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Departamento Ingeniería Gráfica, Diseño y Proyectos.
Departamento Cartográfica, Geodésica y Fotogrametría

<u>Trabajo Fin de Grado</u>

3D MODEL OF THE TOWER OF BENZALÁ (TORREDONJIMENO, JAEN)

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Summary

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Resumen

El progreso continuo de la tecnología, especialmente en topografía, ha llevado a su adopción generalizada en varios campos, incluida la arqueología.

En este Trabajo de Fin de Grado, nuestro objetivo es producir una representación digital tridimensional de un sitio arqueológico utilizando tecnología de escaneo láser terrestre. Esta técnica nos permite obtener escaneos precisos y detallados del terreno, lo que nos permitirá crear un modelo 3D de la Torre Benzalá que puede ser utilizado para la conservación del patrimonio cultural y la documentación del lugar.

Palabras Clave: Arqueología, Escaneo Láser Terrestre, 3D, Patrimonio

Abstract

The continuous progress of the technology, especially in surveying have led to its widespread adoption in various fields, including archaeology.

In this Final Degree Project, we aim to produce a three-dimensional digital representation of an archaeological site using terrestrial laser scanning technology. This technique allows us to obtain precise and detailed scans of the terrain, which will allow us to create a 3D model of the Tower Benzalá that can be used for the preservation of the cultural heritage and documentation of the site.

Key Words: Archeology, Terrestrial Laser Scanning, 3D, Heritage, BIM. Photogrametry.

CHAPTER I. General Introduction

1.1. Introduction

Today, it is clear that cultural heritage is suffering serious consequences due to its deterioration. For their conservation, enhancement and dissemination, it must be said that the archaeological sites and vestiges of all past eras are not to be neglected.

With their complex geometries, heritage sites are typically difficult and time-consuming to digitize using traditional techniques. Scanner technologies have become increasingly important in recent years for surveying and presenting historical assets: Terrestrial laser scanning (TLS) provides a measurement technique that can acquire millimeter-level of detail from the surrounding area, which allows rapid, automatic and periodical estimates.

Having a practical and structured Building Information Modeling (BIM) approach is crucial to creating a reliable model that can provide advantages and incorporate preservation and restoration work.

The tower of Benzalá in Jaen, Spain, serves as a case study to demonstrate our findings. The paper first describes the history of the tower. The scanning campaign is then described in detail and is intended to produce a BIM result, including the data's alignment, cleaning, and merging processes. Based on the point cloud data, the BIM modeling phase is then described.

1.2. Objectives

The main objective of this graduation project is to create a three-dimensional (3D) model of Tower of Benzalá, so that its volumes, construction systems and materials, as well as its current state of conservation, can be determined in subsequent analyses.

It is in the context of creating digital models of existing archaeological sites. The problematic of the project is to create an approach allowing to automate the passage from the point cloud to the digital model. This problem leads us to develop a chain of treatments to automatically extract the maximum amount of information from the point cloud in order to integrate the result in a BIM software.

An efficient processing chain allows to automatically extract the maximum of information from the point cloud of a building information in order to integrate the result in a BIM SOFTWARE.

1.3. Methodology

A work method is a procedure to follow in order to succeed, or, if you look at the work from another angle, it is the approach to a problem.

To carry out this work, we used a methodology that consists in a first step the description of the scanning mission, the collection of data was done by a field work using the faro 3D X 130.

The second step consisted in carrying out a sequence of data processing and to realize this automatic procedure, the following software was used. Faro scene, a closed source software, which processes digital scans and allows to create a dense point cloud.

The third step was to transform the point cloud on a BIM software, the following software was used, Revit, this program provides a set of tools for the creation of three-dimensional contents in general.

This activity diagram highlights the main tasks and manipulations that will be performed to create a point cloud that will be performed to create a 3D model.

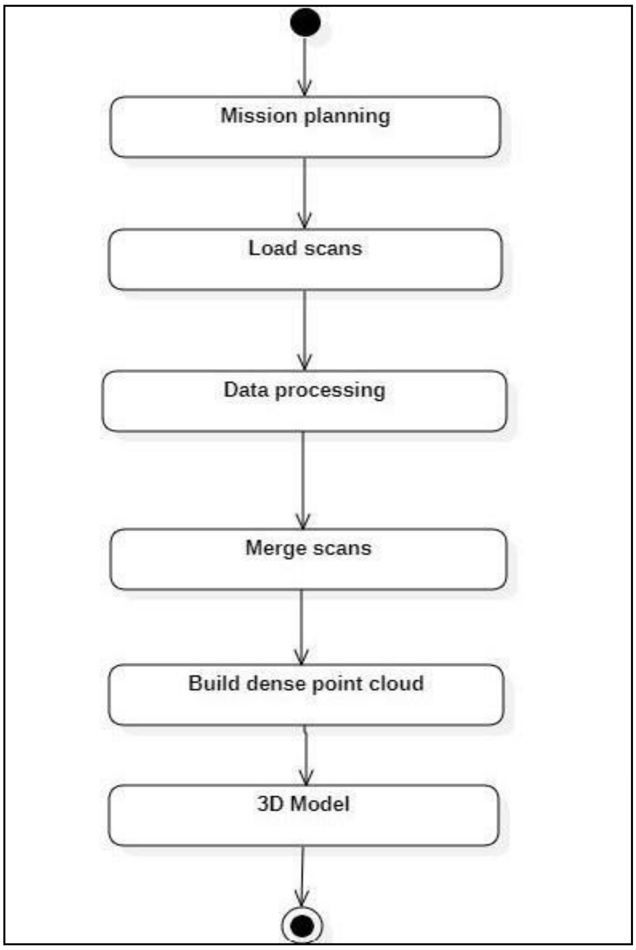


Figure 1: Activity diagram of the adopted methodology

1.4. Contexts of Tower Benzalá

1.4.1. The geographical framework of the study area

The tower of of Benzalá in southern Spain is the subject of our study. The tower in question is located in the area of Aldea Las Casas, about 10 kilometers from the city of Torredonjimeno on the road to Santiago de Calatrava, in the province of Jaén, is located at the top of the Ben-Zala hill, at an altitude of 544 meters.

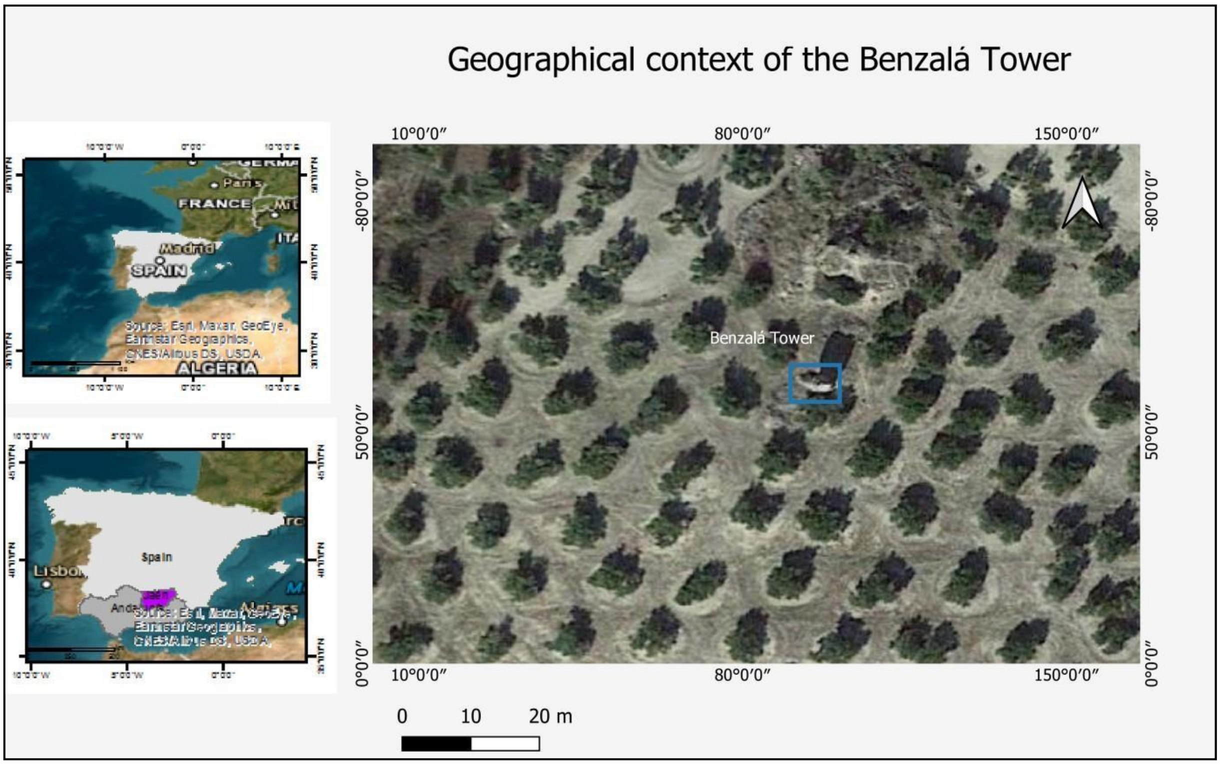


Figure 2: Geographical context of Benzalá Tower

1.4.2. History of the Tower of Benzalá

The complex history of medieval Spain saw the emergence of three personalities, as Christian and Islamic kingdoms vie for power and territory, King Ferdinand III, also known as Ferdinand III of Castile, was a Christian monarch who ruled the Kingdom of Castile from 1217 until his death in 1252.

Ibn al-Ahmar, also known as Muhammad I, was the founder and first sultan of the Nasrid dynasty, which ruled the Emirate of Granada from 1238 until 1492. In 1232, Ibn al-Ahmar was the sultan of Arjona, a town in the province of Jaén, but he was forced to flee after he was defeated by Ferdinand III. He then founded the Emirate of Granada, which he ruled for the rest of his life.

Ibn Hud was the Emir of the Taifa of Murcia from 1228 until 1238. He was a skilled military commander and was able to resist several Christian attempts to conquer his territory. However, in 1238, Ferdinand III launched a successful campaign against the Taifa of Murcia, and Ibn Hud was forced to surrender.

It is easy to understand that, due to the typical fluctuations of territorial conquest, Jaén became a frontier region of conflict between Christians and Muslims. They fought for control of space and farms, which meant that both sides comprehensively fortified their lines by building new forces or strengthening existing ones.

Historical studies indicate that the Tower Benzalá was built between 1242 and 1246, With the definition of the new frontier, after the last expansionist phase and following the expiration of the truces signed by Fernando III, Ibn al-Ahmar, and Ibn Hud, the Castilian monarch planned the conquest of that part of the Jiennese countryside that still remained under Islamic rule, and especially its main urban centers (Arjona and Jaén).

To prevent this, the Muslims built various fortifications in the areas of influence of the main population centers. For this purpose, castles were built such as El Berrueco, Torredelcampo, Fuentetetar, El Término, Torrebenzalá, and so on.

For their part, the Christians, who had undertaken the consolidation of the dominated territories, built other fortresses sometimes ex novo, and sometimes extensively transformed those built during Islamic rule. Examples of these constructions include some built in the domains of the Order of Calatrava, such as Torre de Fuencubierta, Torre Alcázar, Higuera de Calatrava, the Castle of Víboras, Torredonjimeno, Porcuna, and Lopera... [1]

In the 8th century, the location fell under Muslim control and later to the Order of Calatrava, who, according to José López Murillo and Gabriel Ureña Portero in "Tierra de castillos, tierra para soñar" rebuilt the defensive complex that the Arabs had erected in the first third of the 12th century "when the Arab castles of Yayyan (Jaén) and Aryuna (Arjona) realized the danger posed by Fernando III's control of Tuss (Martos)." The castle walls remained standing in the 17th century, according to the testimony of the historian Martín Ximena Jurado recorded in his work "Antigüedades del reino de Jaén" published in 1639. The looting it has suffered over the years has contributed to accelerating its deterioration. [2]

Ximena Jurado (1639) documents and describes the situation of the fortification of Tower Benzalá at that time by means of text and freehand drawing [3], from which it can be deduced that the place was uninhabited, although a large part of the fortification was still standing, describing a triangular plan with a crenellated walled enclosure and towers at the corners, a circular one (the one at the right in the Fig.3) that sheltered the entrance and another square one (which is still preserved).

In short, there were three towers. The largest in the drawing would be in the center of the fortification as drawn by Ximena Jurado. (In the back corner, which is not visible in the drawing, there would be no tower, as it is an area with greater height, due to the orography and easy defense from the walls). The third circular tower, on the right side of the drawing, does not exist today, but there are some remains of its foundations under a nearby olive tree.[4]

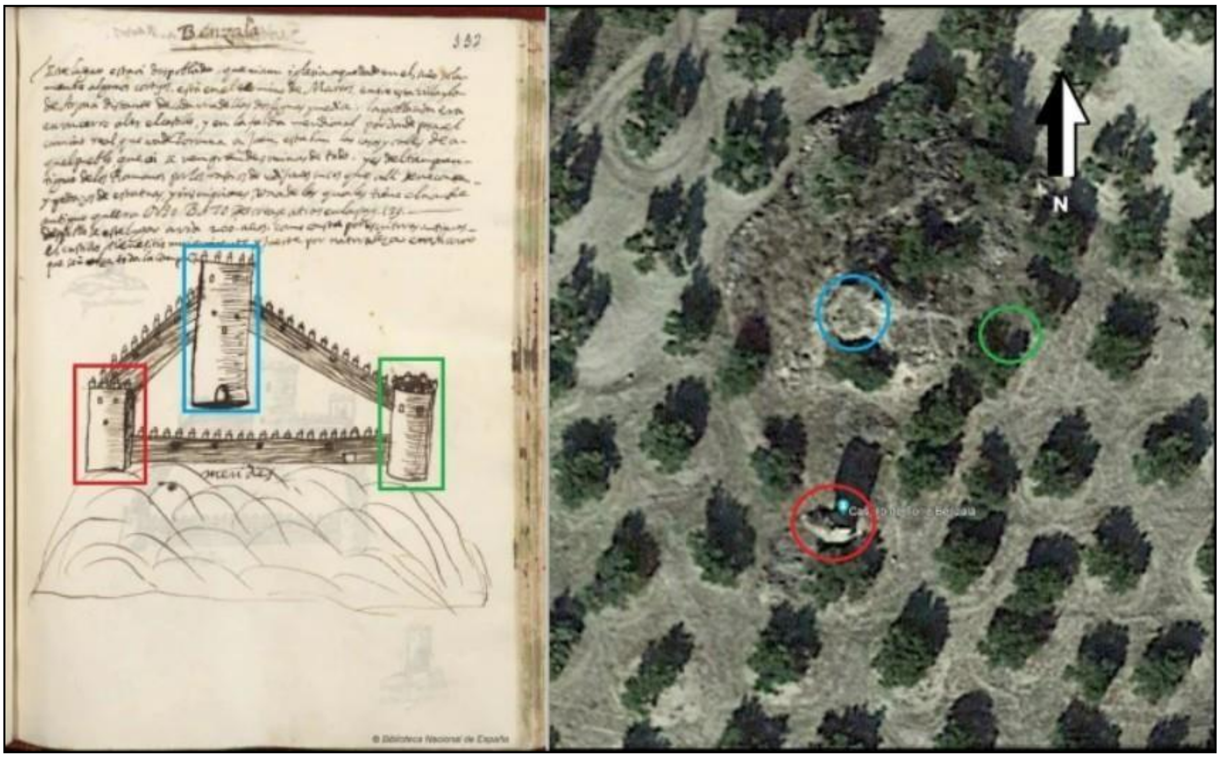


Figure 3: The tower highlighted in red is the one studied [3]

Currently, in Torredonjimeno, Benzalá is a castle in ruins, a square tower remains standing.

On July 11, 1972, the Ministry of Education and Science of Spain declared of public utility "the works and services necessary for the revaluation of the archaeological site of Tower Venzalá and its surroundings and environment". This was the first attempt to carry out conservation work in an ancient Iberian settlement of incalculable heritage value. That initiative, however, fell on deaf ears. Today, nearly half a century later, Benzalá is still waiting for an answer to its call for help so that it does not end up as a mere memory. [2]

1.5. State of the Art of the Existing

Heritage buildings usually have complex (non-parametric) geometries that turn their digitization through conventional methods in inaccurate and time-consuming processes. When it comes to the survey and representation of historical assets, remote sensing technologies have been playing key roles in the last few years: 3D laser scanning and photogrammetry surveys save time in the field. [5]

The technique known as **photogrammetry** makes use of aerial or terrestrial photographs to reconstruct three-dimensional models. The development of digital cameras and image processing software has made it possible for photogrammetry to become a popular method for building precise 3D models out of photos taken from various angles.

Photogrammetry is considered the primary technique for the processing of image data, being able to deliver at any scale of application accurate and detailed 3D information with estimates of precision and reliability of the unknown parameters from measured image correspondences (tie points) [6], Photogrammetry finds its primary fields of applications in cartography and mapping, precise 3D documentation of Cultural Heritage. [7]

On the other hand, the **3D Laser Scanner**, is a remote sensing technology, it uses lasers to precisely measure the distance between the scanner and surrounding objects. This enables the detailed 3D point clouds of historic buildings, monuments, and archaeological sites to be captured.

The environment of the heritage and its rehabilitation lives a revolution which continues today to be set up thanks to the new technologies, the Building Information Model imposes itself gradually in the field. **Building Information Modeling** (BIM) is a digital representation of a facility's physical and functional characters [8]. It is based on technology incorporating information in three dimensions (3D) and integrates the necessary information required by Architecture, Engineering, Construction and Facilities Management (AEC/FM). [9]

Integrating the photogrammetry and laser scanning into BIM workflow provides a notable advantage in the heritage sector, particularly for interventions involving existing buildings. These techniques offer robust capabilities for documenting the initial state, assessing changes over time, and generating as-built documentation.

Our project will address the architectural survey conducted with 3D terrestrial laser scanning, how information is generated and manipulated and how to produce a 3D model using BIM software. The tower of Benzalá in Jaen will be used as a case study to report the process with the goal of cataloging and preserving it.

1.6. Modeling Techniques

1.6.1. Point

The 3D laser scanner, thanks to its technology, allows for the rapid collection of a large quantity of points in the three dimensions X, Y, and Z (counted in the millions) within a minimum amount of time (just a few minutes are sufficient for indoor scanning). The precision achieved is more than sufficient for building applications, typically within a few millimeters per measurement.

The result obtained after assembling the different viewpoints gives rise to an initial 3D model in the form of a "point cloud."

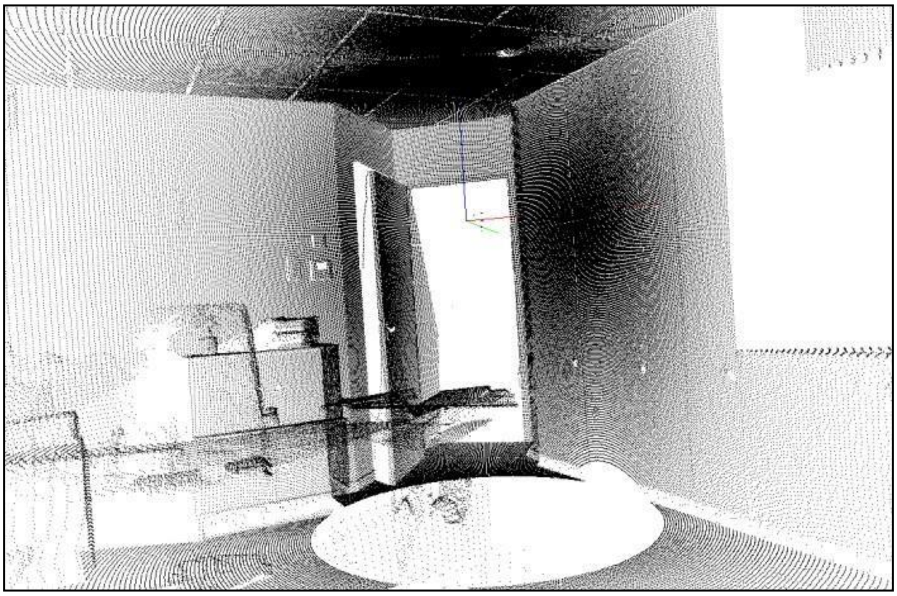


Figure 4: Black & white point cloud from a 3D laser scanner survey [10]

The 3D model obtained at this stage is made up of a multitude of points correctly positioned in space; hence the name "Point Cloud". [10]

1.6.2. 2D

The production of 2D graphic parts from a point cloud involves a step of manual or semi-automatic vectorization of a sliced section of points extracted from the point cloud. [10]

The 2D representation can be realized directly from the point cloud thanks to applications that provide tools and functions to draw in 2D the desired contours or walls .

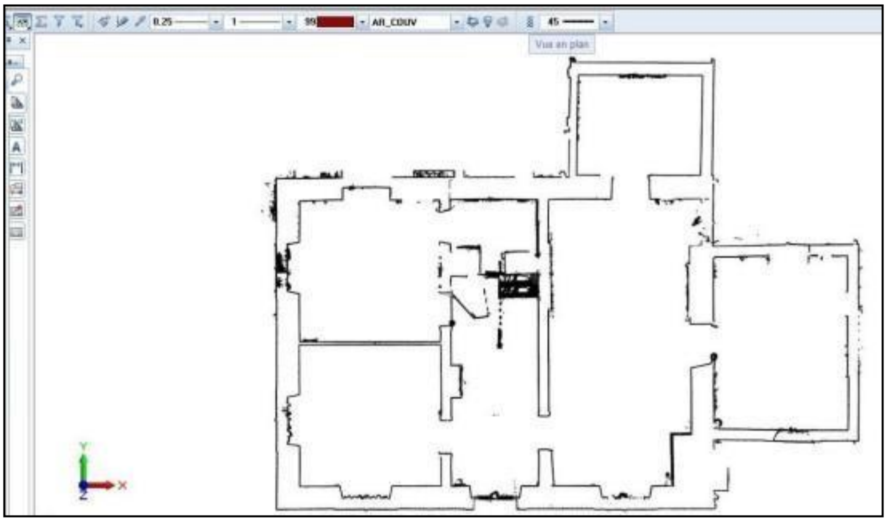


Figure 5: 2D View Extracted from a Point Cloud [10]

1.6.3. 3D

A 3D plane, also called a three-dimensional plane, is a graphical representation of an object, space, or area in a three-dimensional coordinate system.

Once cleaned up, the point cloud can undergo a geometric transformation called "mesh". and thus, give birth to a 3D object. [10]

1.6.4. BIM (Building Information Modeling)

BIM is primarily a 3D digital representation of an environment, a structure or a building with its intrinsic characteristics. It consists of intelligent building component or characteristics of environments which includes data attributes and parametric rules for each object. [11]

BIM technology can realize a 3D virtual model of the construction to be realized or illustrate an existing model. The model becomes absolutely comprehensible from all individuals that participate in its construction while at the same time provides the possibility of important utilities during building life-cycle. [12]

BIM encompasses more than just the development of a 3D model of a building. It also entails details about the phases of design, construction, and maintenance.

BIM technologies allow for the documentation, generation, importation, or manipulation of three-dimensional models using such parametric information as specifications and technical drawings (2D), geometric properties in a collaborative model (3D), constructive temporary programming (four-dimensional (4D)), the definition of amounts and costs (five-dimensional (5D)), sustainability of the project (six-dimensional (6D)), and maintenance and life cycle management (seven-dimensional (7D)). [13]

Despite the trend of scientific community to adopt the BIM technology for the design and life-cycle management of constructions, little research has been undertaken to explore the value of BIM in the management and documentation of cultural heritage monuments. [14]
However, researchers have recently developed different techniques for the reliable and coherent management of information related to cultural heritage. [15]
In the case of cultural heritage objects things are more complex as cultural heritage monuments are mainly made of components and materials whose geometry and characteristics are not representative for typical software libraries. A possible solution to the lack of geometric primitives issue in the current typical BIM software libraries, involves the so called HBIM approach. [16]
Heritage Building Information Modeling (HBIM) is a specialized application of BIM that focuses on the documentation, preservation, and management of heritage buildings or historical structures. HBIM involves creating digital models of heritage buildings to facilitate their conservation, restoration, and ongoing maintenance.

1.7. 3D Laser Scanner Technique

1.7.1. Principle of the method

The principle behind the laser scanning method, also known as LiDAR (Light Detection and Ranging), is to emit laser pulses and measure the time it takes for them to return after impacting a surface or object. This idea makes it possible to calculate precise distances and produce three-dimensional representations of the scanned environment.
Laser Scanner Technologies (TLS) work via a laser beam that travels towards the area being scanned and back, measuring angles and distances with accuracies from millimeters to centimeters. [17]

1.7.2. Laser Scanning Technologies

Laser scanning technologies encompass various methods and systems used to capture three-dimensional data of objects or environments. These technologies differ based on their operational characteristics, scanning mechanisms, and applications.
In recent years, advanced technologies have made it possible to create precise and detailed 3D models to represent buildings as built. Due to the growing need for realistic and accurate 3D models, Drones (UAV) and Terrestrial Laser Scanner (TLS) are emerging as essential tools for reality capture. [18]
In our case, we used terrestrial laser scanning (TLS), for the scanning mission, scanning stations were performed using the FARO Focus X 130 laser scanner.

To allow the fusion of the scans obtained from TLS, an alignment step is applied. This step was performed in order to extract the point cloud.

1.8. BIM and TLS applications in the cultural heritage context

This section provides examples of various BIM and TLS applications in the context of cultural heritage sites. One example is The Engine House Paco's Reais in Lisbon, which was constructed around 1900 and suffered damage from rainwater leakage from the roof and peeling walls. A scanning mission facilitated the creation of a detailed 3D model to support the on-going design project focused on conserving and intervening in the damaged sections of the house.

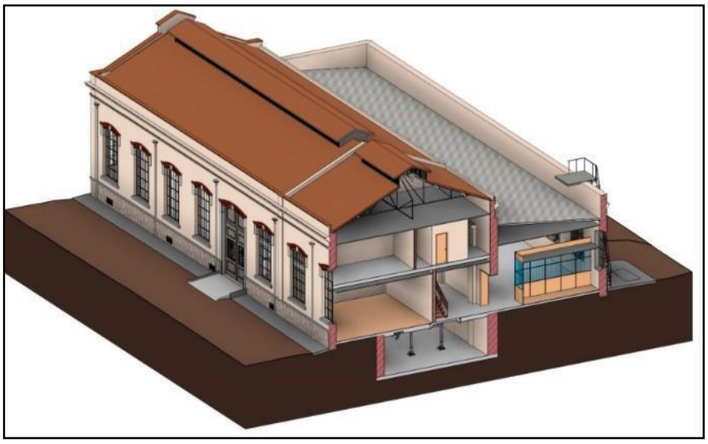


Figure 6: 3D model of the Engine House Paços Reais [5]

Another application is the modelling of the Durham Cathedral. The Cathedral was built in 1093, in the city of Durham, England. The process started with laser scanning that the scans was imported into the BIM platform Revit. The use of laser scanning can record very high and accurate levels of detail in the field for cultural heritage.

Figure 7: 3D model of the Durham Cathedra [19]

CHAPTER II: Scanning Mission and Data Processing

2.1. Introduction

TLS are widely used for reconstruction and 3D visualization. The scanner generates a dense point cloud used to produce a 3D model of the object. There are many reasons for using TLS in reality capture: detection of anomalies, site monitoring, maintenance operations, and creation of a digital BIM model. [20]

A scanning mission using TLS involves deploying the laser scanner to capture 3D data of a specific area or object. Creating a point cloud of millions of individual points that represent the geometry of the scanned area.

2.2. 3D SCANNING METHOD

This section includes the materials used and the procedure for extracting the point cloud.

2.2.1. Equipment used

2.2.1.1. FARO Focus 3D X 13

FARO Laser Scanner Focus 3D X 130 is the instrument chosen to perform 3D scans. It has a data acquisition speed of 976,000 pts/sec with an accuracy of 2mm at 10m and 11mm at 100m.

Figure 8: Faro Focus 3D X 130

2.2.1.2. Spheres Assembly

In the field, scanning campaigns are carried out using assembly spheres, which are used for scan assembly and georeferencing. The positions of the spheres are obtained using GPS.

Figure 9: spheres assembly

2.2.2. Scanning procedure

As the instrument scans, it measures the distance and angle of the laser reflections from the surface of the object, generating a 3D point cloud of the object's geometry.

2.2.2.1. Positioning of the device

If suitable locations for positioning the device have been identified in advance, on-site installation can be completed quickly—in as little as 30 minutes.

To define the stations, some preliminary work is required. The stations are selected to have the least masked or shadowed areas while also having the most frontal viewing angle toward the object to be scanned (see figure 9).

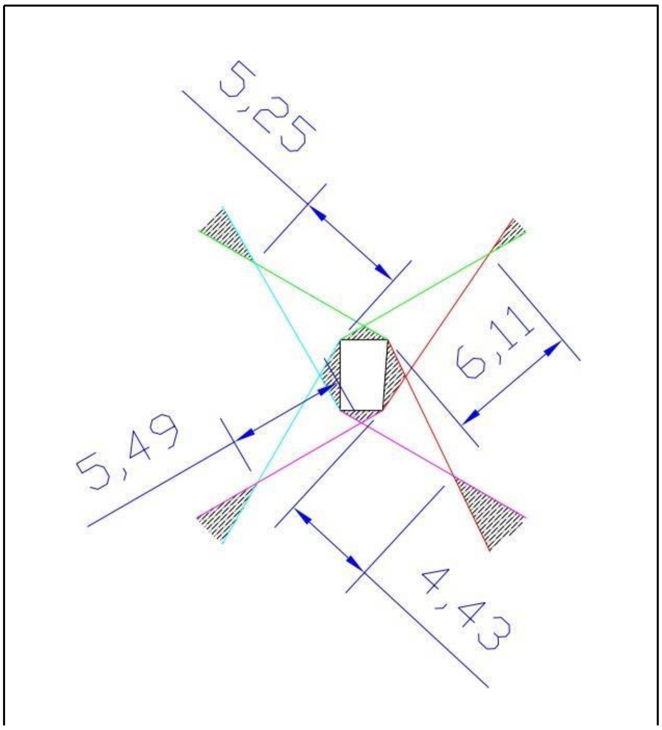


Figure 10: different positioning for scanning

To scan the object from different viewpoints, the scanning process is repeated four times to capture the entire object.

Depending on the parameters set in the scanner, the length of a field scanning site can range from 5 minutes to 8 minutes.

2.2.2.2. Starting up of the device

The scanner's initialization process is initiated and the operating software touch screen is displayed.

Starting from the Home screen, go to Home > Manage > Project > Default Project, From there, we created a new job. In the new job dialog box, enter a name for the job and any other relevant details, such as a description or manager information.

Figure 11: Home Screen of the controller software [21]

2.2.2.3. Configuration du scanner

According to the settings made by the operator in the field, the laser scanner scans. To get the desired results, these parameters specify the scanning parameters, including point density, spatial resolution.

The scanning parameters can be set in one of two ways: manually or by choosing a scan profile, which is a predefined set of scanning parameters. The scanning parameters are overwritten when a scan profile is chosen.

To change the scanning parameters, click the parameters button on the home screen and we select a predefined scan profile.

Figure 12: Change the Scan Parameters [21]

The first thing we select is the profile, we can select our own profile or a default profile, the default profiles are indoor up to 10 m, indoor from 10 m, outdoor up to 20 m ..., The latter is of HD quality.

Figure 13: Scan Profiles List [21]

In our case we will choose the outdoor until 20 m, it is important to know that it is until 20 m does not mean that it will not measure more than 20 m but the parameters of resolution and quality will be suitable to all the objects that are closer to 20 m.

Then we can manipulate the resolution and the quality values. On the left of the following image, we see the resolution and on the right the quality; in this case, for an outdoor profile up to 20 m, we choose a resolution of one eighth and a quality of 4x.

Figure 14: Setting the scan resolution and quality [21]

In the central strip we will see the characteristics of our position having selected these values of resolution and quality, first we will have the duration of the scan, the size of the scan, the mega points and the distance of the points, we could modify the values of resolution and quality with the plus and the minus, if we want the cloud of points be more tense we could increase the resolution, for example increasing the resolution to a fifth.

Then we could adjust the angles of our scan; by default, the scanner records everything you find at 360 degrees from horizontal and -60 degrees to 90 degrees from vertical.

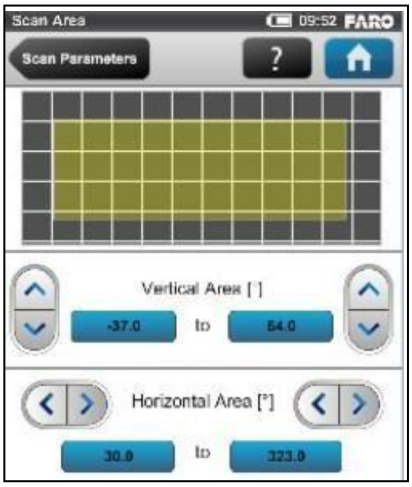


Figure 15: Setting the Scan Range [21]

During the scanning and at each station, we executed two times the scans once in color and another time without color.

Scanning with color using the FARO Focus3D X 130 scanner can aid in enhancing the precision and quality of 3D models. The processing time and file size of the resulting 3D models can increase when scanning in color.
In addition, scanning without color reduces the processing time and file size required for the resulting 3D models, making them simpler to use and analyze.
Another advantage of colorless scanning is that it minimizes the impact of lighting conditions on the resulting 3D models. Color data can be affected by changes in lighting or shading.

Figure 16: Scan with color

After filling in all the scanning parameters, and making sure that the scanner moves freely and that no object can block the vision of the device, we start the scanning operation by clicking on the start scan button on the screen.
The scanning process begins, the scanner's laser turns on, and the scanning view is shown.
The scanner rotates 180 degrees clockwise while scanning. The scanning screen's status bar shows the completed processing steps, and the progress bar shows how the scan is going.
The scan preview displays a picture in grayscale (see figure 12).


Figure 17: Picture in grayscale

2.3. Data Processing

This part gathers all the steps of a process of creation of point clouds obtained by a 3D scanner.

2.3.1. Software Used

It is necessary to provide specialized software that can generate a point cloud, but it is important to note that the accuracy of the model depends on the quality of the obtained scans, for the processing of the scans we used the software FARO SCENE.

Faro Scene is a complete software package for the management, administration, georeferencing, visualization and processing of full scan data obtained from high-resolution 3D scanners.

Figure 18: FARO SCENE

2.3.2. Advantages of Faro Scene

For professionals working in industries like architecture, engineering, and construction, Faro Scene offers a number of benefits. The following are some of Faro Scene's main benefits:

- Provides comprehensive data management capabilities, allowing users to organize, store, and manage large volumes of 3D point cloud data efficiently, registration of multiple scans or point clouds, processing and analyzing point cloud data.
- Reduce the costs of your projects with workflows, automatic data processing, or for the recalibration of scans, fast and efficient export of scan data and a simplified and a simplified user interface.
- Clear and intuitive representation of reality with immersive visualization features that allow you to explore and evaluate digitized data.

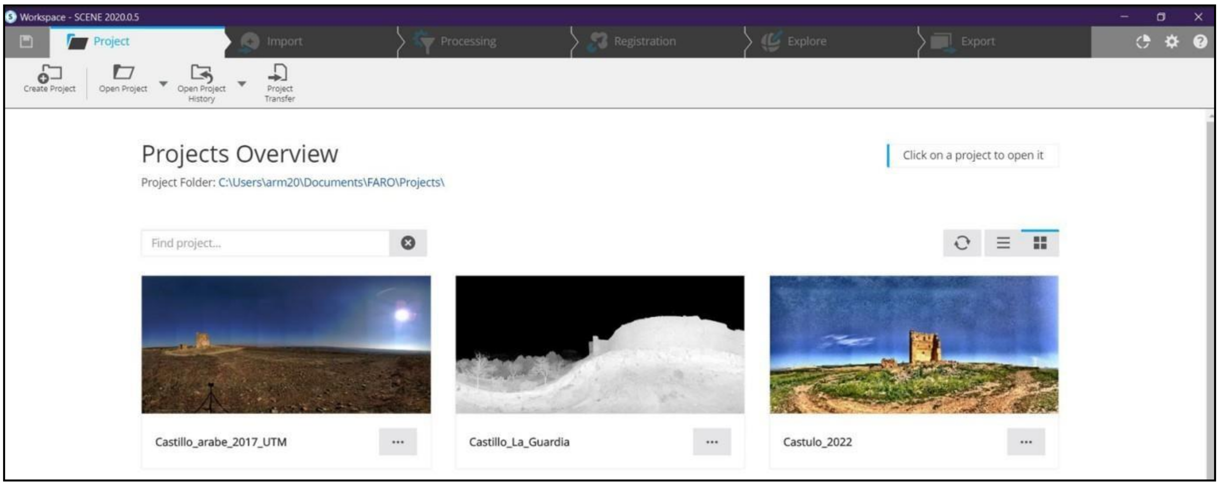


Figure 19: Faro Scene interface

2.3.3. Processing Approach

This activity diagram highlights the main tasks and manipulations that will be performed when processing the scans for the purpose of extracting the point cloud

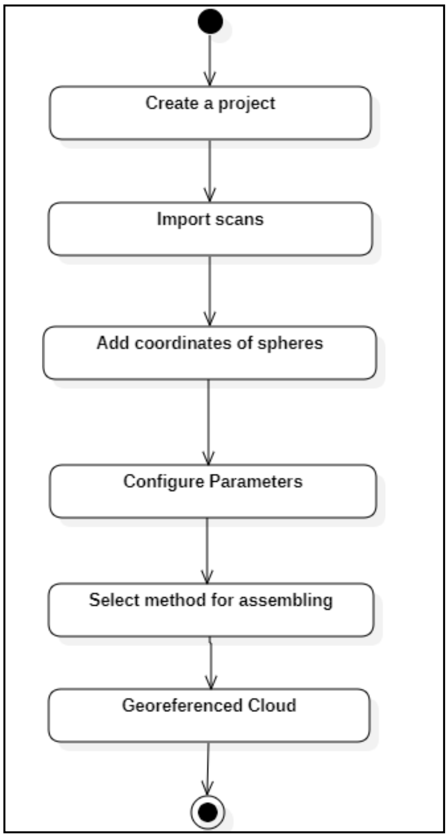


Figure 20: Activity diagram of processing scans

2.3.3.1. Create a new Project

The first step is to create a new project with the name and location of this new project.

2.3.3.2. Import Data

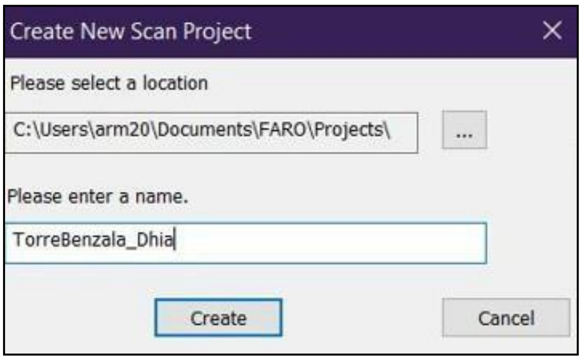
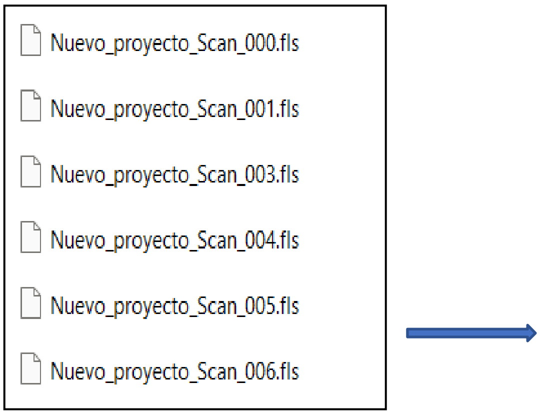


Figure 21 : Create new scan project

Importing the scans is the second step, from which the point cloud will be extracted.



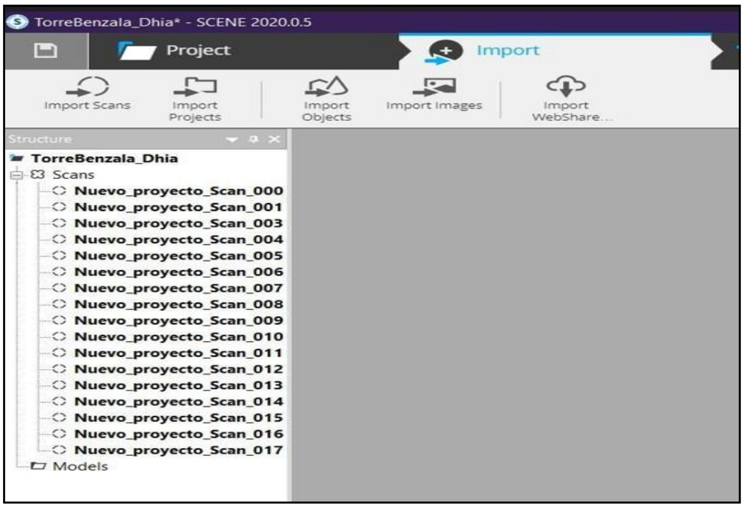


Figure 22 : SCENE data import interface

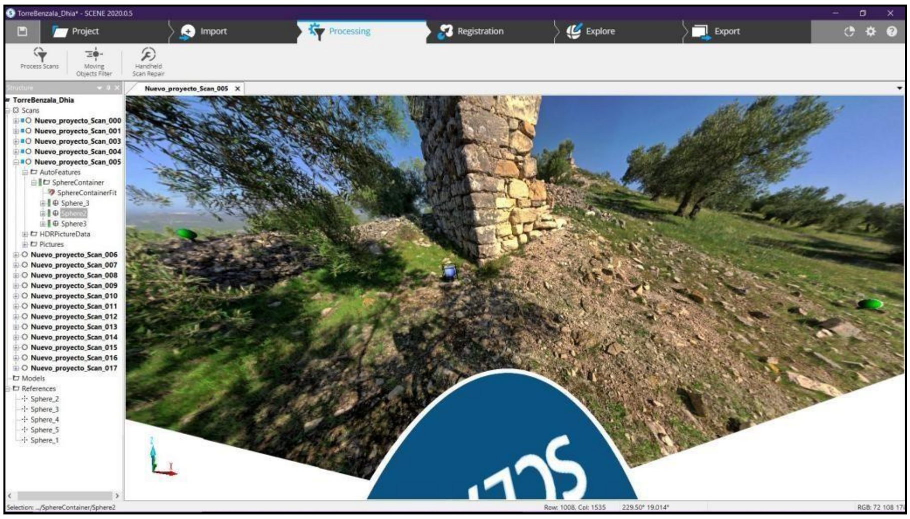


Figure 24: SCENE workspace

2.3.3.3. Add coordinates of spheres for georeferencing

Then, in order to georeferenced the scans, we imported reference points. The purpose of importing reference points is to add precise location data to a 3D point cloud, in the case of this scan campaign, we had a total of five sphere positions (sphere 1, sphere 2, sphere 3, sphere 4 and sphere 5) whose coordinates are measured with a GPS, making it possible to geo-reference the point cloud, to assign spatial coordinates in a known reference system. This allows linking the digital model to the real environment, this is called indirect georeferencing. In the process of scanning data, we used two reference systems:

For scanner registration, we used a local reference system. Each scan has its own local reference system, whose origin is the center of the scan. When we registered the scans, all the clouds of points changed to a common reference system.

When all the scans are registered, we use the spheres to translate the registered cloud of points to a global reference system: ETRS89 UTM 30N (EPSG: 25830).

Spheres_coordinates.csv: Bloc de notas

Archivo Edición Formato Ver Ayuda

```
Sphere_1,408507.32,4187432.08,537.58
Sphere_2,408502.44,4187437.97,540
Sphere_3,408496.58,4187431.52,538.49
Sphere_4,408510.26,4187430.69,537.06
Sphere_5,408501.18,4187431.32,538.1
```

Figure 25: Spheres Coordinates

2.3.3.4. Configuration of the scanning parameters

Here is an illustrative diagram of the raw scan processing followed by assembly and georeferencing.

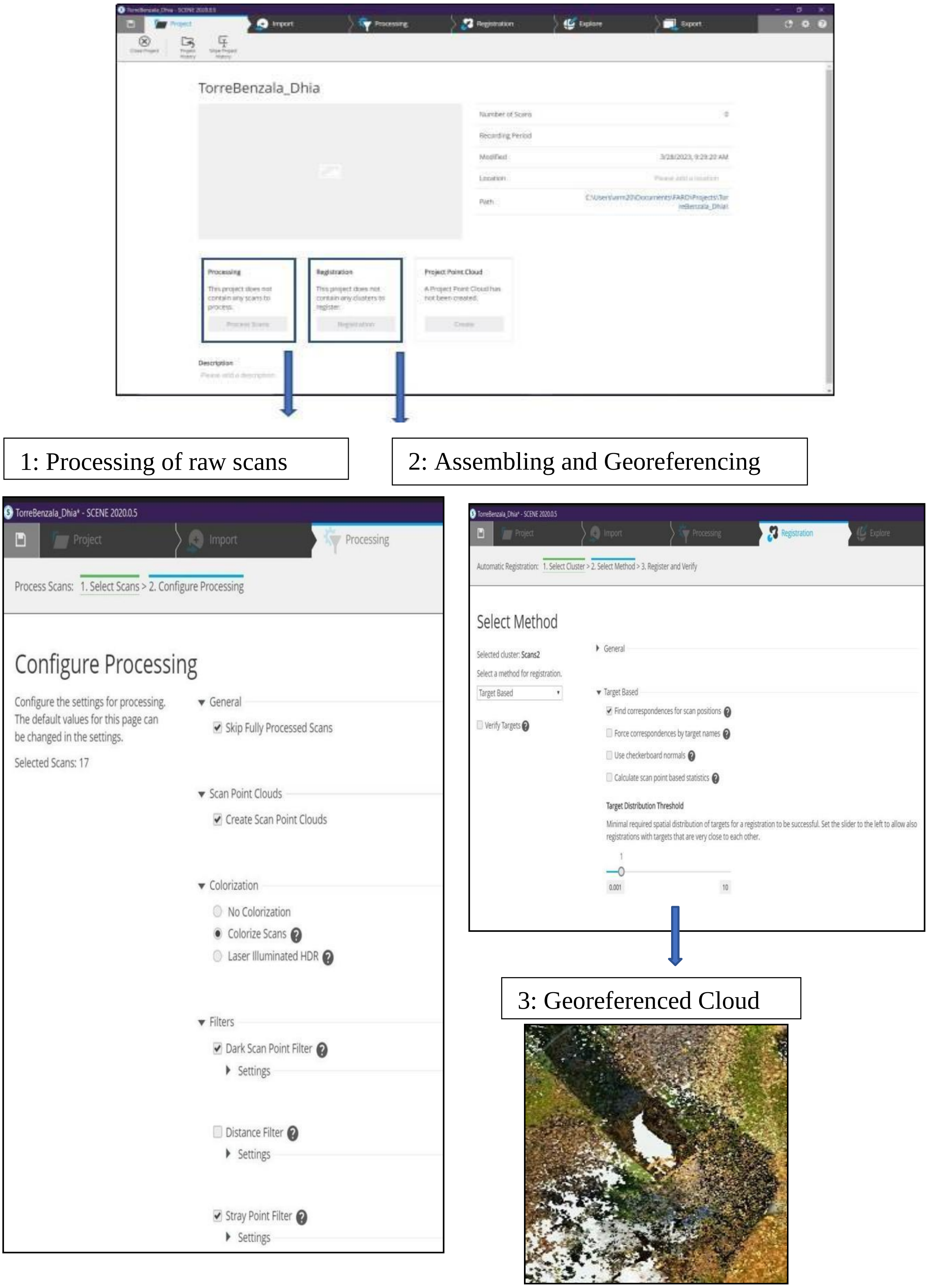


Figure 26: Procedure for processing and georeferencing scans on SCENE

To start processing, we will first select the scans we want to process and align, then we will configure the processing parameters to optimize the registration process, such as the filtering parameters, we choose "Dark scan Point Filter" and "Stray Point Filter " to remove noise, outliers, or unwanted.

Now, the configuration is complete, and of course, go to the next step, which is to select the method of registration, we choose the registration method "Target based", it's the most common method used to register point clouds together.

In our case, the "target-based" registration method uses spheres as reference points. The process uses the known coordinates of these targets to precisely align the scans relative to each other, the software can determine the position and orientation of the scans relative to the spheres and determine the overlap.

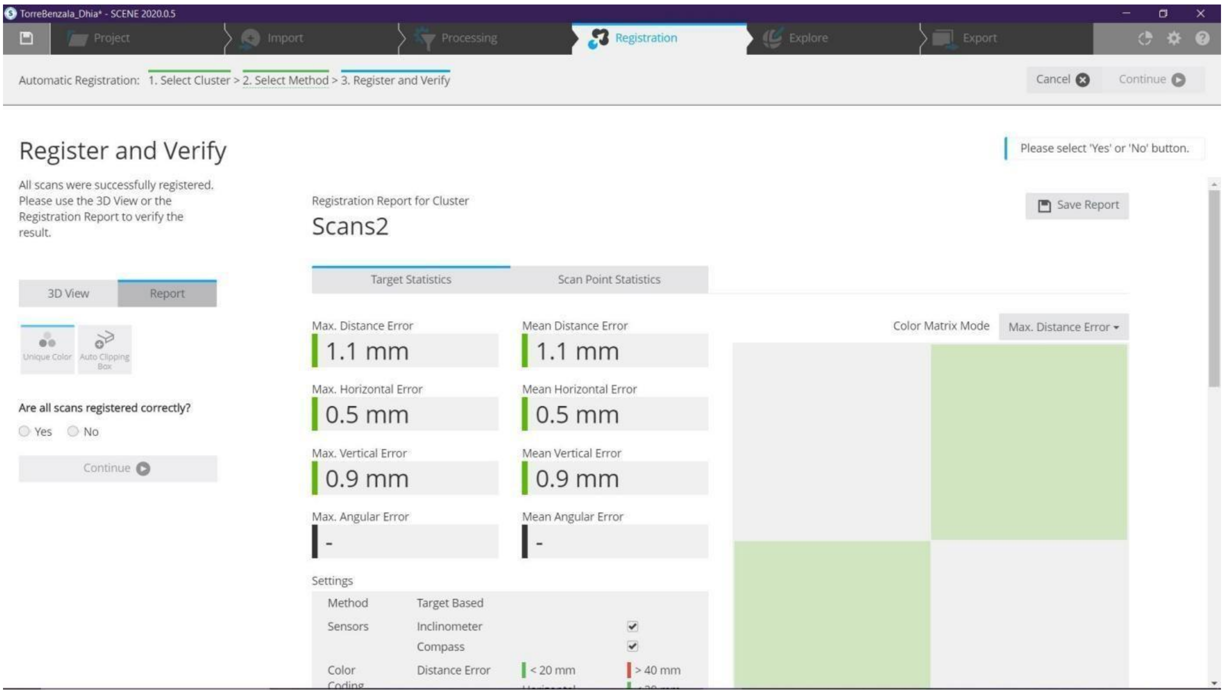


Figure 27: Report that summarizes the errors

After processing in Faro Scene, the software can generate a report that summarizes the errors and results of the entire process. It allows us to visualize the deviations and to understand the quality of the alignment. This report can include information such as:

- "Max. Distance Error" is the maximum allowed deviation of the measured points from the corresponding reference points.
- "Mean. Distance Error" refers to the average distance error in a scene. This measure indicates the average of the deviations between the measured points and the reference points in a 3D point cloud.

- "Max. Horizontal Error" quantifies the maximum deviation between the measured points and the reference points in a horizontal plane.

"Mean. Horizontal Error" refers to the average horizontal error between the measured points and the reference points in a 3D point cloud.

- "Max. Vertical Error" quantifies the maximum deviation between the measured points and the reference points in a vertical plane.

"Mean. Horizontal Error" refers to the average vertical error between the measured points and the reference points in a 3D point cloud.

These errors are generated to evaluate the quality and accuracy of the registration or alignment process in the software.

Point Error	< 8 mm	> 20 mm
Overlap	> 25.0 %	< 10.0 %

Figure 28 : Color Coding

Cluster/Scan	Connections	Max. Point Error [mm]	Mean Point Error [mm]	Min. Overlap
Nuevo_proyecto_Scan_012	6	7.4	6.2	33.1 %
Nuevo_proyecto_Scan_013	5	7.9	5.9	23.7 %
Nuevo_proyecto_Scan_014	5	15.3	8.8	25.2 %
Nuevo_proyecto_Scan_015	8	8.4	6.9	22.0 %
Nuevo_proyecto_Scan_016	5	16.3	10.0	32.2 %
Nuevo_proyecto_Scan_017	6	14.2	11.0	41.5 %
Nuevo_proyecto_Scan_000	7	16.3	9.9	25.2 %
Nuevo_proyecto_Scan_001	5	13.9	5.6	44.8 %
Nuevo_proyecto_Scan_003	5	14.2	5.8	45.1 %
Nuevo_proyecto_Scan_004	6	6.3	4.5	37.3 %
Nuevo_proyecto_Scan_005	4	8.4	4.5	26.9 %
Nuevo_proyecto_Scan_006	2	4.6	4.2	37.3 %
Nuevo_proyecto_Scan_007	5	10.8	8.1	26.9 %
Nuevo_proyecto_Scan_008	6	7.9	5.3	22.9 %
Nuevo_proyecto_Scan_009	4	8.3	5.4	22.0 %
Nuevo_proyecto_Scan_010	5	6.5	4.5	42.6 %
Nuevo_proyecto_Scan_011	4	6.0	4.9	42.6 %

Figure 29: Scan Point Statistics

Cluster/Scan 1	Cluster/Scan 2	Point Error [mm]	Overlap
Nuevo_proyecto_Scan_013	Nuevo_proyecto_Scan_012	4.9	64.9 %
Nuevo_proyecto_Scan_013	Nuevo_proyecto_Scan_014	5.9	32.7 %
Nuevo_proyecto_Scan_013	Nuevo_proyecto_Scan_008	7.9	23.7 %
Nuevo_proyecto_Scan_015	Nuevo_proyecto_Scan_012	6.0	33.1 %
Nuevo_proyecto_Scan_015	Nuevo_proyecto_Scan_013	5.5	55.8 %
Nuevo_proyecto_Scan_015	Nuevo_proyecto_Scan_014	6.2	49.8 %
Nuevo_proyecto_Scan_015	Nuevo_proyecto_Scan_016	7.1	60.7 %
Nuevo_proyecto_Scan_015	Nuevo_proyecto_Scan_017	8.4	64.4 %
Nuevo_proyecto_Scan_015	Nuevo_proyecto_Scan_008	7.6	22.9 %
Nuevo_proyecto_Scan_015	Nuevo_proyecto_Scan_009	8.3	22.0 %
Nuevo_proyecto_Scan_015	Nuevo_proyecto_Scan_010	5.7	53.0 %
Nuevo_proyecto_Scan_016	Nuevo_proyecto_Scan_014	7.7	51.3 %
Nuevo_proyecto_Scan_016	Nuevo_proyecto_Scan_007	10.8	32.2 %
Nuevo_proyecto_Scan_017	Nuevo_proyecto_Scan_014	9.0	41.5 %
Nuevo_proyecto_Scan_017	Nuevo_proyecto_Scan_016	7.9	63.6 %
Nuevo_proyecto_Scan_017	Nuevo_proyecto_Scan_001	13.9	57.0 %
Nuevo_proyecto_Scan_017	Nuevo_proyecto_Scan_003	14.2	64.1 %
Nuevo_proyecto_Scan_000	Nuevo_proyecto_Scan_014	15.3	25.2 %
Nuevo_proyecto_Scan_000	Nuevo_proyecto_Scan_016	16.3	61.4 %
Nuevo_proyecto_Scan_000	Nuevo_proyecto_Scan_017	12.5	55.0 %
Nuevo_proyecto_Scan_000	Nuevo_proyecto_Scan_001	4.3	66.6 %
Nuevo_proyecto_Scan_000	Nuevo_proyecto_Scan_007	10.1	57.6 %
Nuevo_proyecto_Scan_000	Nuevo_proyecto_Scan_003	5.0	65.5 %
Nuevo_proyecto_Scan_000	Nuevo_proyecto_Scan_004	5.5	50.6 %
Nuevo_proyecto_Scan_001	Nuevo_proyecto_Scan_003	2.2	97.6 %
Nuevo_proyecto_Scan_001	Nuevo_proyecto_Scan_005	3.3	44.8 %
Nuevo_proyecto_Scan_003	Nuevo_proyecto_Scan_005	3.4	45.1 %
Nuevo_proyecto_Scan_004	Nuevo_proyecto_Scan_001	4.3	62.6 %
Nuevo_proyecto_Scan_004	Nuevo_proyecto_Scan_003	4.3	49.2 %
Nuevo_proyecto_Scan_004	Nuevo_proyecto_Scan_005	2.9	58.1 %
Nuevo_proyecto_Scan_004	Nuevo_proyecto_Scan_007	6.3	37.9 %
Nuevo_proyecto_Scan_006	Nuevo_proyecto_Scan_004	3.9	37.3 %
Nuevo_proyecto_Scan_006	Nuevo_proyecto_Scan_007	4.6	55.0 %
Nuevo_proyecto_Scan_007	Nuevo_proyecto_Scan_005	8.4	26.9 %
Nuevo_proyecto_Scan_008	Nuevo_proyecto_Scan_012	6.3	55.1 %
Nuevo_proyecto_Scan_009	Nuevo_proyecto_Scan_012	7.4	53.9 %
Nuevo_proyecto_Scan_009	Nuevo_proyecto_Scan_008	2.2	91.7 %
Nuevo_proyecto_Scan_009	Nuevo_proyecto_Scan_010	3.6	89.3 %
Nuevo_proyecto_Scan_010	Nuevo_proyecto_Scan_012	6.5	54.3 %
Nuevo_proyecto_Scan_010	Nuevo_proyecto_Scan_008	3.1	90.3 %
Nuevo_proyecto_Scan_011	Nuevo_proyecto_Scan_012	6.0	52.3 %
Nuevo_proyecto_Scan_011	Nuevo_proyecto_Scan_013	5.4	56.6 %
Nuevo_proyecto_Scan_011	Nuevo_proyecto_Scan_008	4.8	49.2 %
Nuevo_proyecto_Scan_011	Nuevo_proyecto_Scan_010	3.6	42.6 %

Figure 30: Scan Point Statistics

The software package offers tools to improve the quality of the point cloud, the "Eliminate Duplicate Points " will reduce the overall point count by eliminating different types of (unwanted) points.

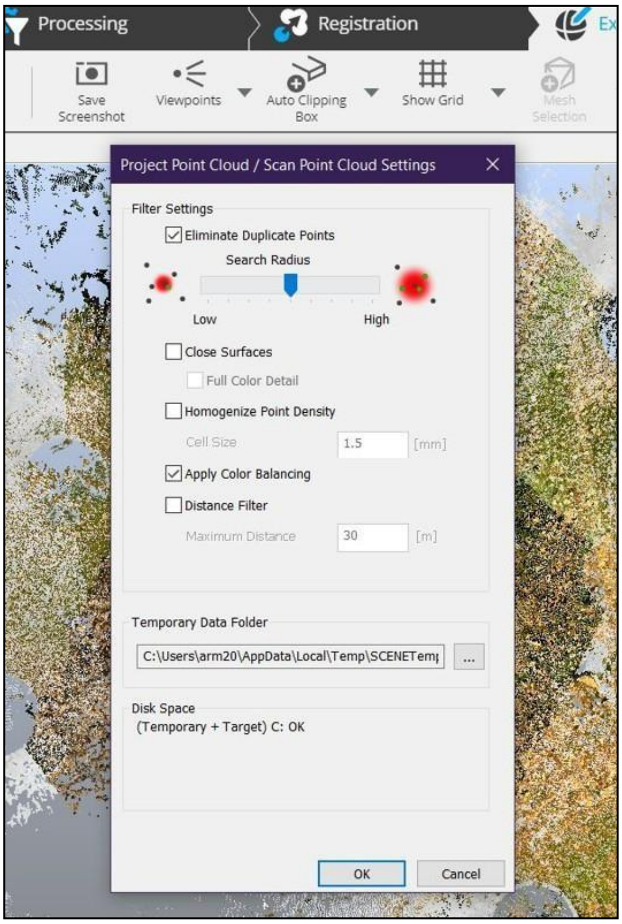


Figure 31: Eliminate Duplicate Points

The last step is the export of the point cloud. Export the scan point clouds into different file formats to use them in other applications such as Revit.

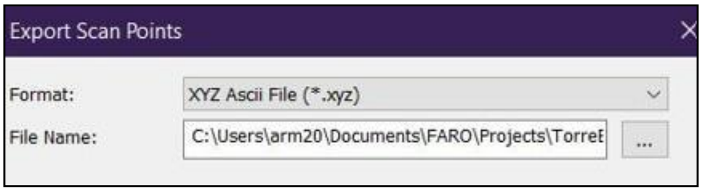


Figure 32: Export the scan point clouds

2.3.4. Cleaning the point cloud

At this stage, the point cloud needs to be exported to proceed with the second stage of processing. It should be loaded into software such as Autodesk Recap.

Autodesk Recap, a free tool, allows you to generate an .rcp file from a laser scanner file, which can be further utilized in Revit for analysis and modeling purposes.

Once the point clouds are obtained, it is necessary to clean them by removing outliers and errors from the data. This process is known as point cloud cleaning or filtering.

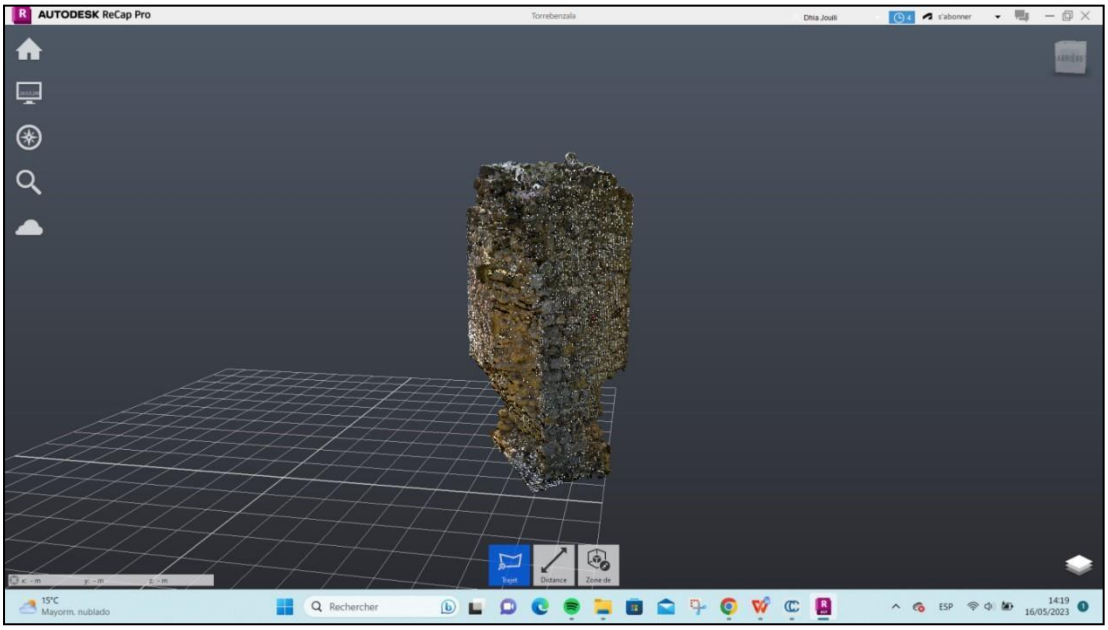


Figure 33 : Point cloud after cleaning

Next, we will create a mesh using Agisoft Metashape to detect anomalies and destroyed parts of the tower, the figure shows the current state of the tower and its destruction.

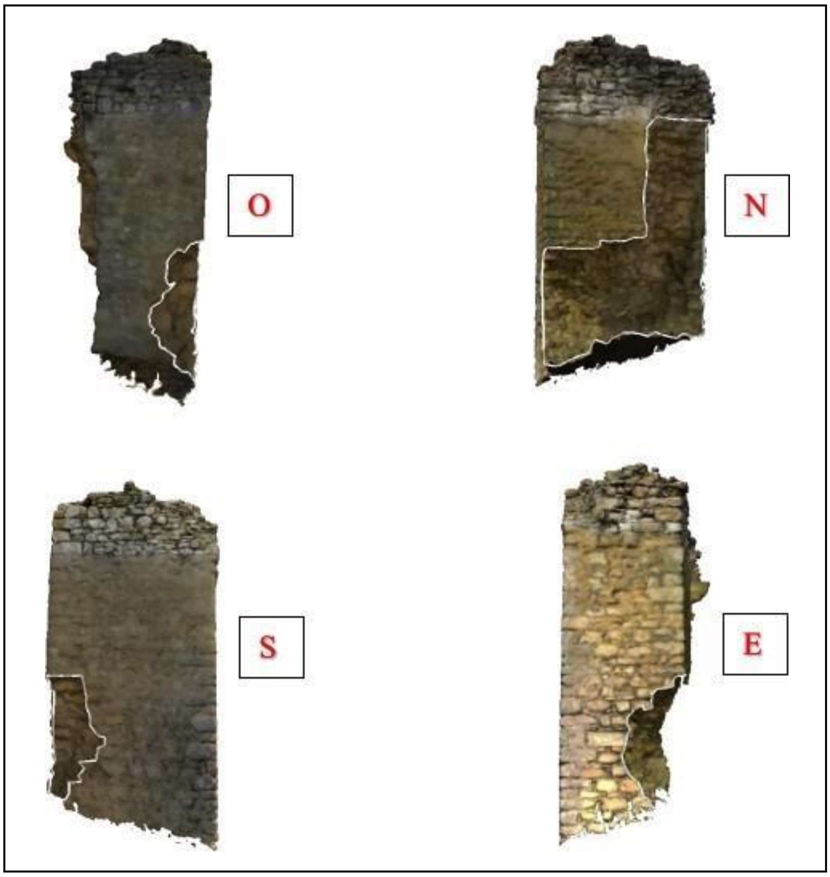


Figure 34: Mesh of the four faces of the tower

CHAPTER III: 3D Modeling and Results

3.1. Introduction

In this section, we will describe the different steps to convert a point cloud, which has been processed using the "Faro Scene" software, into a Digital Model. The modeling process using the "Revit" software.

"Revit" is software developed by Autodesk. It is the software I have chosen for modeling. Indeed, Revit is one of the leaders in the BIM software market, and it can read point clouds. Everything is designed to make use of this point cloud as specific commands are integrated into the software.

3.2. 3D Modeling

3.2.1. Create a project

The first step is to create a new project in Revit and choose the "Architectural template" model.

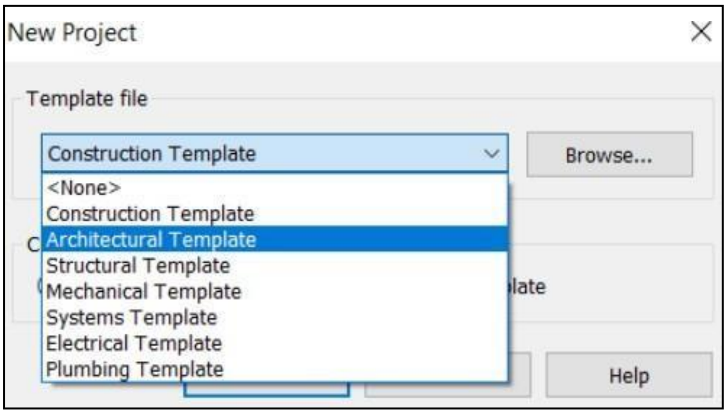


Figure 35: Create a project and choose a Template File

The architectural template in Revit is a starting model containing pre-established parameters and configurations to facilitate the creation of architectural drawings. It contains the following:

- views, nomenclatures, legends, sheets, families, etc.
- contents of element libraries (walls, beams, doors, windows, foundations, floors).

then, we will set the units, to redefine the units, in the Manage tab, click on the Units tool in the Settings group.

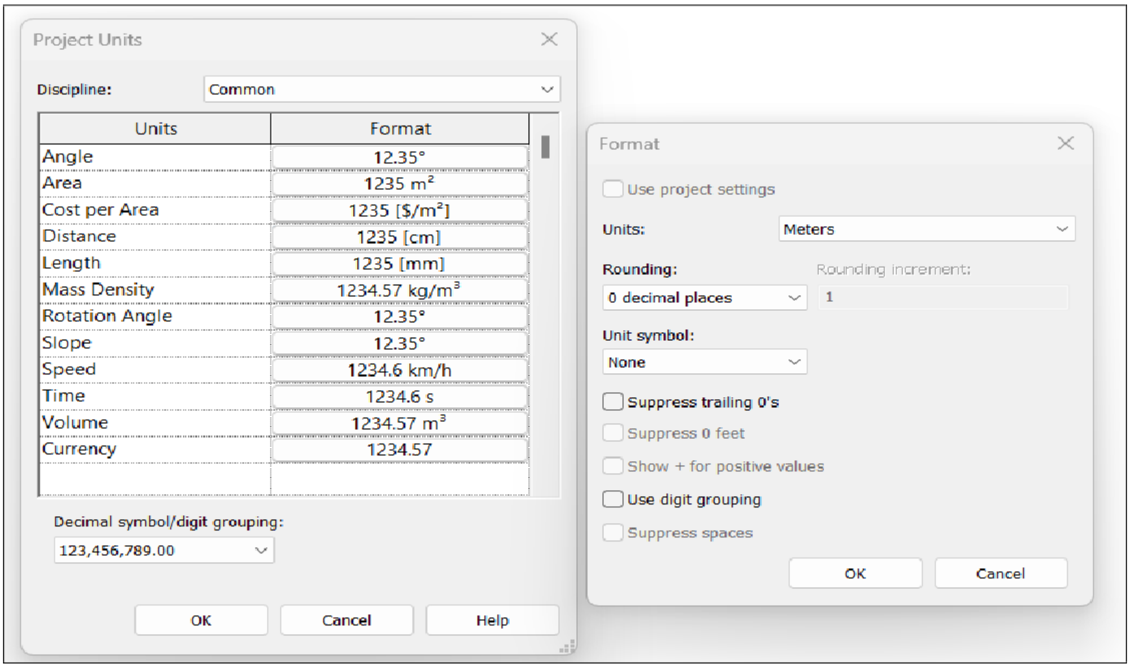
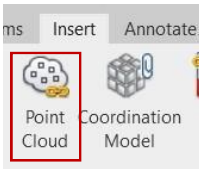


Figure 36: Configure Unit

3.2.2. Insert the point cloud

The second step is to import the point cloud into Revit. This point cloud will be exported from "SCENE" and then cleaned in "Recap Pro".



To insert the point cloud, follow the steps below:

1. Click on the "Insert" function in the ribbon and then choose the "Point cloud" option.
2. select the cloud and define Positioning

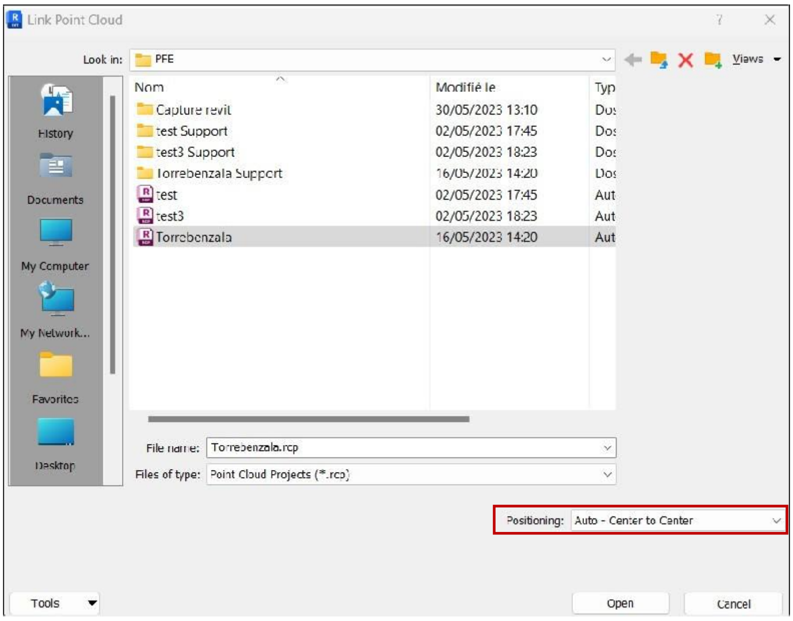


Figure 37: Insert the point cloud

3.2.3. Levels definition

Once the point cloud is imported, we can start configuring the Revit project. One of the first steps is to define the elevation of the levels.

In the project browser, we will select an elevation view (e.g., East) to create, modify the elevations.

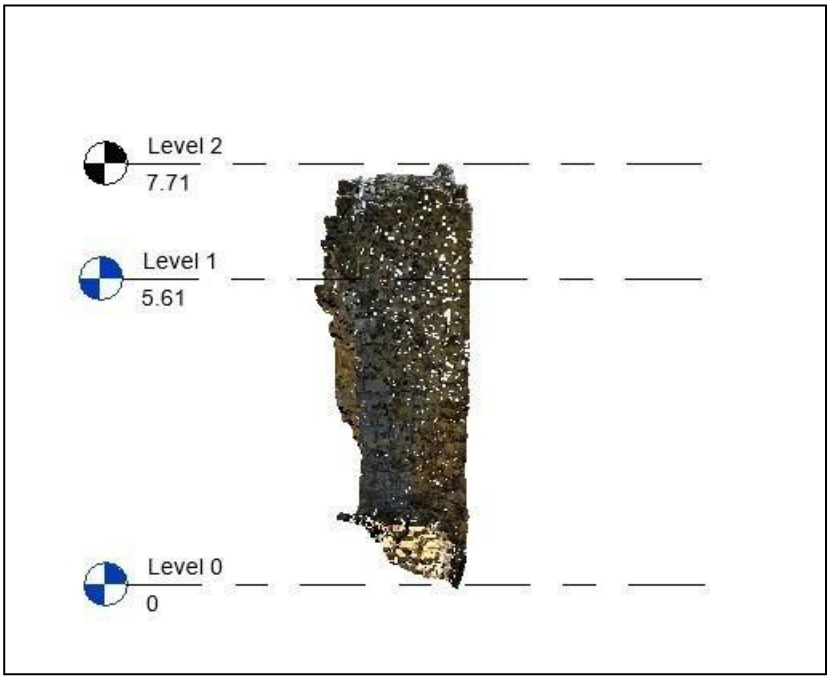
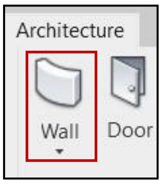


Figure 38: Creation of levels

3.2.4. Creating walls

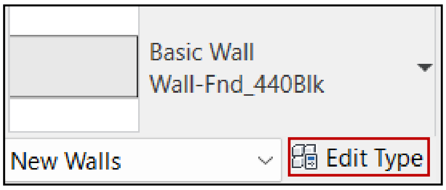
The modeling can start now that the elevations have been established. The first step is to identify the load-bearing walls from "Level 0" to the "Roof" level is the first step. By superimposing the two-point cloud sections and paying attention to the identical walls at each level, this can be done very quickly.

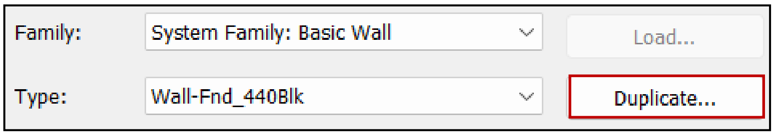
In the ribbon's "Architecture" tab, select "Wall".



The properties window proposes default wall types.

To create the one you want, click on





The type of material can be modified to suit the project objective.

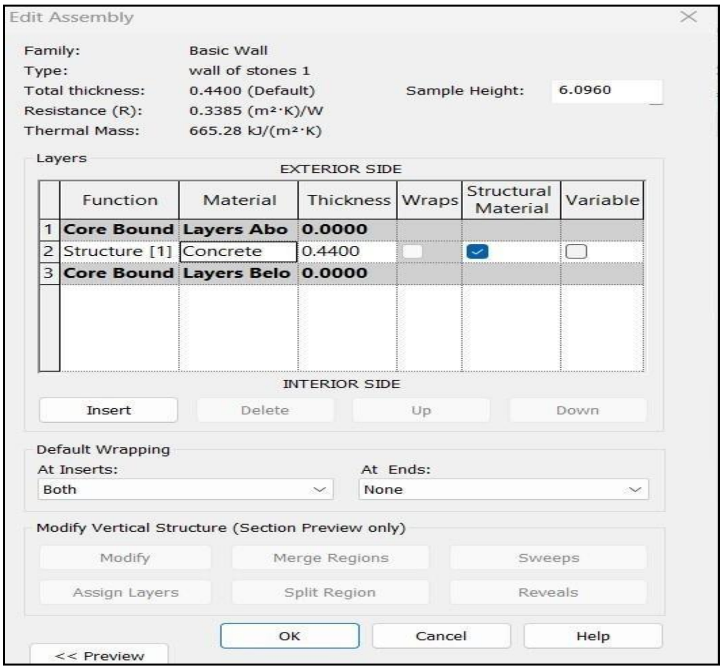


Figure 39 : Material browser

Once the "material browser" window appeared, I made some changes to customize the appearance of the walls. First, I changed the type of material used for the walls, choosing "stones" as a material that matched design specs. Then I added an extra visual touch by incorporating an image as the surface layer of the wall. This image provided a realistic and aesthetically pleasing texture for the walls.

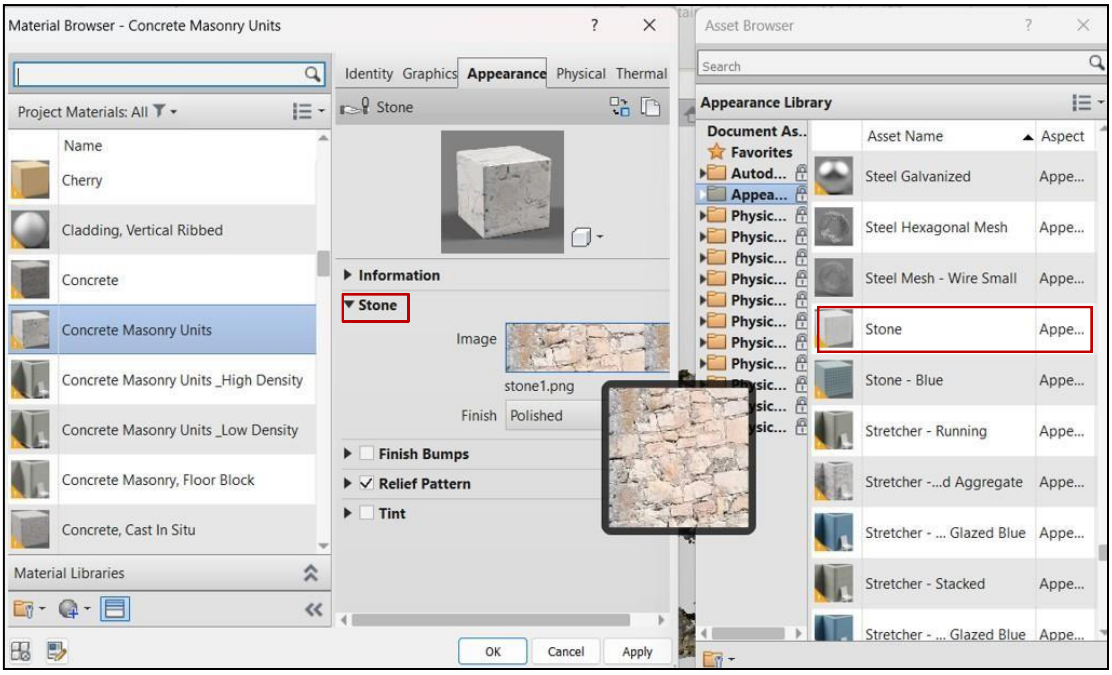


Figure 40: Change wall material

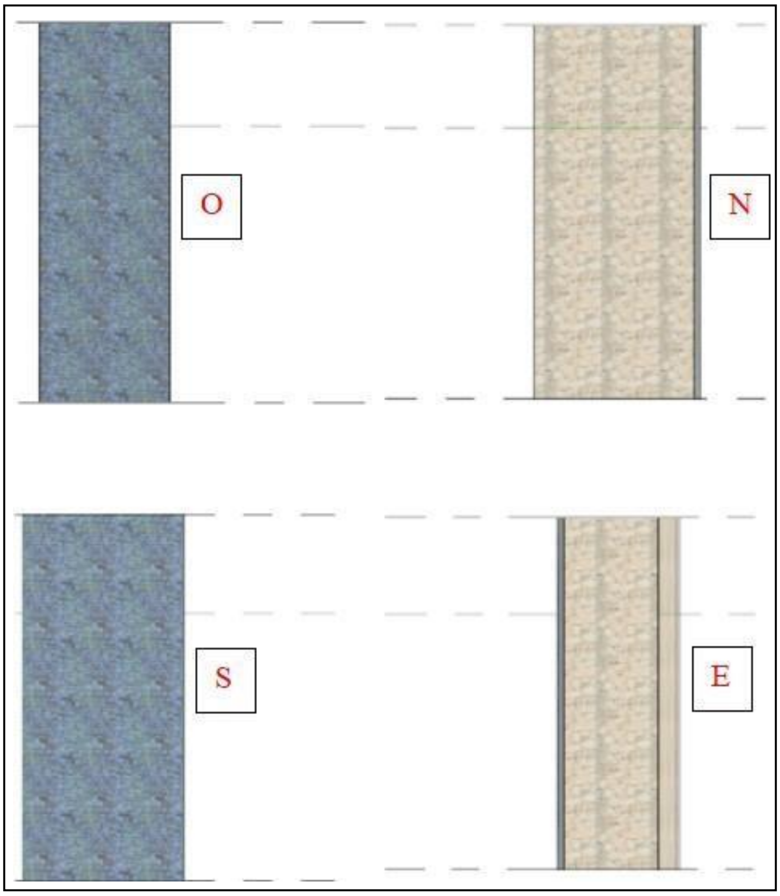


Figure 41: Faces of the Tower

3.2.5. Creating the roof

Once the walls are placed, it will be possible to model the roof of this tower, In the "Architecture" tab of the ribbon, choose "Roof"

The properties window offers default type roofs

We select the relevant walls by clicking on them one by one or by using a selection window to group them. After selecting the walls, Revit will automatically generate a roof based on the shape of the selected walls.

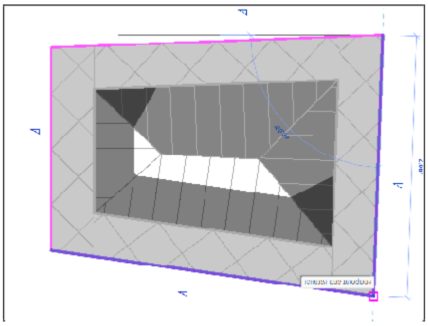


Figure 42: Creation of roof

Then we will change the type of materials for the roof, which is done in the same way as the walls; we will therefore choose the stones as a material. Then I add an image as the surface layer of the roof.

We obtain a tower modeled in 3D with the walls and the roof, once all these elements have been modeled, our model is now fully modeled. Below the figure represents a 3D view.

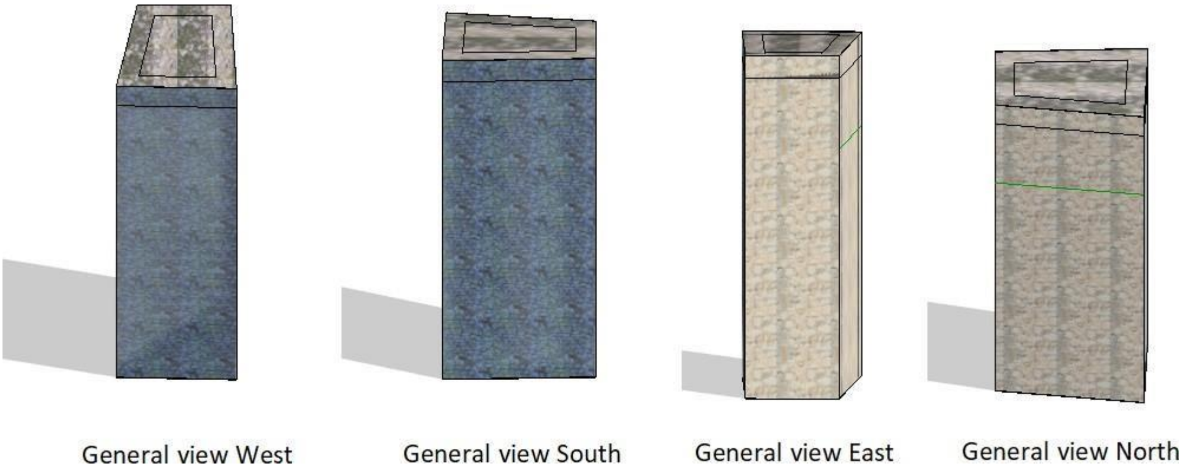


Figure 43: 3D View of the Tower

In the last part of the project, I tried doing the modeling of the rest of the fortress just to offer a vision of the total reconstruction, Therefore, the reconstruction that is proposed is approximate and in order to give more substance to the modelling work.

To create a 3D model of the fortress, we drew mainly on the documents of Ximena Jurado which highlights the condition and shape of Tower Benzalá, as the castle takes a triangular shape with a crenelated walls and towers at the corners.

We attempted to create a model of the castle, focusing on the remaining sections. We sketched a drawing, which highlights a prominent round tower (Figure 44), while the largest tower in the drawing is a square tower. The tower at the front is the tower of Benzalá, and it was designed based on the cloud point perspective.

Figure 44: Total View of the fortress

General Conclusion

This end-of-studies project made it possible to integrate 3D scanners into the BIM process, especially for projects rehabilitation heritage sites.

Due to the 3D scanner, it is possible to capture precise data on the geometry and structure of heritage sites, enabling detailed documentation of their current state. This data can be integrated into a BIM model, creating a digital model of the site. This model facilitates the planning of rehabilitation work by providing an accurate visualization of different solutions and enabling virtual collaboration among stakeholders. By integrating these technologies, the rehabilitation of heritage sites becomes more efficient, precise, and well-documented, contributing to their long-term preservation.

The main objective of the project was to develop a processing chain that would automatically extract maximum information from the point cloud of a site to be rehabilitated, with the aim of integrating the results into BIM software as a basis for the digital model. This topic allowed me to explore new applications of 3D scanning and modeling based on a point cloud.

So I tried to model the site to be rehabilitated, this work began with the acquisition of data with a 3D scanner. Due to the faro 3D X 130 we extracted data in the form of scans.

Then, we process these scans using processing software to extract a georeferenced point cloud.

Processing point clouds is a broad topic, including registration/georeferencing, point cloud cleaning, and processing time involved in processing and distributing point clouds. The value of the point cloud depends on how usable the information it contains is, which requires removing objects that are deemed to be noise or unnecessary. Cleaning the point cloud is directly related to one of the benefits of 3D scanning.

Through the point cloud we will create a 3D model, the "Revit" software that we used for the modeling seems to be the most suitable for the integration of 3D scanner data. This BIM software is more and more widespread in the world of construction and it seems certain that Revit will become the reference in the years to come in terms of built projects.

Besides the 3D scanner, scanning technologies such as photogrammetry are numerous. This will open new horizons for scaling up data acquisition methods and assessing their respective strengths and limitations. By integrating multiple technologies, it will be possible to harness the benefits of each and improve the overall data acquisition and modeling process in future projects.

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