. The progress dialog box will appear displaying the current processing status. To cancel processing click Cancel button.

PhotoScan allows to project the orthomosaic onto a plane set by the user, providing that mesh is selected as a surface type. To generate orthomosaic in a planar projection choose Planar Projection Type in Build Orthomosaic dialog. You can select projection plane and orientation of the orthomosaic. PhotoScan provides an option to project the model to a plane determined by a set of markers (if there are no 3 markers in a desired projection plane it can be specified with 2 vectors, i. e. 4 markers). Planar projection type may be useful for orthomosaic generation in projects concerning facades or surfaces that are not described with Z(X,Y) function. To generate an orthomosaic in planar projection, preliminary generation of mesh data is required.

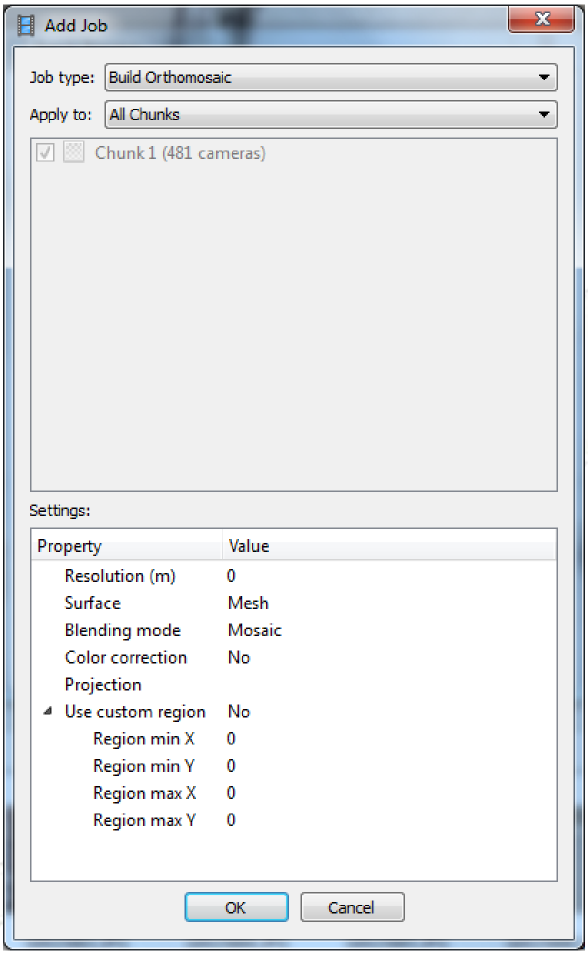


Figure 0.28. Building orthophoto

- exporting results.

PhotoScan supports export of processing results in various representations: sparse and dense point clouds, camera calibration and camera orientation data, mesh, etc. Orthomosaics and digital elevation models (both DSM and DTM), as well as tiled models can be generated according to the user requirements.

Point cloud and camera calibration data can be exported right after photo alignment is completed. All other export options are available after the corresponding processing step.

If you are going to export the results (point cloud / mesh / tiled model / orthomosaics) for the model that is not referenced, please note that the resulting file will be oriented according to a default coordinate system (see axes in the bottom right corner of the Model view), i. e. the model can be shown differently from what you see in PhotoScan window. To align the model orientation with the default coordinate system use Rotate object button from the Toolbar.

In some cases editing model geometry in the external software may be required. PhotoScan supports model export for editing in external software and then allows to import it back as it is described in the Editing model geometry section of the manual.

Main export commands are available from the File menu and the rest from the Export submenu of the Tools menu.

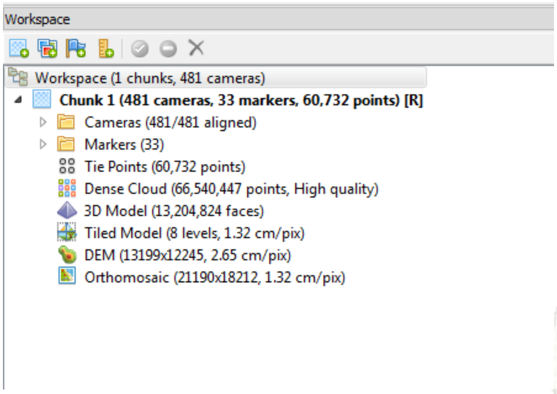


Figure 0.29. Show results

To export sparse or dense point cloud:

1. Select Export Points... command from the File menu.
2. Browse the destination folder, choose the file type, and print in the file name. Click Save button.
3. In the Export Points dialog box select desired Type of point cloud - Sparse or Dense.
4. Specify the coordinate system and indicate export parameters applicable to the selected file type, including the dense cloud classes to be saved.
5. Click OK button to start export.
6. The progress dialog box will appear displaying the current processing status. To cancel processing click Cancel button.

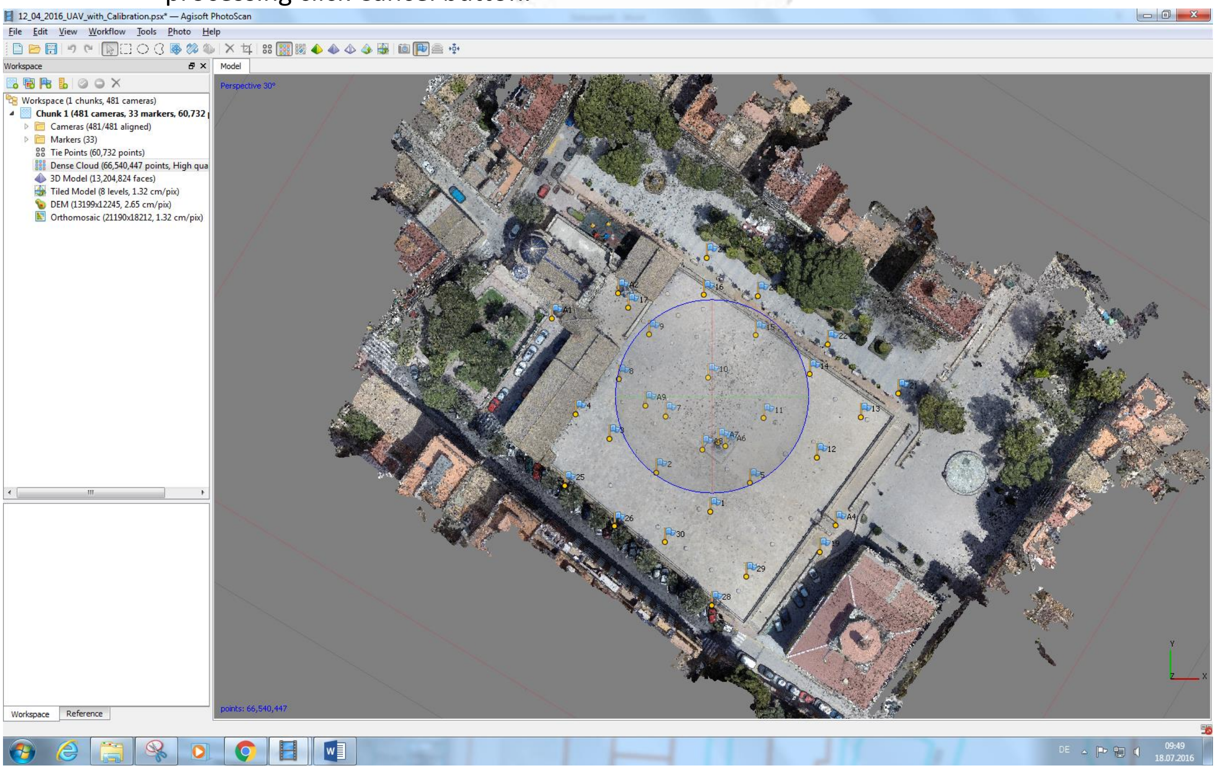


Figure 0.30. Point cloud

To export 3D model:

1. Select Export Model... command from the File menu.
2. Browse the destination folder, choose the file type, and print in the file name. Click Save button.
3. In the Export Model dialog specify the coordinate system and indicate export parameters applicable to the selected file type.
4. Click OK button to start export.
5. The progress dialog box will appear displaying the current processing status. To cancel processing click Cancel button.

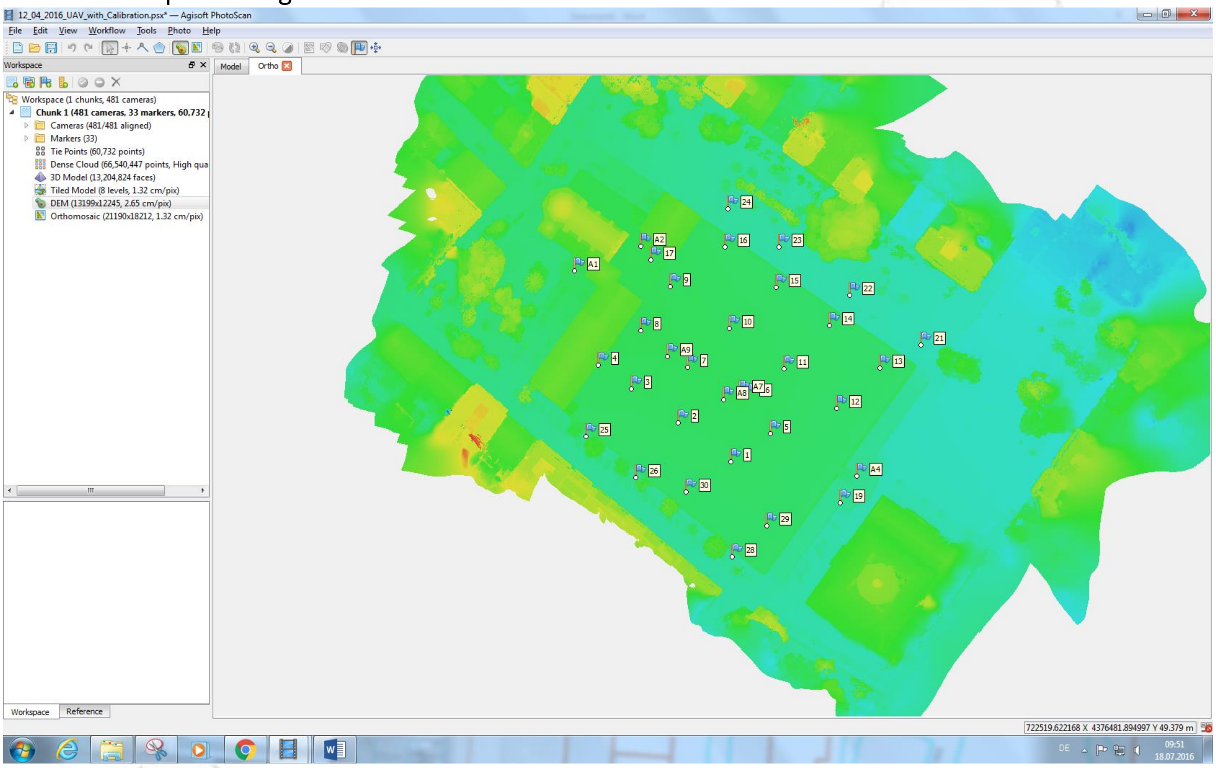


Figure 0.31. DEM

To export Orthomosaic:

1. Select Export Orthomosaic... command from the File menu.
2. In the Export Orthomosaic dialog box specify coordinate system for the Orthomosaic to be saved in.
3. Check Write KML file and / or Write World file options to create files needed to georeference the orthomosaic in the Google Earth and / or a GIS .
4. Click Export button to start export.
5. Browse the destination folder, choose the file type, and print in the file name. Click Save button.
6. The progress dialog box will appear displaying the current processing status. To cancel processing click Cancel button.

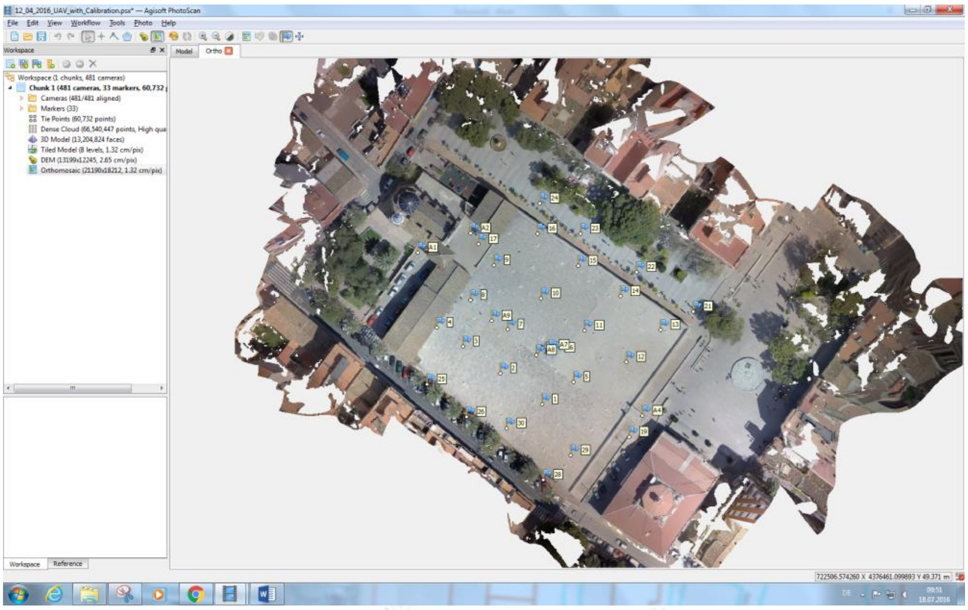


Figure 0.32. Ortophoto

If you are using PhotoScan in the full function (not the Demo) mode, intermediate results of the image processing can be saved at any stage in the form of project files and can be used later. The concept of projects and project files is briefly explained in the Saving intermediate results section.

The list above represents all the necessary steps involved in the construction of a textured 3D model , DEM and orthomosaic from your photos. Some additional tools, which you may find to be useful, are described in the successive chapters.

PhotoScan allows to perform general workflow operations with multiple chunks automatically. It is useful when dealing with a large number of chunks to be processed.

Batch processing can be applied to all chunks in the Workspace, to unprocessed chunks only, or to the chunks selected by the user. Each operation chosen in the Batch processing dialog will be applied to every selected chunk before processing will move on to the next step. To start batch processing:

1. Select Batch Process... command from the Workflow menu.

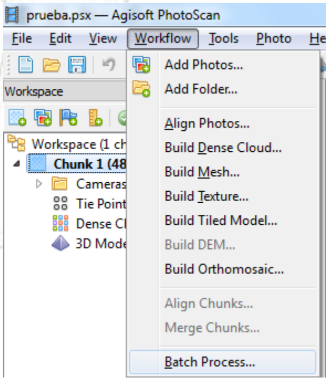


Figure 0.33. Create catch

2. Click Add to add the desired processing stages.
3. In the Add Job dialog select the kind of operation to be performed, the list of chunks it should be applied to, and desired processing parameters. Click OK button when done.

4. Repeat the previous steps to add other processing steps as required.
5. Arrange jobs by clicking Up and Down arrows at the right of the Batch Process... dialog box.
6. Click OK button to start processing.
7. 7. The progress dialog box will appear displaying the list and status of batch jobs and current operation progress. To cancel processing click the Cancel button.

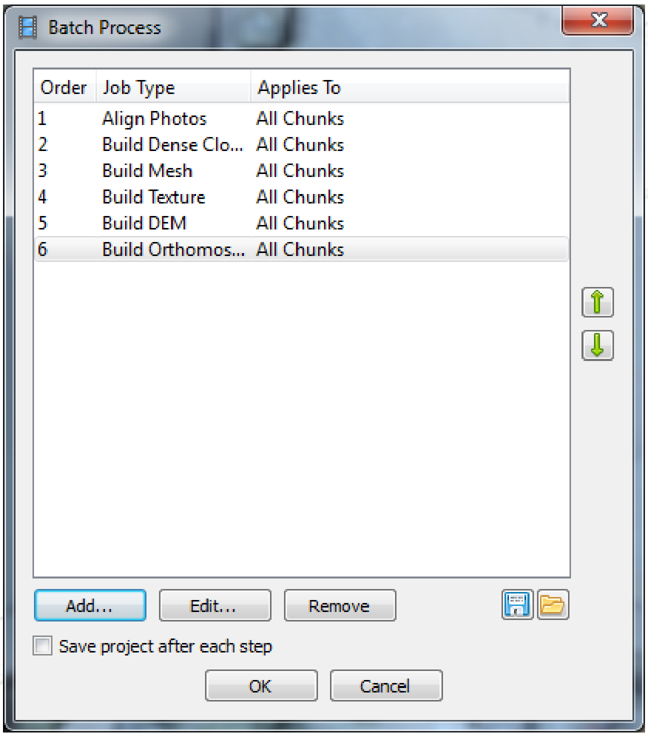


Figure 0.34. Batch

Control Points

Coordinate System: PROJCS["**ETRS89 / UTM zone 30N**",GEOGCS["ETRS89",**DATUM**["**European Terrestrial Reference System 1989**",SPHEROID["GRS 1980",6378137,298,257222101,AUTHORITY["EPSG","7019"]],TOWGS84[0,0,0,0,0,0,0],AUTHORITY["EPSG","6258"]],PRIMEM["Greenwich",0,AUTHORITY["EPSG","8901"]],UNIT["degree",0,01745329251994328,AUTHORITY["EPSG","9102"]],AUTHORITY["EPSG","4258"]],PROJECTION["Transverse_Mercator",AUTHORITY["EPSG","9807"]],PARAMETER["latitude_of_origin",0],PARAMETER["central_meridian",-3],PARAMETER["scale_factor",0,9996],PARAMETER["false_easting",500000],PARAMETER["false_northing",0],UNIT["metre",1,AUTHORITY["EPSG","9001"]],AUTHORITY["EPSG","25830"]]

Table 0.1. Photoscan control points

#Label	X/East	Y/North	Z/Altitude	Error_(m)	X_error	Y_error	Z_error	X_est	Y_est	Z_est
1	722514,706	4376448,88	49,0964	0,037762	0,008224	-0,032819	0,016769	722514,714	4376448,85	49,113169
10	722514,215	4376486,32	49,4235	0,116645	-0,022041	0,064982	0,094327	722514,193	4376486,39	49,517827
11	722529,733	4376475	49,2064	0,046512	-0,024574	-0,03463	-0,01898	722529,709	4376474,97	49,18742
12	722544,55	4376463,94	48,6608	0,046535	-0,020723	-0,036403	-0,02027	722544,529	4376463,9	48,64053
13	722556,88	4376475,29	48,5927	0,040898	-0,026998	-0,030606	0,002664	722556,853	4376475,26	48,595364
14	722542,589	4376487,22	48,777	0,026053	-0,0157	0,019962	0,005811	722542,573	4376487,23	48,782811
15	722527,442	4376498,13	48,8498	0,084348	-0,031225	0,076413	0,017338	722527,41	4376498,2	48,867138
16	722513,063	4376509,42	49,0854	0,109541	-0,049074	0,096778	0,015001	722513,014	4376509,52	49,100401
17	722491,952	4376505,78	50,303	0,049528	0,017878	0,012601	0,044436	722491,97	4376505,79	50,347436
19	722545,698	4376437,08	46,236	0,213997	0,00406	0,046846	-0,208767	722545,702	4376437,12	46,027233
2	722499,733	4376459,74	49,3159	0,03718	0,032643	-0,017745	-0,001396	722499,766	4376459,72	49,314504
21	722568,368	4376481,89	43,086	0,040998	-0,019416	-0,021398	-0,029086	722568,349	4376481,87	43,056914
22	722548,176	4376495,79	43,735	0,066566	-0,01037	0,058525	-0,029973	722548,166	4376495,85	43,705027
23	722528,343	4376509,41	44,446	0,143301	-0,036103	0,135813	-0,028045	722528,307	4376509,54	44,417955
24	722513,861	4376520,2	44,978	0,150017	-0,044833	0,133235	0,05238	722513,816	4376520,33	45,03038
29	722524,873	4376430,55	48,6164	0,024805	-0,009284	-0,0048	0,022496	722524,863	4376430,55	48,638896
3	722486,563	4376469,27	49,4791	0,086557	0,06223	0,018612	-0,057212	722486,625	4376469,29	49,421888
30	722502,077	4376440,29	48,7248	0,057242	0,049707	-0,016084	-0,023392	722502,126	4376440,27	48,701408
4	722477,138	4376476,07	49,57	0,149859	0,135772	0,029825	-0,055982	722477,274	4376476,1	49,514018
5	722525,82	4376456,8	49,154	0,047378	-0,035069	-0,031699	0,003164	722525,785	4376456,76	49,157164
7	722502,323	4376475,4	49,8282	0,044758	0,024049	0,032705	-0,01885	722502,347	4376475,44	49,80935
8	722489,177	4376485,81	50,0781	0,049174	0,015081	0,044741	0,013744	722489,192	4376485,86	50,091844

9	722497,587	4376498,49	49,7409	0,161995	-0,009723	-0,150499	0,059142	722497,577	4376498,34	49,800042
A1	722470,474	4376502,83	49,533							
A2	722489,087	4376509,78	50,517							
A4	722550,219	4376444,74	45,971							
A6	722519,048	4376467,11	50,229							
A7	722517,069	4376468,2	50,547							
A8	722512,609	4376466,27	49,772							
A9	722496,739	4376478,55	49,925							
25								722473,77	4376455,94	46,049131
26								722487,718	4376444,37	45,582683
28								722515,096	4376421,89	44,798188
point 1								722500,049	4376438,27	48,61239
point 2								722484,503	4376543,76	46,250401
point 3								722553,988	4376440,22	45,673871
point 4								722527,128	4376402,55	43,45034
point 5								722443,422	4376469,52	53,588846
point 6								722475,637	4376500,58	49,959967
uav7								722463,335	4376511,89	47,879584
uav1								722565,052	4376454,38	42,632153
uav2								722551,203	4376443,75	45,788013
uav3								722542,971	4376449,12	48,456995
uav4								722532,34	4376409,65	43,930886
uav5								722517,174	4376463,58	50,06122
uav6								722469,682	4376453,39	45,962194
uav8								722456,183	4376531,94	47,706862
uav9								722469,98	4376500,54	49,482826
uav10								722479,525	4376530,69	48,253824
uav11								722497,397	4376527,68	45,648438
uav12								722567,297	4376475,73	49,338535
# Total error				0,047593	0,026076	0,036236	0,016496			

Note: This table is obtained directly from Photoscan.

VI. Matlab code

```
function [R,T,Yf,dY,Err,Euler,Euler_gon] = rot3dfit(X,Y)
%ROT3DFIT Determine least-square rigid rotation and translation.
% [R,T,Yf] = ROT3DFIT(X,Y) permforms a least-square fit for the
% linear form
%
% Y = X*R + T
%
% where R is a 3 x 3 orthogonal rotation matrix, T is a 1 x 3
% translation vector, and X and Y are 3D points sets defined as
% N x 3 matrices. Yf is the best-fit matrix.
%
% See also SVD, NORM.
%
% rot3dfit: Frank Evans, NHLBI/NIH, 30 November 2001
%

% ROT3DFIT uses the method described by K. S. Arun, T. S. Huang, and
% S. D. Blostein, "Least-Squares Fitting of Two 3-D Point Sets",
% IEEE Transactions on Pattern Analysis and Machine Intelligence,
% PAMI-9(5): 698 - 700, 1987.
%
% A better theoretical development is found in B. K. P. Horn,
% H. M. Hilden, and S. Negahdaripour, "Closed-form solution of
% absolute orientation using orthonormal matrices", Journal of the
% Optical Society of America A, 5(7): 1127 - 1135, 1988.
%
% Special cases, e.g. colinear and coplanar points, are not
% implemented.

    error(nargchk(2,2,nargin));
    if size(X,2) ~= 3, error('X must be N x 3'); end;
    if size(Y,2) ~= 3, error('Y must be N x 3'); end;
    if size(X,1) ~= size(Y,1), error('X and Y must be the same size'); end;

    % mean correct

    Xm = mean(X,1);
    X1 = X - ones(size(X,1),1)*Xm;
    Ym = mean(Y,1);
    Y1 = Y - ones(size(Y,1),1)*Ym;

    % calculate best rotation using algorithm 12.4.1 from
    % G. H. Golub and C. F. van Loan, "Matrix Computations"
    % 2nd Edition, Baltimore: Johns Hopkins, 1989, p. 582.

    XtY = (X1')*Y1;
    [U,S,V] = svd(XtY);
    R = U*(V');

    %Euler angles

    Euler=[atan2(R(2,3),R(3,3)) atan2(-R(1,3),sqrt(R(2,3)^2+R(3,3)^2)) atan2(R(1,2),R(1,1))];
    Euler_gon=Euler*180/pi;

    % solve for the translation vector

    T = Ym - Xm*R;

    % calculate fit points

    Yf = X*R + ones(size(X,1),1)*T;

    % calculate the error

    dY = Y - Yf;
    Err = norm(dY,'fro'); % must use Frobenius norm
```

VII. Python code

Imports | pruebaobj | objloader | AIM120D.mtl | Silo1.mtl

```python
# Basic OBJ file viewer. needs objloader from:
#  http://www.pygame.org/wiki/OBJFileLoader
# LMB + move: rotate
# RMB + move: pan
# Scroll wheel: zoom in/out
import sys, pygame
from pygame.locals import *
from pygame.constants import *
from OpenGL.GL import *
from OpenGL.GLU import *

# IMPORT OBJECT LOADER
from objloader import *

pygame.init()
viewport = (800,600)
hx = viewport[0]/2
hy = viewport[1]/2
srf = pygame.display.set_mode(viewport, OPENGL | DOUBLEBUF)

glLightfv(GL_LIGHT0, GL_POSITION,  (-40, 200, 100, 0.0))
glLightfv(GL_LIGHT0, GL_AMBIENT, (0.2, 0.2, 0.2, 1.0))
glLightfv(GL_LIGHT0, GL_DIFFUSE, (0.5, 0.5, 0.5, 1.0))
glEnable(GL_LIGHT0)
glEnable(GL_LIGHTING)
glEnable(GL_COLOR_MATERIAL)
glEnable(GL_DEPTH_TEST)
glShadeModel(GL_SMOOTH)           # most obj files expect to be smooth-shaded

# LOAD OBJECT AFTER PYGAME INIT
#obj = OBJ(sys.argv[1], swapyz=True)
obj = OBJ("SketchUp.obj", swapyz=True)
clock = pygame.time.Clock()

glMatrixMode(GL_PROJECTION)
glLoadIdentity()
width, height = viewport
gluPerspective(90.0, width/float(height), 1, 100.0)
glEnable(GL_DEPTH_TEST)
glMatrixMode(GL_MODELVIEW)

rx, ry = (0,0)
tx, ty = (0,0)
zpos = 5
rotate = move = False
while 1:
    clock.tick(30)
    for e in pygame.event.get():
        if e.type == QUIT:
            sys.exit()
        elif e.type == KEYDOWN and e.key == K_ESCAPE:
            sys.exit()
        elif e.type == MOUSEBUTTONDOWN:
            if e.button == 4: zpos = max(1, zpos-1)
            elif e.button == 5: zpos += 1
            elif e.button == 1: rotate = True
            elif e.button == 3: move = True
        elif e.type == MOUSEBUTTONUP:
            if e.button == 1: rotate = False
            elif e.button == 3: move = False
        elif e.type == MOUSEMOTION:
            i, j = e.rel
            if rotate:
                rx += i
                ry += j
            if move:
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT)
    glLoadIdentity()

    # RENDER OBJECT
    glTranslate(tx/20., ty/20., - zpos)
    glRotate(ry, 1, 0, 0)
    glRotate(rx, 0, 1, 0)
    glCallList(obj.gl_list)

    pygame.display.flip()
```

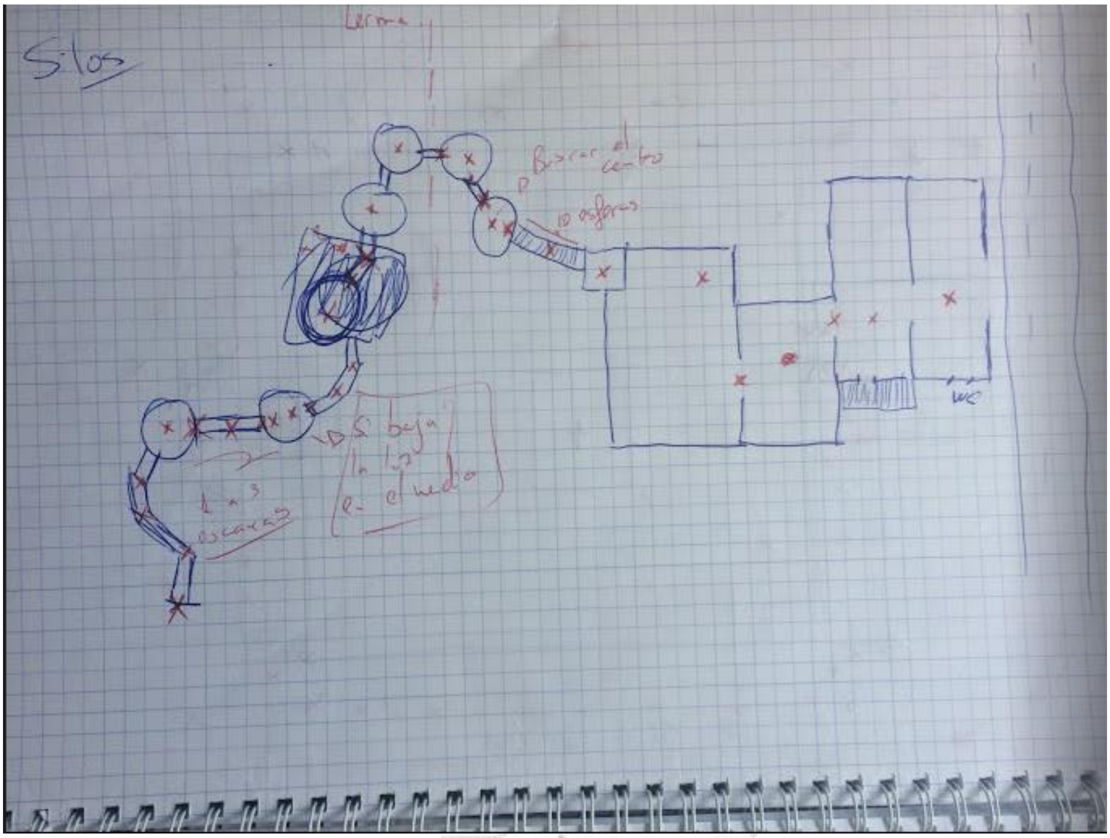
Imports | pruebaobj | objloader | AIM120D.mtl | Silo1.mtl

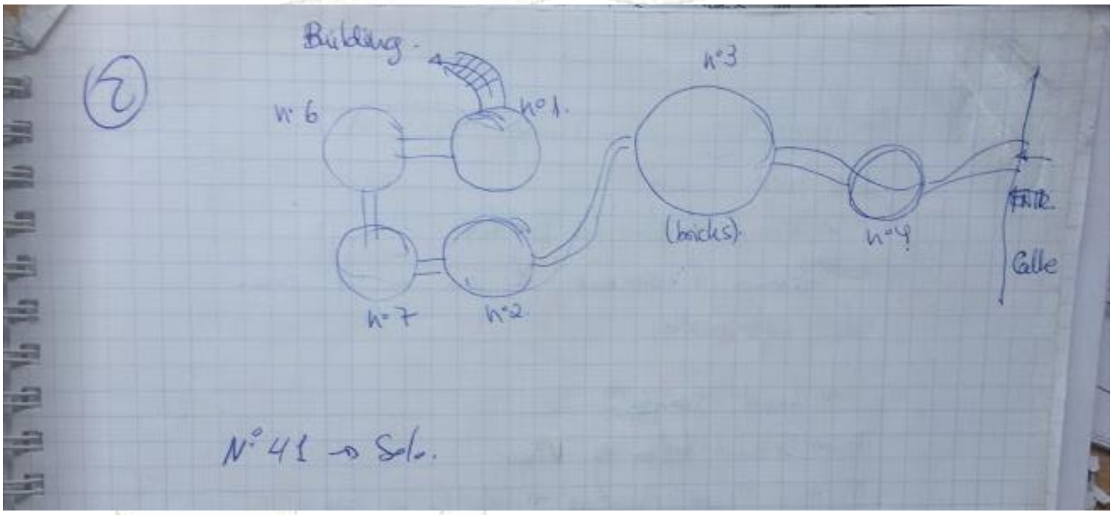
```python
import pygame
from OpenGL.GL import *

def MTL(filename):
    contents = {}
    mtl = None
    for line in open(filename, "r"):
        if line.startswith('#'): continue
        values = line.split()
        if not values: continue
        if values[0] == 'newmtl':
            mtl = contents[values[1]] = {}
        elif mtl is None:
            raise ValueError, "mtl file doesn't start with newmtl stmt"
        elif values[0] == 'map_Kd':
            # load the texture referred to by this declaration
            mtl[values[0]] = values[1]
            surf = pygame.image.load(mtl['map_Kd'])
            image = pygame.image.tostring(surf, 'RGBA', 1)
            ix, iy = surf.get_rect().size
            texid = mtl['texture_Kd'] = glGenTextures(1)
            glBindTexture(GL_TEXTURE_2D, texid)
            glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER,
                GL_LINEAR)
            glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER,
                GL_LINEAR)
            glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA, ix, iy, 0, GL_RGBA,
                GL_UNSIGNED_BYTE, image)
        else:
            mtl[values[0]] = map(float, values[1:])
    return contents
    def __init__(self, filename, swapyz=False):
        """Loads a Wavefront OBJ file. """
        self.vertices = []
        self.normals = []
        self.texcoords = []
        self.faces = []

        material = None
        for line in open(filename, "r"):
            if line.startswith('#'): continue
            values = line.split()
            if not values: continue
            if values[0] == 'v':
                v = map(float, values[1:4])
                if swapyz:
                    v = v[0], v[2], v[1]
                self.vertices.append(v)
            elif values[0] == 'vn':
                v = map(float, values[1:4])
                if swapyz:
                    v = v[0], v[2], v[1]
                self.normals.append(v)
            elif values[0] == 'vt':
                self.texcoords.append(map(float, values[1:3]))
            elif values[0] in ('usemtl', 'usemat'):
                material = values[1]
            elif values[0] == 'mtllib':
                self.mtl = MTL(values[1])
            elif values[0] == 'f':
                face = []
                texcoords = []
                norms = []
                for v in values[1:]:
                    w = v.split('/')
                    face.append(int(w[0]))
                    if len(w) >= 2 and len(w[1]) > 0:
```

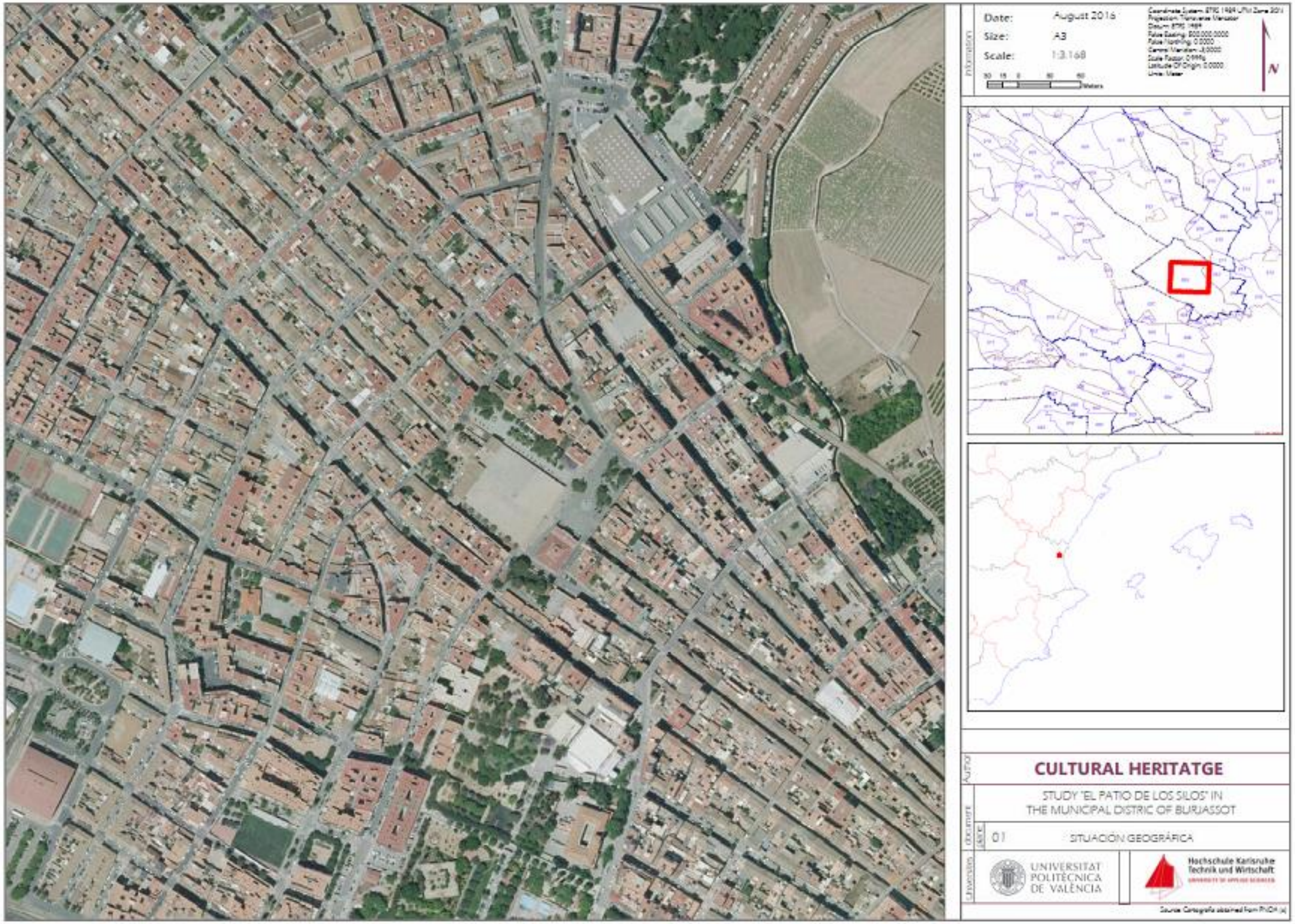
```
            w = v.split('/')
            face.append(int(w[0]))
            if len(w) >= 2 and len(w[1]) > 0:
                texcoords.append(int(w[1]))
            else:
                texcoords.append(0)
            if len(w) >= 3 and len(w[2]) > 0:
                norms.append(int(w[2]))
            else:
                norms.append(0)
        self.faces.append((face, norms, texcoords, material))

self.gl_list = glGenLists(1)
glNewList(self.gl_list, GL_COMPILE)
glEnable(GL_TEXTURE_2D)
glFrontFace(GL_CCW)
for face in self.faces:
    vertices, normals, texture_coords, material = face

    mtl = self.mtl[material]
    if 'texture_Kd' in mtl:
        # use diffuse texmap
        glBindTexture(GL_TEXTURE_2D, mtl['texture_Kd'])
    else:
        # just use diffuse colour
        glColor(*mtl['Kd'])

    glBegin(GL_POLYGON)
    for i in range(len(vertices)):
        if normals[i] > 0:
            glNormal3fv(self.normals[normals[i] - 1])
        if texture_coords[i] > 0:
            glTexCoord2fv(self.texcoords[texture_coords[i] - 1])
        glVertex3fv(self.vertices[vertices[i] - 1])
    glEnd()
glDisable(GL_TEXTURE_2D)
glEndList()
```

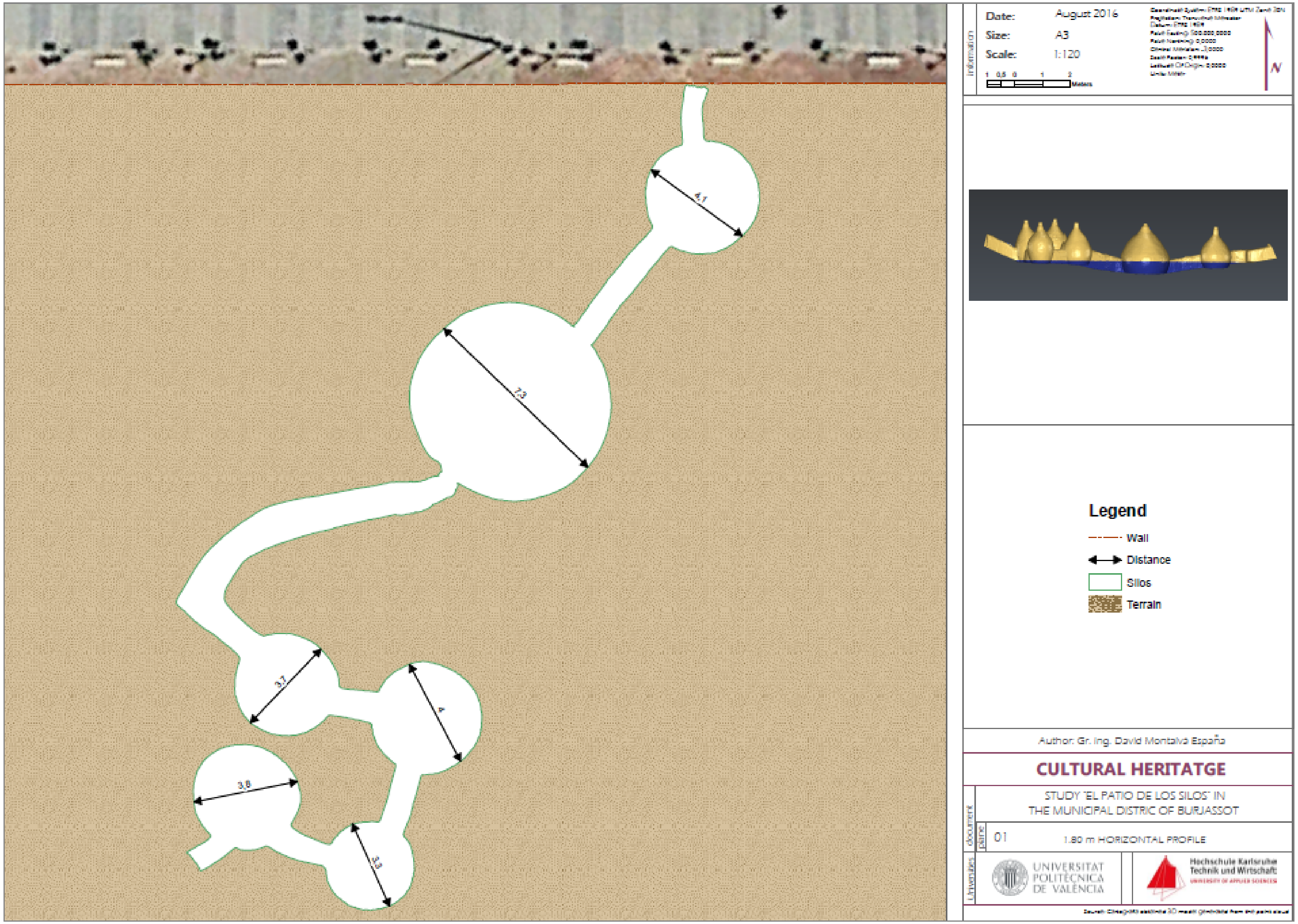
Appendix II: Maps

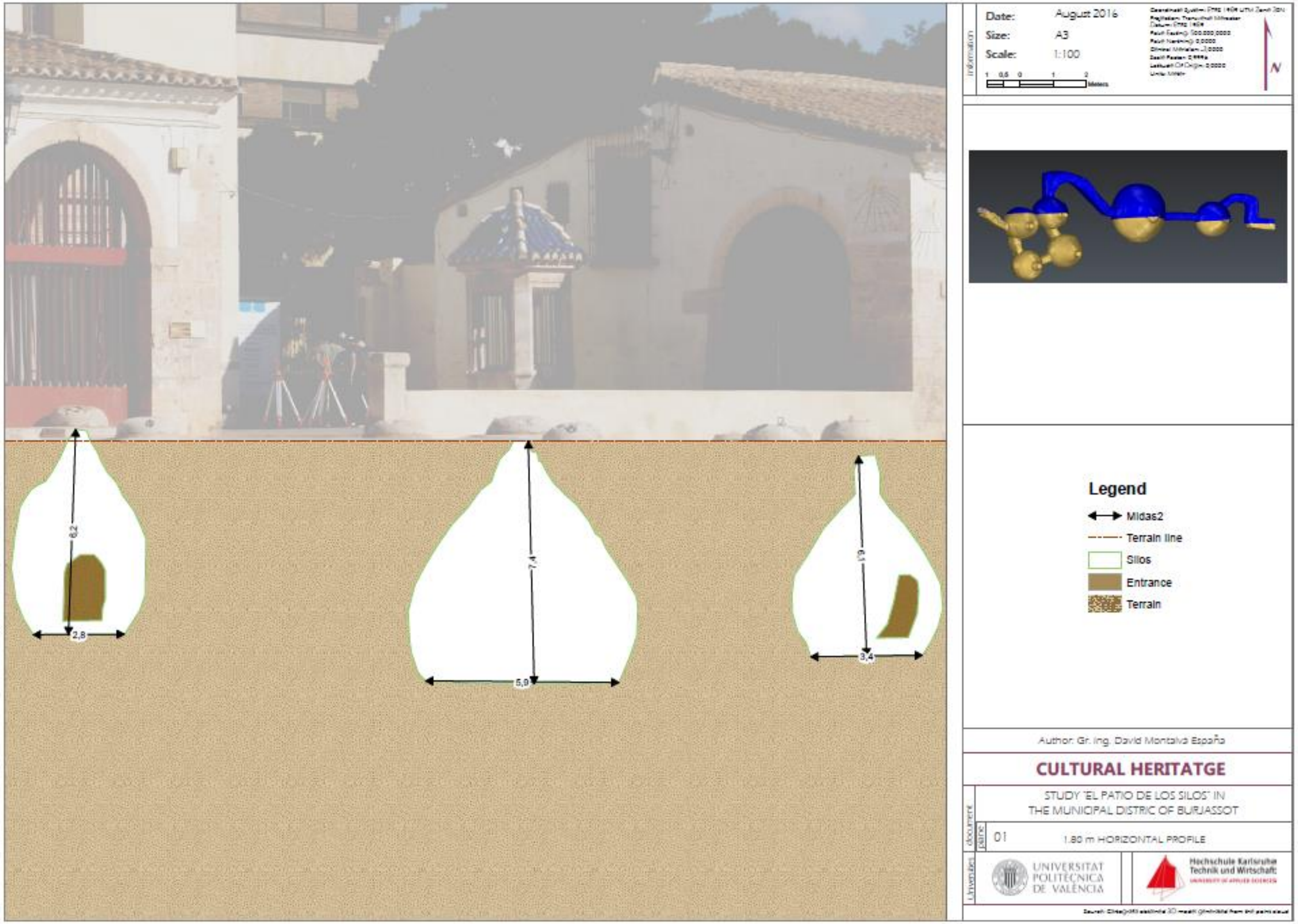
- Place the scans outside
- Place the scans inside
- Geographic information
- Horizontal profile
- Vertical profile


Silos
wc


Building
n°6
n°1
n°3
(bricks)
n°4
n°7
n°2
Calle


Date:
August 2016
Size:
A3
Scale:
1:3.168
Meters
N
CULTURAL HERITATGE
STUDY "EL PATIO DE LOS SILOS" IN
THE MUNICIPAL DISTRIC OF BURJASSOT
01
SITUACIÓN GEOGRÁFICA
UNIVERSITAT POLITÈCNICA DE VALÈNCIA
Hochschule Karlsruhe Technik und Wirtschaft


Information
Date: August 2016
Size: A3
Scale: 1:120
1 0,5 0 1 2
Meters
N
4,1
7,3
3,7
4
3,8
3,3
Legend
Wall
Distance
Silos
Terrain
Author: Gr. Ing. David Montalvá España
CULTURAL HERITATGE
document
STUDY "EL PATIO DE LOS SILOS" IN
THE MUNICIPAL DISTRIC OF BURJASSOT
plane
01
1.80 m HORIZONTAL PROFILE
Universities
UNIVERSITAT POLITÈCNICA DE VALÈNCIA
Hochschule Karlsruhe Technik und Wirtschaft


6,2
2,8
7,4
5,9
6,1
3,4
information
Date: August 2016
Size: A3
Scale: 1:100
1 0,5 0 1 2
Meters
N
Legend
Midas2
Terrain line
Silos
Entrance
Terrain
Author: Gr. Ing. David Montalva España
CULTURAL HERITATGE
document
STUDY "EL PATIO DE LOS SILOS" IN
THE MUNICIPAL DISTRIC OF BURJASSOT
plane
01
1.80 m HORIZONTAL PROFILE
Universities
UNIVERSITAT POLITÈCNICA DE VALÈNCIA
Hochschule Karlsruhe
Technik und Wirtschaft

7. References

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Responsibility for cultural heritage through Geomatics

Tri-national Cultural Heritage Documentation in Burjassot, Spain (2015-2016)

The Silos of Burjassot are a Spanish national monu-ment in the area of Valencia. Three universities, Universidad Politecnica de Valencia, Aristoteles University Thessaloniki and Hochschule Karlsruhe worked together with funding from the Landes-stiftung Baden-Württemberg to apply several geodetic methods, like geodetic network measure-ment, terrestrial and UAV photogrammetry, thermo-graphy and GPR to obtain a 3d model of the silos and their surroundings in Burjassot.

TLS viewer (left) and Bird's-eye view (rigth)

The measurement and the processing of the data have been split between several students of the above mentioned universities.

During the campaign performed in Burjassot from April 11th to 15th different task were realized as: laser scanning, thermography, photogrammetry and ground penetration radar.

Data Collection

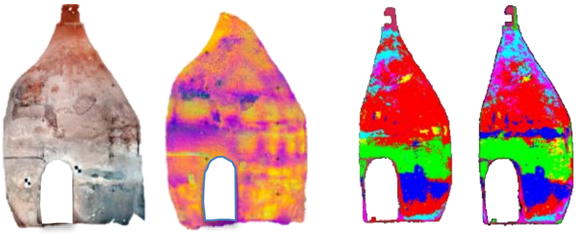
APK: HSKA Flir One App 1.0. (Android)

In this project the laser scanner used was the Faro X130, performing 70 scans during one day of campaign. The thermography was done with two different cameras, Flir Thermacam B4 and Flir One. 200 photos per silo were taken using the Flir Thermacam B4. 100 photos per silo were taken using the Flir One, in the visible and thermal spectrum at the same time using the HSKA Flir One App created for it.

Workflow

After data collection, the points cloud were regis-tered and georeferenced, creating a 3D model of the Silo-Yard. In addition, different 3D models of the silos were created from multispectral imagery (Figures a and b).

A classification software was created in order to obtain the different materials found inside the silos, using visible and thermal images. The image classification was done with the algorithms maxi-mum likelihood and K nearest neighbors (Figures c and d).



a b c d

Visible orthophoto (a), thermal orthophoto (b), maximum likelihood classification (c) and K nearest neighbors classification (d) of the silo 3.

Results

To visualize the point cloud a TLS web viewer was created. Besides, the models created were visuali-zed with Unity game engine to freely view different parts of the Silos of Burjassot.

Composition of orthophoto (top left), point cloud (top right), 3D print (bottom left) and RGB point cloud (bottom right).

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