GEOMATICS I

Metric Survey Planning

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The notes on Metric Survey Planning describes the main criteria to be used to correctly plan a metric survey intervention able to answer to specific requests of the final users.

ERAMCA

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1. Introduction

Metric Survey is a technical tool usually needed in engineering and architectural interventions.

The main aim of the metric survey is to provide an accurate and detailed description of the object's geometry on which the intervention has to be planned to allow engineers and architects to design all the needed interventions correctly.

As with all technical interventions, Metric Survey planning must also be faced in three phases: project, execution, and quality assessment.

A Metric survey's final result must be considered a unique 3D coordinate system.

Considering the main aims of the ERAMCA Master, the coordinate systems to be used have the Z-axis coincident with the local vertical direction, which represents the directions of the loads that will be considered for all the structural analysis and designs.

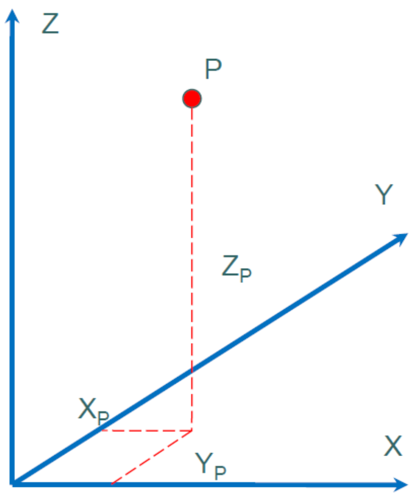

Figure 1 – The cartesian coordinate system for building's metric survey

The result of a Metric Survey is a 3D model of the surveyed object with the level of detail (LoD) and accuracies, satisfying the final users' needs.

a. The 3D Model

A 3D model is a set of surfaces that define empty and total volumes.

All the metric survey techniques (total station, laser scanner, photogrammetry, GNSS, etc.) can measure the 3D coordinates of single points. The only knowledge of these coordinates does not allow the realization of a 3D model without some more logical actions that the surveyor has to perform.

A set of the 3D point is not a 3D model because it lacks <u>topology</u>.

Topology is the organization, flow, and structure of vertices/edges/faces of a 3D model. It is how well it is possible to organize a set of known 3D points in a 3D model that is efficient, clean, and detailed.

A complete metric survey aims to build a 3D model and not only a set of points with known coordinates in a given coordinate system.

Therefore, a metric survey must be completed with accurate 3D modeling after acquiring a set of known coordinates.

The modeling phase of a metric survey runs in two subsequent steps: segmentation and surface reconstruction.

b. From points to 3D models

To better understand what a 3D model is, refer to Figure 2.

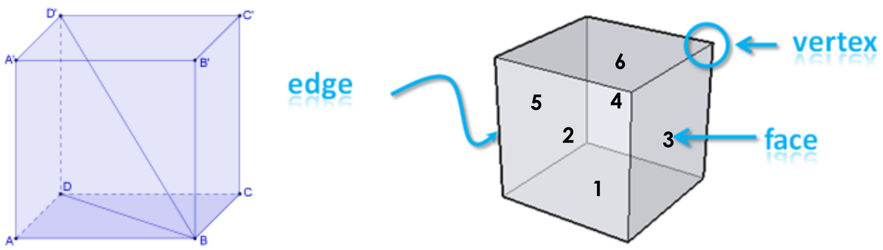

Figure 2 – The 3D model of a cube

Figure 2 shows the height points (vertexes) surveyed with some tools to define the 3D model of a solid: A – B – C – D – A' – B' – C' – D.'

After the point's acquisition is made, the surveyor, by using CAD software, can join the surveyed points by using lines (edges): AB – BC – CD – DA – AA' – BB' – CC' – DD'- A'B' – B'C' – C'D' – D'A'.

The edges are finally used to define the six solid's faces:

- AB – BC – CD – DA defines the face 1;
- AB – BB' – B'A' – A'A define the face 2;
- BC – CC' – C'B' – B'B define the face 3;
- CD – DD' – D'C' – C'C define the face 4;
- AD – DD' – D'A' – A'A define the face 5;
- A'B' – B'C' – C'D' – D'A' define the face 6.

The six generated faces share their edges with other faces to define the total volume of the solid.

The edge's generation process is called segmentation based on the known points. The segmentation process is a set of procedures performed to isolate a 2D region, which can be interpreted as a unique surface of a known equation (e.g., a plane).

Figure 2 shows the traditional approach to metric survey, where the needed points to define 2D regions are selected by the surveyor before estimating the coordinates. It is possible to say that in these cases, the surveyor that analyzes the object during the measurement process performs the segmentation and, by using their experience and the comprehension of the surveyed object, define the edges of the simple surfaces to be generated at the end.

Today many metric survey techniques offer surveyors a different strategy.

Laser scanners, automatic digital photogrammetry, SLAM-based instruments, and structured light scanners allow the acquisition of point clouds using automated tools (see Figure 3).

The automatic acquisition means that the selection of the surveyed points is "not intelligent": therefore, the eight vertexes needed to build up the solid of Figure 2 could be not present in the point cloud or, if they are present, it is difficult, or almost impossible, to understand where they are.

When the object allows the hypothesis to substitute a subset of points with simple surfaces, the segmentation must be performed by using specific software, which helps, more or less automatically, the extraction of the edges of the possible known surface (e.g., a plane, a sphere, a cylinder, etc.) as shown in Figure 4.

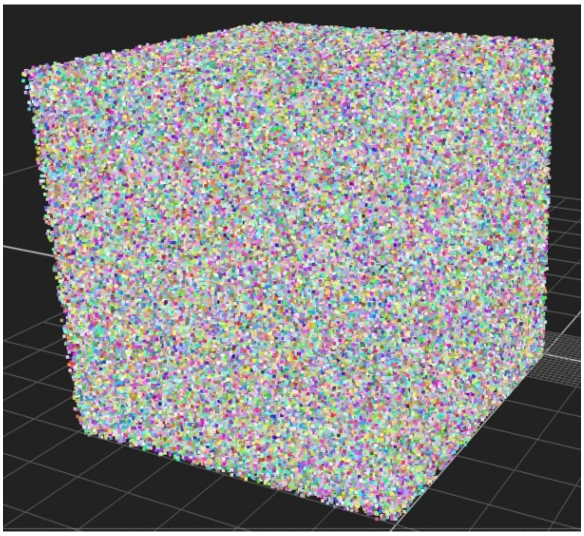

Figure 3 – Point cloud of a cube

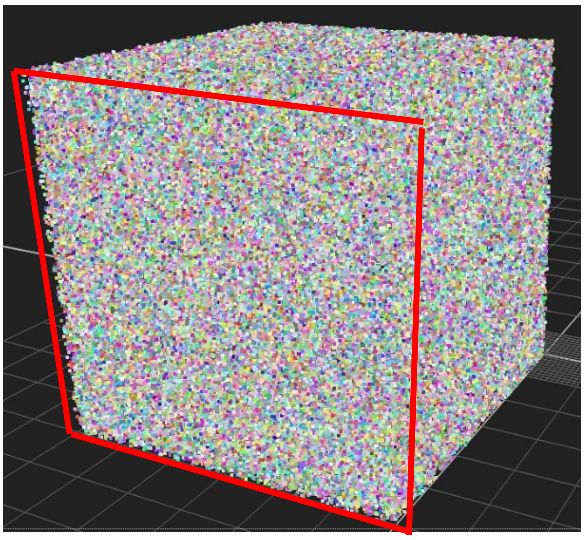

Figure 4 – Automatic segmentation (edge extraction)

After the segmentation, a proof of the adopted hypothesis has to be performed: *ad-hoc* software allows rapid visualization of the distances between the selected surface and the region of the point cloud isolated during the segmentation process (see Figure 5).

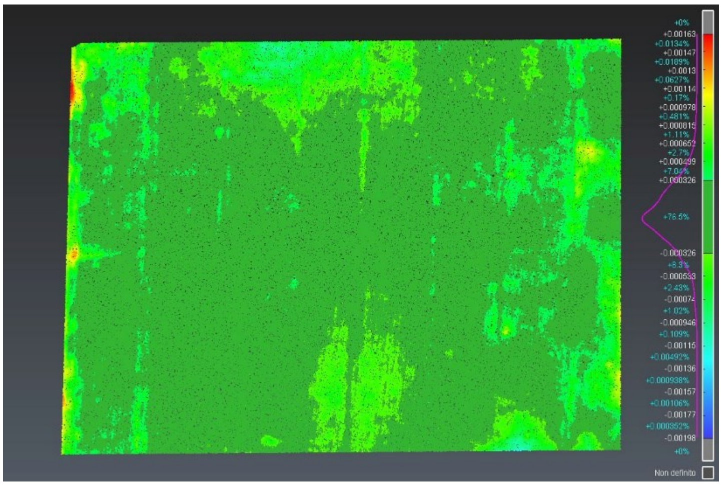

Figure 5 – Statistical comparison between a plane and the set of points

In the case shown in Figure 5, it can be seen that the distance between all the points selected from the previous segmentation phase is less than 2 mm.

If the metric survey's accuracy is greater than or equal to 2 mm, then replacing the selected points with the plane is admissible.

This simplification involves substantially reducing the memory occupation of the final 3D model with considerable advantages for its management and visualization.

When finding a simple surface to substitute a subset of points is impossible, an automatic solution could be found using the TIN (Triangulated Irregular Network) approach. This solution, present in all the 3D modeling software, is based on the algorithm invented by Boris Nikolayevich Delone (Russian mathematicians of the XX century, also known as Delaunay, a French transcription of his original surname).

A set of sparse 3D points is modeled using triangles defined so that the circumscribing sphere does not contain other points of the subset.

The algorithm is fully automatic and therefore does not require the intervention of the surveyor during the elaboration. Still, it preserves all the points of the subset and, thus, does not allow a reduction of the memory occupation.

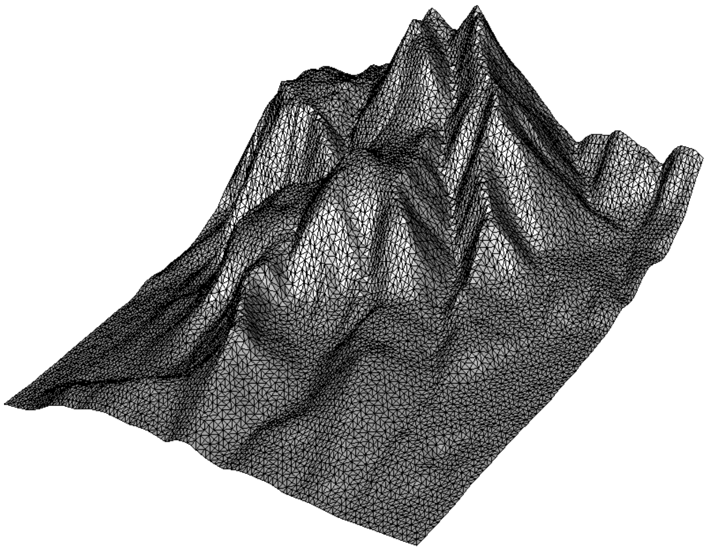

Figure 6 – 3D TIN model of a set of sparse points

These two alternative methods can be used in different parts of the object to be surveyed, and the results merged in a unique 3D model.

Suppose these procedures are applied correctly in the end. In that case, the obtained 3D model will be the smallest in terms of occupation of memory by preserving the accurate description of the surveyed object with the required accuracy[1].

2. Metric Survey's project

The metric survey is the first step in engineering and architecture design. Therefore, the metric survey has to satisfy the professionals' needs in terms of accuracy and level of detail (LoD).

It is impossible to conceive a metric survey that could satisfy all the possible needs

[1] The correct meaning of "accuracy" is explained in the notes on Measurement Theory

because every specialist must extract different information, which is the base for their project.

Therefore, it is impossible to plan a correct metric survey without understanding the uses of the 3D model that will be realized at the end of the metric survey process.

There are two different project levels to be developed when a Metric Survey is needed.

The first level of design refers to understanding the real needs of the final users (engineers and architects). It must be developed in close collaboration between the surveyor and the results user.

The second level defines how the Metric Survey must be executed to reach the goals fixed in the previous phase.

The correct definition of these two project levels will allow to correctly plan all the operative phases and ensure the goal's achievement accurately and rigorously.

a. First-level design

Main decisions

The first things that must be fixed before starting with a Metric Survey are the final accuracy, the LoD in the different parts of the object to be surveyed, and the deliverables.

Each of these characteristics will influence the management of the metric survey from its beginning.

Therefore, fixing the above topics must be defined accurately with the collaboration of the final user.

The chosen **accuracy** is strictly connected with the precision that the surveyor has to guarantee during all the measurement processes (from primary data acquisition to the modeling phase).

For example, if the final accuracy has been fixed at 5 cm, the precision of the points that define the final model must be not greater than 2.5 cm if the probability of 95% is accepted.

The definition of the **LoD** in different parts of the surveyed object will influence the choice of the detailed survey techniques that will be used and, therefore, the needed time and equipment that the surveyor must be able to provide.

The kind of **deliverables** will also influence the organization of the work: if the deliverables are 2D drawings (e.g., plans, sections, elevations), the number of needed points is reduced concerning the number of points required for the realization of a complete 3D model.

Historical surveys

Usually, existing buildings and, generally speaking, Cultural Heritage assets have been surveyed in the past. Old surveys, if not private property, could be recovered in public archives or some publications or maybe put at the disposal of the professionals who did them.

These kinds of already done metric surveys are essential to understand the changes that occurred from the survey date up to now, and sometimes, the unchanged portions of the object could be recovered from them.

Old surveys and drawings help plan the new survey's interventions and check if the surveyed differences are acceptable or not after a direct inspection.

Selection of points to be surveyed

By differencing the required points (coming out from the first step of the first-level design) and the valuable points that could be resumed from historical surveys, the new needed points are evident for the surveyor.

Considering the amount and the location of the new needed points, the surveyor can plan the second-level design.

This step always requires a direct inspection of the site to identify the environmental constraints that will give necessary information for the next step.

Selection of the detailed survey techniques

The selection of the detailed survey techniques must take into consideration both technical and economic aspects.

The first thing that must be considered is the location of the new points that must be surveyed by analyzing the accessibility with the different instruments, the lighting conditions, the climate, and how long the surveyors could occupy the site without making/having noise.

The cost of the primary data acquisition is the second aspect that must be considered. The number of people to be involved, their cost of travel and stay, and the daily rate for the use of the instruments are just a few examples of the elements that serious planning has to consider.

Today the experiences show that the best solution is to adopt a correct balance between all the techniques which allow automatic survey (e.g., automated digital photogrammetry, range-based techniques, SLAM-based systems).

In some cases also, total stations and GNSS could be considered, although they cannot acquire a large number of points in a limited time and, in the GNSS case, they are usable only in outdoor spaces.

b. Second-level design

Once the surveyed techniques for the detailed survey are defined, it is possible to move to the second-level design of the metric survey.

This phase could be subdivided into three steps: control network establishment, second-order network establishment, and detailed survey planning.

Control network

The control network consists of a set of points that have the aim:

- to materialize the unique coordinate system that will be used to refer to the final 3D model;
- to limit the error propagation so that the final 3D model will respect the limits of the accuracy stated in the first step of the first-level design.

The vertexes of the control network must be reduced to a minimum number by respecting a rule: they have to circumscribe the space where the detailed survey will be done.

The vertexes of the control network must be materialized so that they can be recognized and used at least for the time needed to complete the detailed survey and check for its completeness and accuracy.

Suppose it is foreseeable that the object to be surveyed must be put under a monitoring action. In that case, the vertexes of the control network must be materialized permanently and documented using a sketch allowing their finding during the monitoring period.

Figure 7 – Permanent materialization of control network's vertexes

To reach the accuracy of the points of the detailed survey, fixed in the first step of the first-level design of the metric survey, the precision of the control network's vertexes must be almost 1/10 of the precision of the final points. For example, if the required accuracy of the points has been set at 5 cm (so the precision at 2.5 cm with a 95% probability), the precision of the three coordinates of the vertexes of the control network must be almost 2.5 mm.

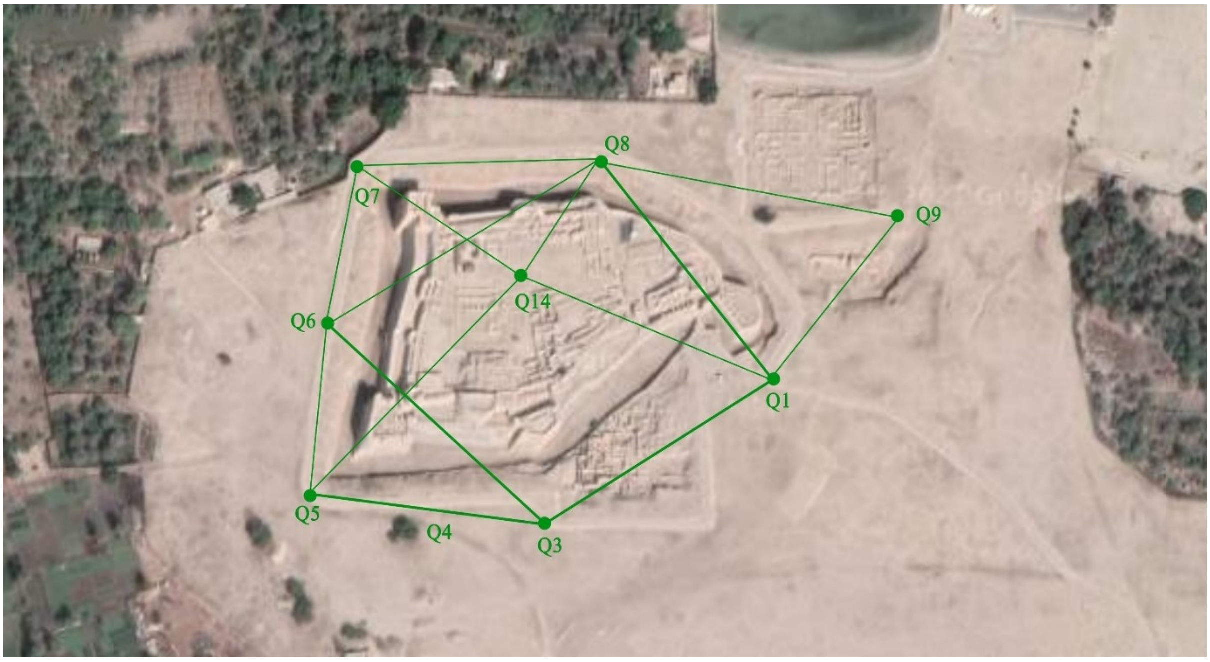

Figure 8 – Control network and GNSS baselines

To reach these precisions, usually, the metric survey considers different techniques for planimetric and altimetric coordinates.

Regarding planimetric surveying of a control network, GNSS methods are usually used in a relative positioning technique everywhere possible. In case also total stations can be mainly used in indoor spaces.

For altimetry, differential leveling is always used to guarantee millimetric precision.

The acquired measurements (baselines from GNSS, or angle, and distances from total station) are used to estimate the coordinates of the control network's vertexes in a rigorous adjustment approach to check and certify the reached precisions.

Figure 9 – GNSS baseline measurement

Second-order network

In many cases, a second-order network must be realized to materialize the coordinate system defined by the control network in the places and with the strategies required by the detailed survey techniques that will be adopted.

Limiting to the survey of buildings and complexes of buildings, automatic digital photogrammetry, range-based techniques (e.g., Terrestrial Laser Scanner), and SLAM-based systems are used.

Those three survey techniques require some points of known coordinates to ease the estimation of the final point's coordinates.

Figure 10 – Marker used both for TLS and Terrestrial Photogrammetry

Photogrammetry requires some Ground Control Points (GCPs) in specific locations to allow the external orientation of the acquired images. Those points could be materialized by clear signals or by details of the object to be surveyed.

Terrestrial Laser Scanner systems and SLAM-based systems require some artificial marks to ease the registration of the scans acquired from different positions.

Their location and materialization must be carefully planned before starting the survey.

Figure 11 – GCPs positions

Also, in this case, GNSS and total stations can be used to acquire the needed primary data for estimating their coordinates and precisions.

In this step, the precision that must be guaranteed can be almost 1/5 of the final accuracy required for the final 3D model.

Detailed survey

Once the control and second-order networks have been defined and established, the detailed metric survey can start.

As was said before, mostly automatic techniques are used, such as Terrestrial and aerial Laser Scanner systems, terrestrial and aerial automatic digital photogrammetry, and SLAM-based systems.

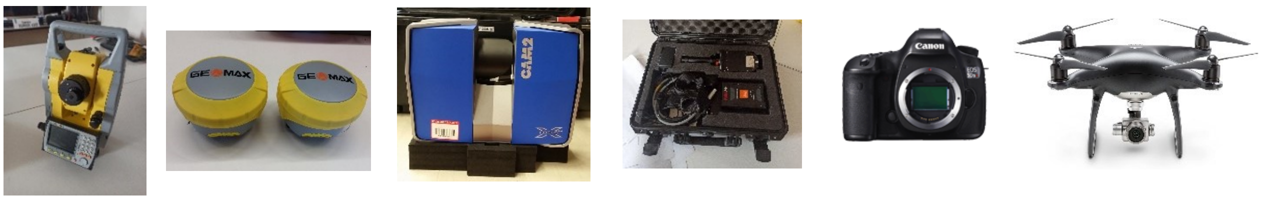

Figure 11 – Set of instruments used for the metric survey: total station, GNSS receivers, Terrestrial Laser Scanner, SLAM-based system, terrestrial digital camera, and a drone equipped with h digital camera.

In some cases, especially in indoor spaces, arrangements to guarantee the correct lighting of the surfaces to be surveyed must be adopted.

Using drones for aerial photogrammetric surveys must be carefully planned by considering local laws and regulations to obtain permission for the flights by local authorities.

The detailed survey can run in parallel, so correct planning of the activities must be performed to avoid wasting time for the operators.

3. Conclusions

The metric survey must be accurately planned before starting the on-the-field operations to allow the collection of all the necessary equipment for developing all three steps of the second-level design.

During the second-order network survey, some extra points must be surveyed to allow a check of the accuracy of the 3D model.

Only the correct planning of all the steps of the survey and the involvement of skilled operators who know all the details of the activities can ensure good results. It must be remembered that the required final precision for the 3D model can be reached only if the primary data acquisition is correct.

The subsequent data treatments cannot increase the precision: on the opposite, each manipulation of the primary data to obtain the 3D model, as explained in the first paragraphs, will decrease the precision.