3

THE GEOMETRIC SURVEY
TECHNICAL REPORT

The surveyed building

Location : Via Ardigò 11, Mantova, Italy.
Building: Torre dei Gambulini

The survey project aims to obtain the geometric, materic and degree survey of the studied ancient "Torre dei Gambulini". It consists in a 37 meters height for 7.7x7.7 m base medieval tower located in the hostorical center of Mantova, incorporated for three sides into the building of the *"Archivio di Stato di Mantova"*.

The survey project

The definition of a "**Survey Project**" is the first step in any kind of survey process: considering the final results that we need to obtain, we can establish the steps to proceed with the work and the most efficient tools at our disposal to be used. This allows to avoid any kind of waste in term of time and money, that colud deeply be influenced by a right acquisition schema.

In this specific case, the purpose of the survey was the restitution of orthophotos of the elevations of the Torre dei Gambulini in Mantova (through Photogrammetric Survey) at a scale of 1:50, and the production of its plans and sections at a scale of 1:100 (through Terrestrial Laser Scanner). In this way, at the end of the process we have obtained a precise Geometric Survey of the building.

The main steps to follow have been:
1. Direct survey
2. Laser scanner survey
3. Photogrammetric survey

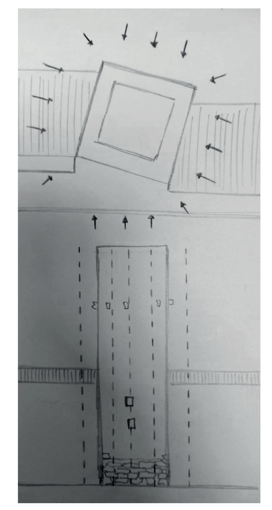
After a primary phase of direct survey, to have a first perception of the architectural objects, with the topographic survey we can obtain a great precision from the geometric point of view but poor results from the colour and materic one. To improve this aspect of the survey, we have to use the integration of the photogrammetry.

1 _ The direct survey

1. The first inspection and the photographical survey

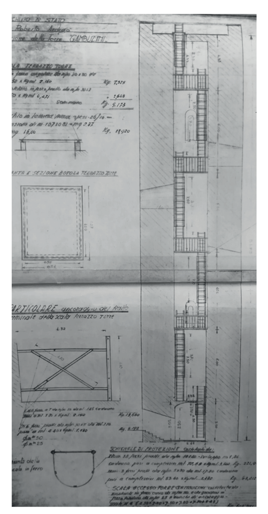
The objective of the first inspection is to take note of the most evident features of the building, such as the relationship with the context, the volume, the internal distribution and the architectural-decorative elements.
In order to facilitate the collection of information, it may be useful to take pictures of the whole and details, describing the building as exhaustively as possible. In this way, once at home, it will be easier to work on the geometrical reproduction of the elements more difficult to remember and check.

2. The eidotype



The creation of an eidotype, a schematic representation on an approximate scale of what must be detected, helps the operator to follow a process.
The eidotypes start from a large scale, which takes into account the context, gradually going more and more into the particular. They allow to become aware of the object and understand from the beginning if the survey has produced some errors.

3. The historical-critical research



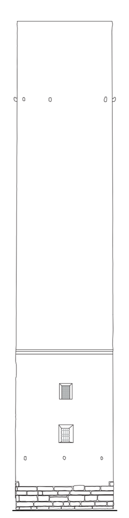
The aim of this phase is the research of informations about the history of the builng, and so about the changings it has undergone over time: how it was when it hs been built, how it has developed during times both about addings and demolitions, how it changed use. Sometimes it's possible to find also drawings realized in the past that could be very useful as starting point of the precise geometrical survey.

4. The direct measurements

The second phase, aimed at taking consciousness of the artifact, consists in the direct metric survey of the tower, done using specific instruments, such as rigid meter, metric rib, laser distance meter, etc... The direct survey is based on two key concepts:

-**Multiscalarity**: proceed from general to particular, always keeping attention on large scale.
-**Discretization**: transforming something that is continue into something that is punctual, choosing t the fundamental points.

5. First geometrical reproduction



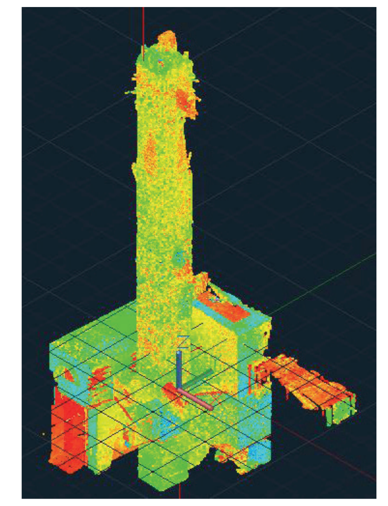
Already at the end of these first phases it is possible to obtain a first geometric survey of the artifact, which will certainly not be precise because it is based on inevitable approximations and subject to errors of measurement and evaluation of the surveyer.
On the basis of a careful analysis of the data collected, the project of in depth survey should be developed to obtain a reproduction faithful to the survey aims.

2 _ The Laser Scanner survey

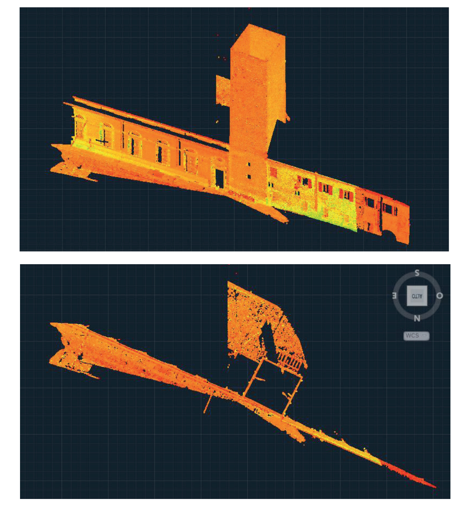
Laser scanner specifications
Leica RTC360 3D Laser Scanner

Some parameters about the visualization of the cloud:
- the type of visualization (scan colors, object colors, normal, intensity, elevation are the possibilities),
- the point dimension (from 1 to 10)
- the level of detail (from 1 to 10).

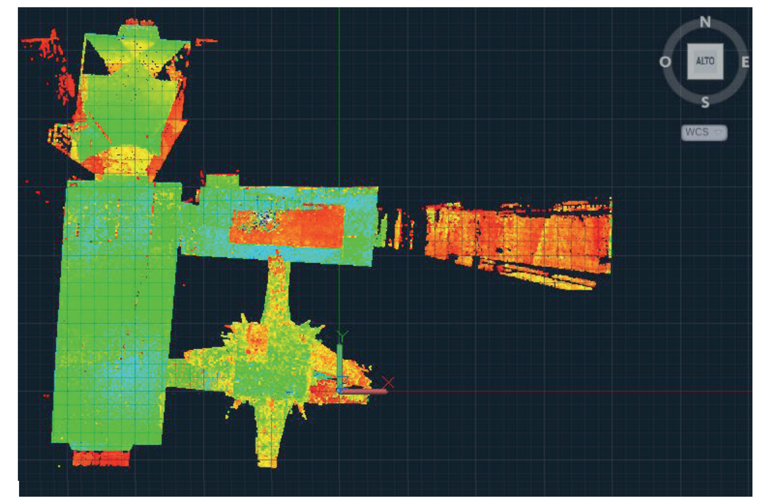
It could be useful to change them to improve the visualization.



1. Data acquisition



In this case, we already had an old point cloud of the external elevation of the Tower, so we used a Laser Scanner to survey the topography of the internal ones, in order to put them together to obtain a complete 3D model of the tower.

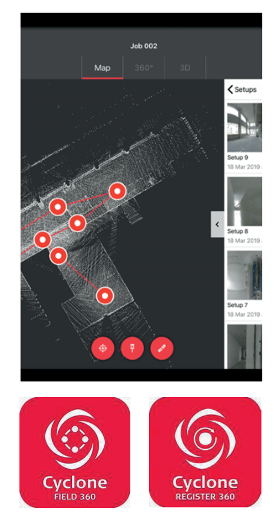


The laser scanner survey has been developed taking two different detection for each accessible level of the tower, and then of the adjacent spaces of the Archivio, to obtain information both about the dimensioning of the internal spaces and both about the walls ones. We differently choose the resolution and the precision of each detection considering the single case conditions and the time at our disposal.
The Laser Scanner automatically rotates on its vertical axis and up the horizontal one and manages to emit and read a very high number of points per second. The instrument positions itself on a point and starts the scan that detects everything that succeeds to see. If there are areas that are not visible from the first station you move to a second and a new scan starts and so on.

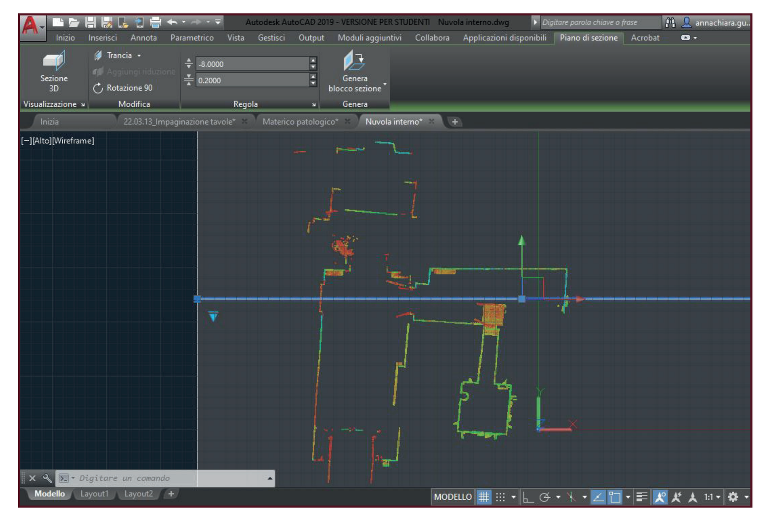
Both for the plans and for the sections now it's neccessary to define a section plane, or more precisely a slice: an horizontal one for the first ones and vertical ones for the second ones.

To obtain an as much as possible precise result, the thickness of this slices must be choosen considering the scale of the drawings and the visualization of the points, of course. More in detail, the value must be calculated with the same formula used for the graphic error, so multiplying the factor of scale for 0.2mm. In our case, the results is 0.02m for the 1:100 sections. These values could then be arised a little bit (at maximum of the double) in case that the visualization of the points in that slice is not enough good to obtain a complete redrawing of the sectioned elements.

2. Data elaboration



It doesn't be necessary to worry about joining different scans because the onboard software takes care of it. The *Leica Cyclone FIELD 360* App connects field data with the scanner and office data logging with the *Cyclone REGISTER 360* app. In this way, the detector can automatically capture, record and examine the scanned data and the images obtained in the field. This makes it possible to check for errors or shortcomings during detection.

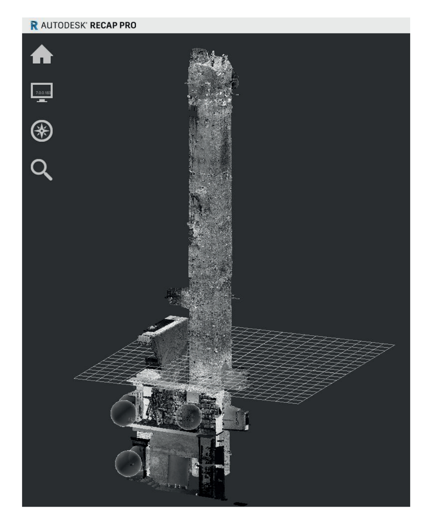


The laser scanner returns a point cloud: a set of points in a given coordinate system. In a three-dimensional coordinate system, these points are generally defined by X, Y, and Z coordinates, and represent the outer surface of an object. The point could be seen as a text file in which each row represents a measured point in the space, described by different informations:

- 3 Spatial coordinates X,Y,Z
- 3 Coordinates of the color RGB (0-255)
- 3 Directions of the normal at point Nx,Ny,Nz.

Every point of this cloud with its coordinates could be used later to orientate and scale correctly our model in the space.

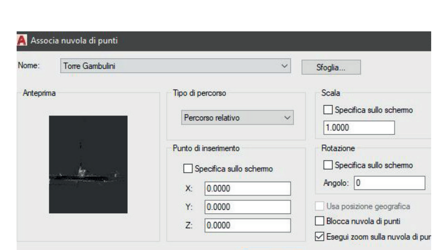
The point cloud could be simultaneusly seen in its tridimensional view on **Autodesk ReCap PRO**, that allows to have a more complete visualization of the objects.
Also in this case it is allowed to change the type of visualization (that are the same of the cloud on AutoCad) considering the specific situations.



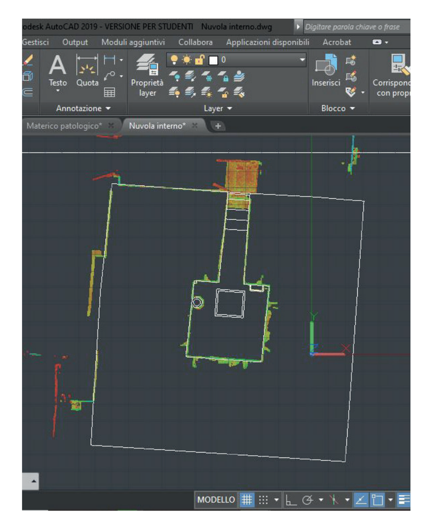
3. Point cloud redrawings and measurment

The Dense Cloud obtained could now be used to produce the technical drawings of the surveyed area. In our specific case, the aim was to redraw the plans and the vertical sections of the Tower in 1:100 scale. The software used has been *AutoCad*.

After having set up the program in meters, the point cloud could be inserted using the global WCS: the coordinates in the space must be 0,0,0 and the scale must be 1.

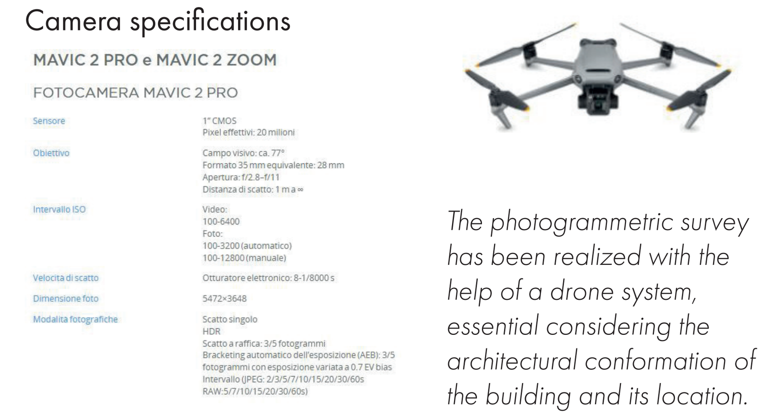


The redrawing phase requires a very careful work, that must follow some objective rules to be sure to obtain a correct result, but at the same time, some choices depend on the personal perception and sensitivity of the surveyer. It's for this reason that a survey result **can't never be considered complitely objective and absolute.**



3 _ The Photogrammetric survey

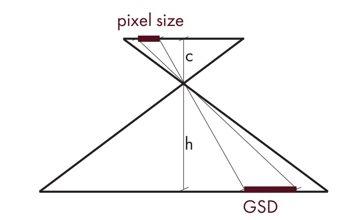
Camera specifications



The photogrammetric survey has been realized with the help of a drone system, essential considering the architectural conformation of the building and its location.

1. Photo Shooting

CAMERA MODEL: Mavic 2 PRO
RESOLUTION: 5472 x 3648
FOCAL LENGHT: 10.26 mm
PIXEL SIZE: 2.41 x 2.41 µm
PRECALIBRATION: no



c : h = pixel size : GSD
focal lenght : distance = sensor size : covered areas

Using the proportion we find the maximum distance from which we can take photos to obtain an acceptable result at 1:50 scale with a graphic error of 0.2 (GSD = 0.2 x 50 = 10mm = 1cm). Taking into account the characteristics of our camera and the use of a focal length of 10.26 mm, we get a maximum distance of 42.57 m. (10.26 mm : x = 0.00241mm : 10).

In our specific case, using a drone we have had the possibility to take the pictures from a considerably less distance from the tower, approximately 5m, for all the elevations. It has been changed in case of obstacles.

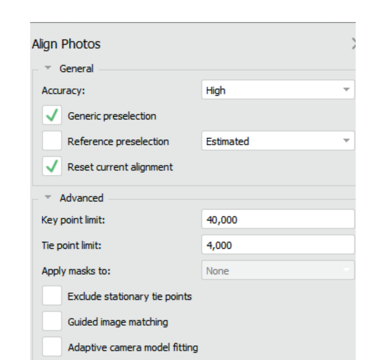
The meteorological condition was cloudy, so it was perfect to obtain an homogeneous quality of the pictures, with no too high exposure nor shadows.

2. Photo Adding and Quality Check

After taking the photos and checking that they reflect the necessary characteristics requests, we proceeded with the insertion on *Agisoft Metashape Professional (64 bit)* where their quality was estimated, so that we can easily discard those with errors that made them unsuitable. We have to check that the quality is enough high and that the area remains well covered by the remained pictures. Later, a manual editing phase was carried out through the creation of masks on the images in order to eliminate the areas in sharp contrast and superfluous elements such as sky and roads, that could slow down the processing of the various phases.
In this case 668 photos have been used.

3. Photo Alignment

The aim of this operation is to give to the photos a relative orientation. We set a high general accuracy, a key point limit of 40.000 and a tie point limit of 4.000 (right values for the chosen scale of representation). The result of the photo alignment is a sparse cloud of points, with every point (of the original images) fixed in a relative space.



Now we have a **point cloud** in which we can see all the camera positions. In this case **668 photos** have been allined.

4. Model Orientation

The aim of this operation is to obtain an absolute orientation of our model. We need at least 3 target to check the orientation of the photos.
We proceed with the search for markers (**GCP**, Ground Control Points) in the photos, the points that will serve us to orient our model. Since no markers were placed during the survey, a cloud of points was used, obtained by means of the laser scanner, for the detection of GCP, in order to geo-reference and scale the model.

We insert the points found in each photo where the elements chosen as markers are visible. At least two photographs in which the element appears are required to find the correspondence of the point in the photos (stereoscopy). For greater security, we have identified the exact position of the marker in as many photos as possible, taking care the pixel error.
Once the process was completed for each GCP we optimized the cameras to ensure greater accuracy of our model.

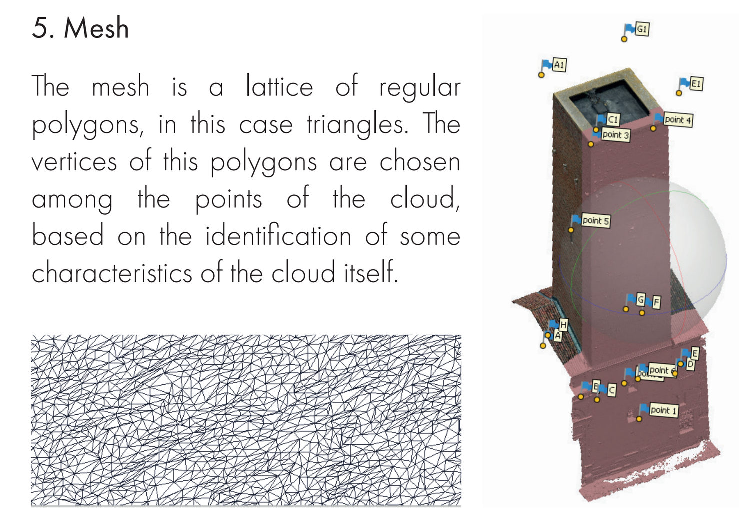
Label	X error (cm)	Y error (cm)	Z error (cm)	Total (cm)	Image (pix)
point 1	0.427881	-0.727716	1.13772	1.41671	4.385 (7)
point 3	0.910049	-1.71791	0.781655	2.09532	7.362 (7)
point 5	-1.11832	3.18646	-1.50165	3.69582	5.545 (10)

4. Dense Cloud

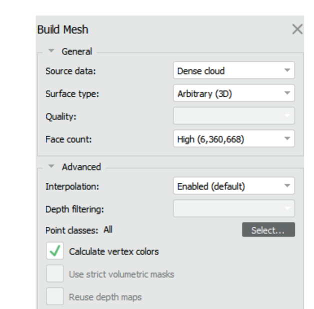
We proceed with the generation of the dense point cloud using medium quality and mild filtering. Despite this, as we will see, the average quality is more than sufficient for our aims.

5. Mesh

The mesh is a lattice of regular polygons, in this case triangles. The vertices of this polygons are chosen among the points of the cloud, based on the identification of some characteristics of the cloud itself.



We choose an high quality for the elaboration, we disabled the automatic completion by the software of some missing parts of the building, for which there was not enough data, and we thick the option *"calculate vertex colors"* to obtain also those kind of informations.

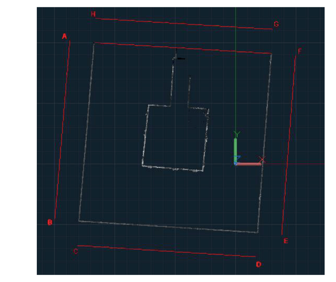


The final mesh can be visualized in different ways ("model shaded" or "model solid").

6. Orthomosaic

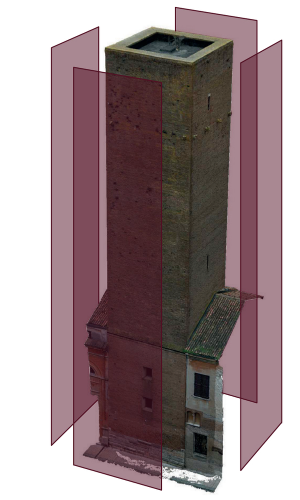
Each orthomosaic to be generated requires a **projection plane** identified by at least three points, taken considering two points aligned on the vertical axis and two on the horizontal axis.
Considering the aim of our survey, we decide to create four orthophotos of the elevations and one of the coverage. Once the point cloud has been exported to the AutoCAD program, without changing the scale and putting it in the axis origin, we find the coordinates of the points we need to create our projection plane.

To these values we have to add a Z value to obtain the parallel planes we need.



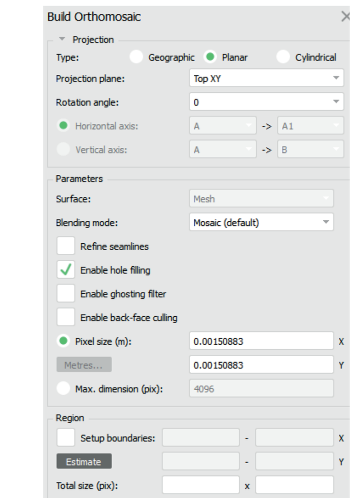
Parallel segments Coordinates

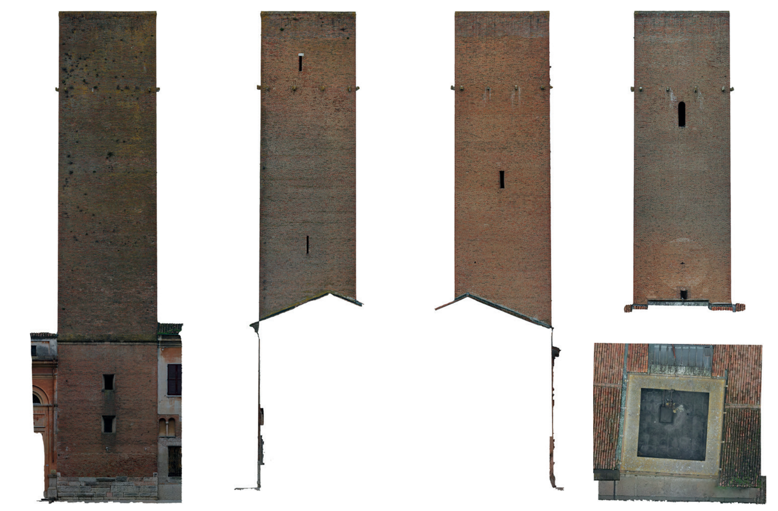
A x=-6.8580 y=+5.0966 z=0
B x=-7.4798 y=-2.2699 z=0
C x=-6.5473 y=-3.3519 z=0
D x=+0.8480 y=-3.8260 z=0
E x=+1.9090 y=-2.9049 z=0
F x=+2.4782 y=+4.4830 z=0
G x=+1.5427 y=+5.5579 z=0
H x=-5.8000 y=+6.0106 z=0



The pixels of our orthophoto have a side of 0.00150883m but such a complex number will be very inconvenient for subsequent calculations and checks.

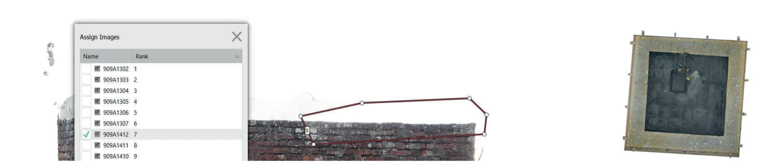
For this reason we decide to increase the size of the side to 0.005 m (**5mm**), either to compensate for any big errors due to distance, or to improve the operability of the data.





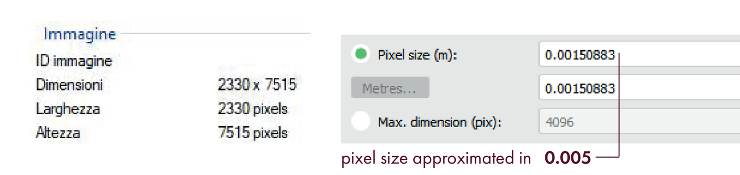
7. Orthomosaic improvement

The first results present some no defined parts in the orthophoto.
We proceeded with the **polygon strategy**: after cleaning the model with the polygonal areas and resizing the calculation region, we assign images without undefined objects in some specific points of the orthophoto. To improve the quality we have used also *Photoshop*, that allowed us to delete the useless border elements and improve te light and colour texture of the images



8. Orthomosaic scaling

After the creation of the orthophotos, it is necessary to put them in scale to obtain the necessary dimensional informations about the object surveyed. We have to multiply the number of pixel for the pixel dimension, to obtain the real height and lenght of the orthophotos. After this calculation, we have put the image on *AutoCad* where we have scaled it using the founded dimension.



ex: 7515 x 0.005 = 37.575 m.

9. Orthomosaic redrawings and measurment

Afterwards, you can export the orthomosaic obtained in various image formats (JPG/TIFF/PNG). The image can then be used to realize the vector drawing through CAD, to return the façades. The finished orthophotos are ready to obtain all the dimensional and quality informations about the architectural object of study.