Terrestrial Laser Scanning for underground marble quarry planning: Comparison of multi-temporal 3D point clouds

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INTRODUCTION

Terrestrial Laser Scanning (TLS) is becoming increasingly important for surveying applications.

This technique can acquire thousands to millions of points per second with a range up to few kilometres.

In the last years the relative precision was a few millimetres at 50 m while now the same precision is achievable at more than 100 m.

Leica ScanStation 2 Laser Scanner

Only three years ago it could take hours to acquire a full scene within a field of view of 360° (azimut) x 270° (zenit); nowaday it takes 3 to 10 minutes.

Trimble TX8 Laser Scanner

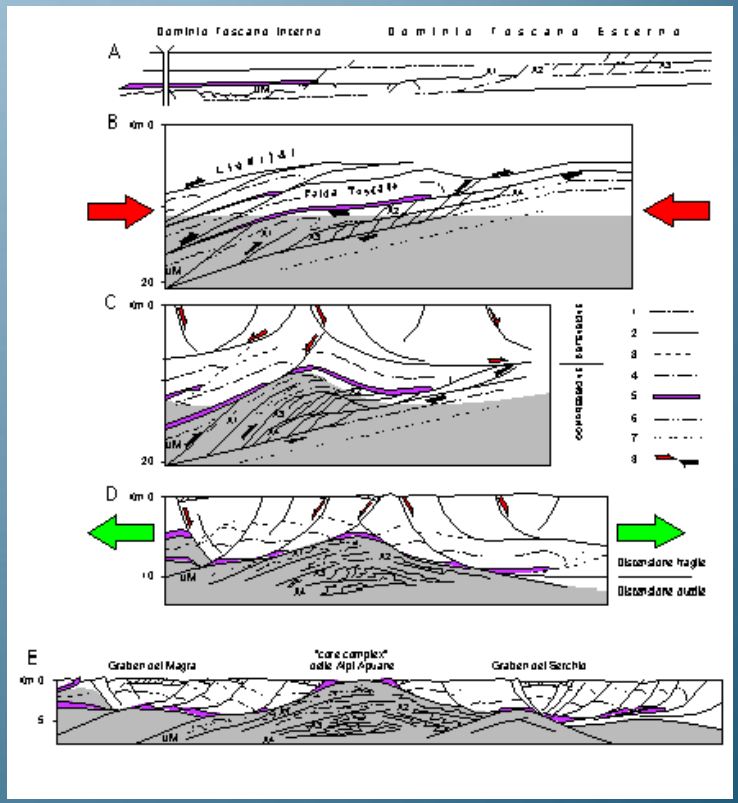
AIM

By the use of geomatic techniques, integrating Terrestrial Laser Scanning (TLS), topographic measurements with Total Station (TS), Global Positioning System (GPS) and High Resolution Photos, the main scope of this study is to perform a multi-temporal point cloud comparison.

The general purpose of the work is to show an innovative and efficient method to investigate the morphological changes due to the material extraction in an underground marble quarry of the Apuan Alps (Tuscany, Italy) over a time spam of about two years.

STUDY AREA

The **underground marble quarry** is named **Sottovettolina** and it is located in the valley of Forno, in the Apuan Alps.

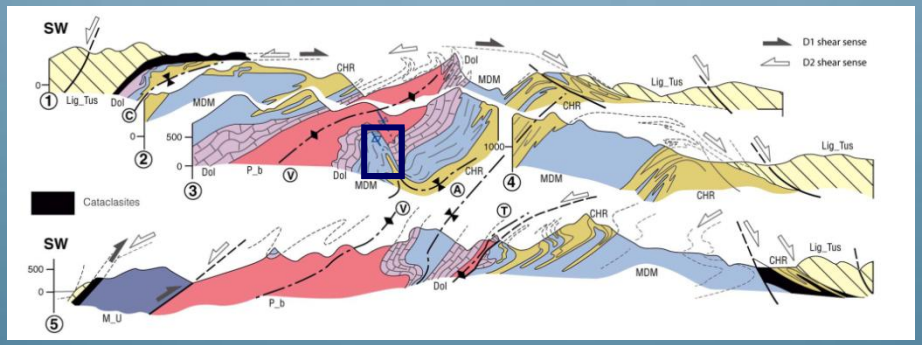


Apuan Alps are a metamorphic complex outcropping as a tectonic window, resulting from two main tectono-metamorphic events:

- **D_1 phase** (Lower Miocene): ductile compressional event due to the continental collision between Sardina-Corsica block and Adria plate;
- **D_2 phase** (Upper Miocene): distensional event that led to an isostatic rebalance.

STUDY AREA

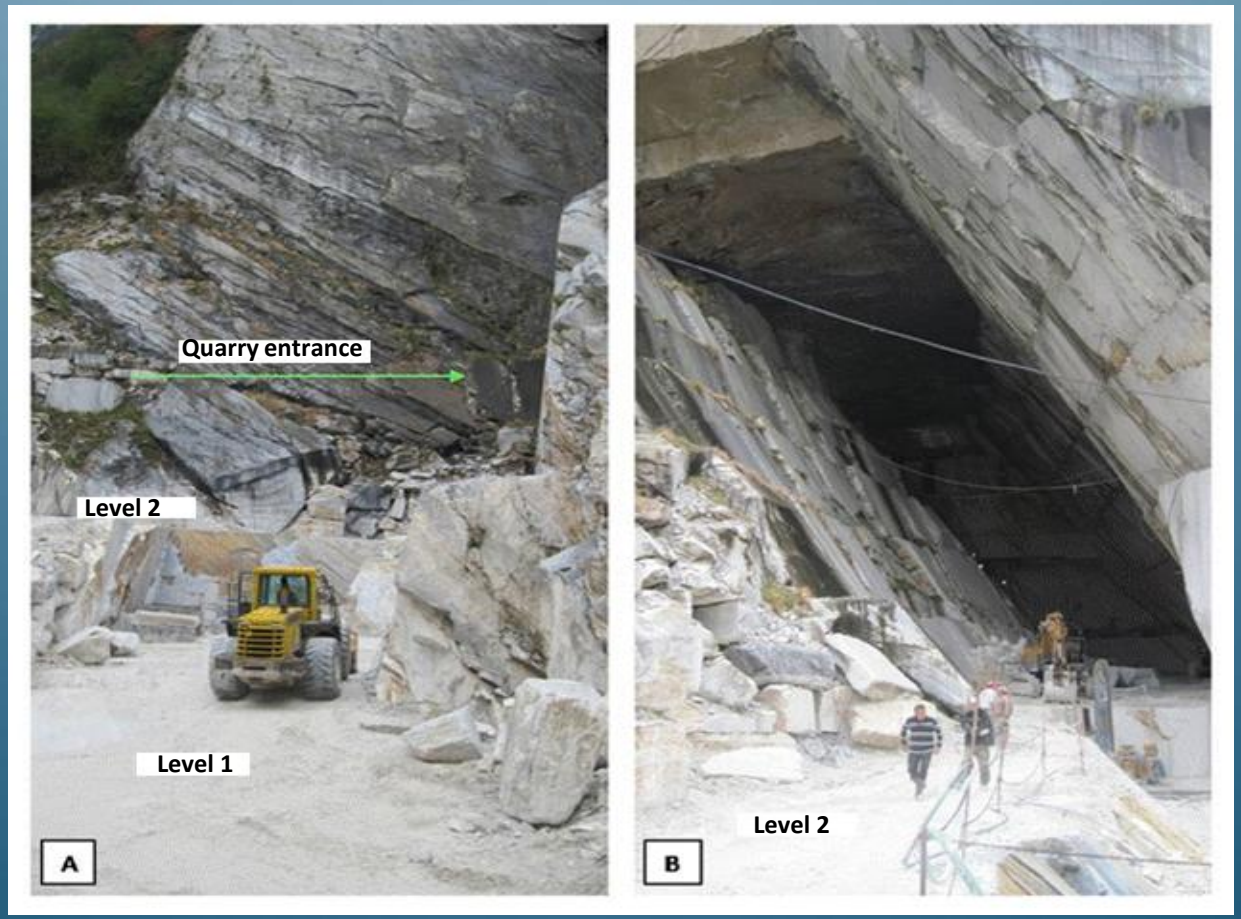
The excavation is carrying on in the core of a late (D_2) antiform fold structure located in the inverted limb of the *Orto di Donna* syncline belonging to the D_1 phase.



The marble varieties extracted from the quarry belong to the groups of **Grey Marbles** and **Veined Marbles**

STUDY AREA

The quarry consists of 2 levels (Fig. A): the underground level extends over 90 m (Fig. B).



Outside

Quarry entrance

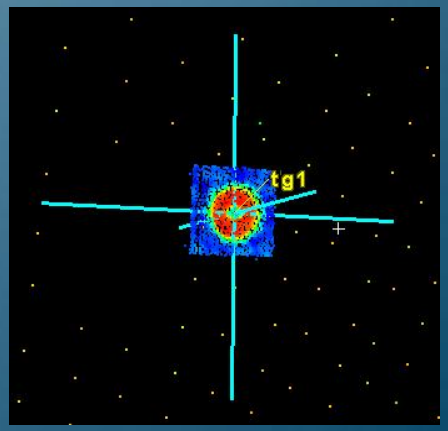
TERRESTRIAL LASER SCANNING

Leica ScanStation2 Laser Scanner

5 target supports were permanently fixed at convenient locations not subject to excavation during the first field survey in **October 2012.**

Targets were used as reference for the first topographic survey and the same were used as system constrain for the second topographic survey in **May 2014.**

Leica Geosystems blue planar targets allow automatic identification and extraction by Leica™ Cyclone software.

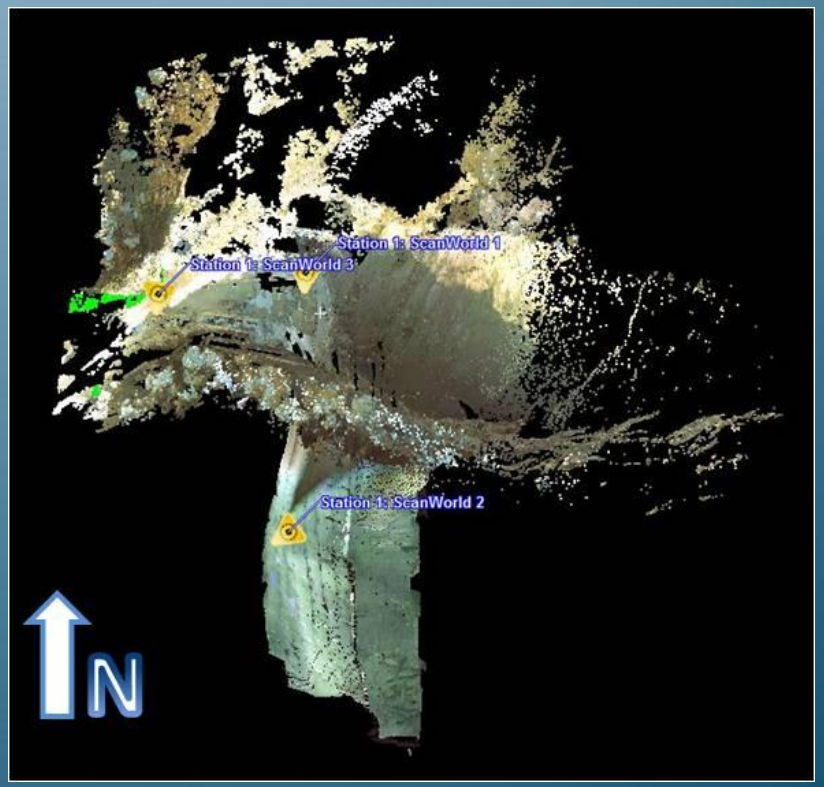


Scan detail of a Leica planar target

TERRESTRIAL LASER SCANNING

Three scans were necessary to survey the area; the spatial resolution was set to 5 cm at a distance of 50 m giving a point cloud of 50 million points.

Leica™ ScanStation2 Laser Scanner



Top view of 3D Laser Scans

DIGITAL PANORAMA PHOTOS

After every scan, replacing the Laser Scanner with the Nodal Ninja 3II series panoramic tripod head, high resolution images of all the around area were taken by an external digital camera.

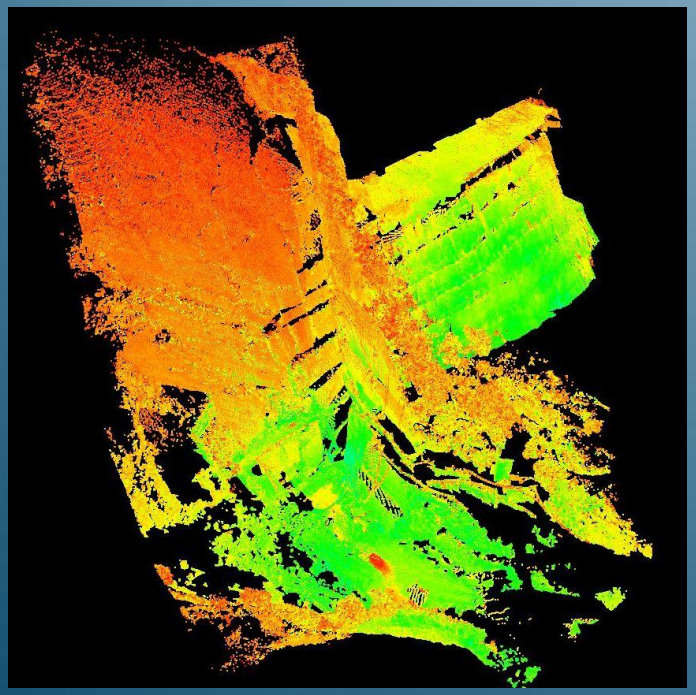
External camera (Nikon D80)

Example of a panoramic photo

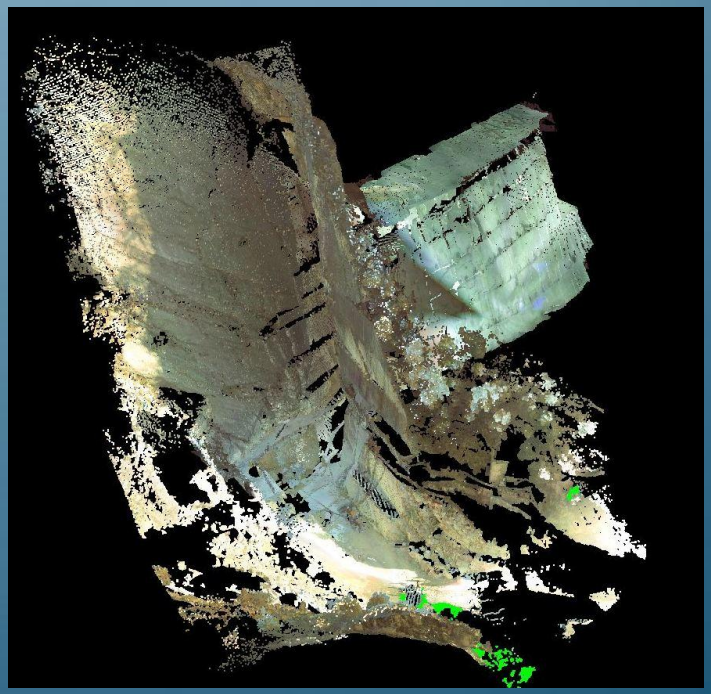
3D POINT CLOUDS

The **point clouds** can be displayed by:

- Intensity values
- Textured points with RGB info from the external digital panorama photo



Intensity point cloud



Textured point cloud

GPS AND TOTAL STATION

- Accurate topographic measurement of reflectors/prisms and targets were used as system constraints with Total Station (mm)

Leica circular prism

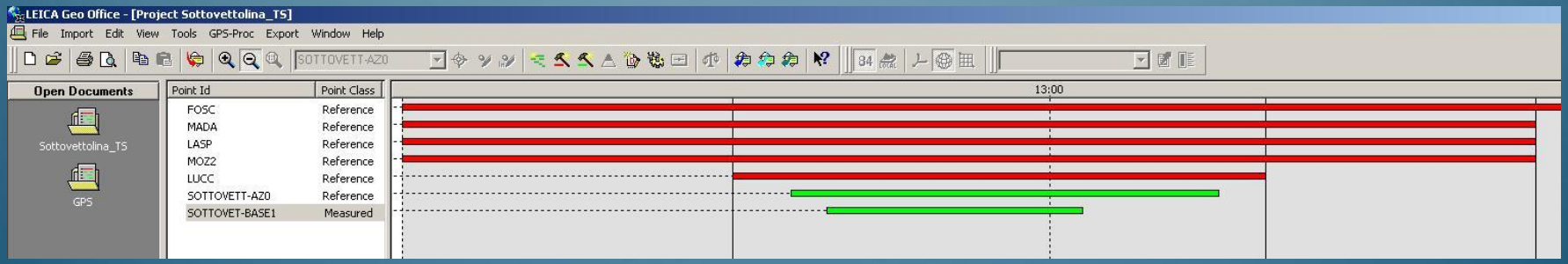
Leica MS50 Total Station

- Measurement in static modality for more than 3 hours of individual reference reflectors/prisms with two geodetic GPS (cm)

Leica Viva GS15 GPS

DATA PROCESSING

- GPS data were post-processed with differential method using simultaneous data of five permanent GPS stations (*Borgo a Mozzano* (MOZ2), *La Spezia* (LASP), *Pieve Fosciana* (FOSC), *Lucca* (LUCC) and *Pisa* (MADA)) available on Leica SmartNet ItalPos official site (http://it.smartnet-eu.com/rinex-30-sec_568.htm).



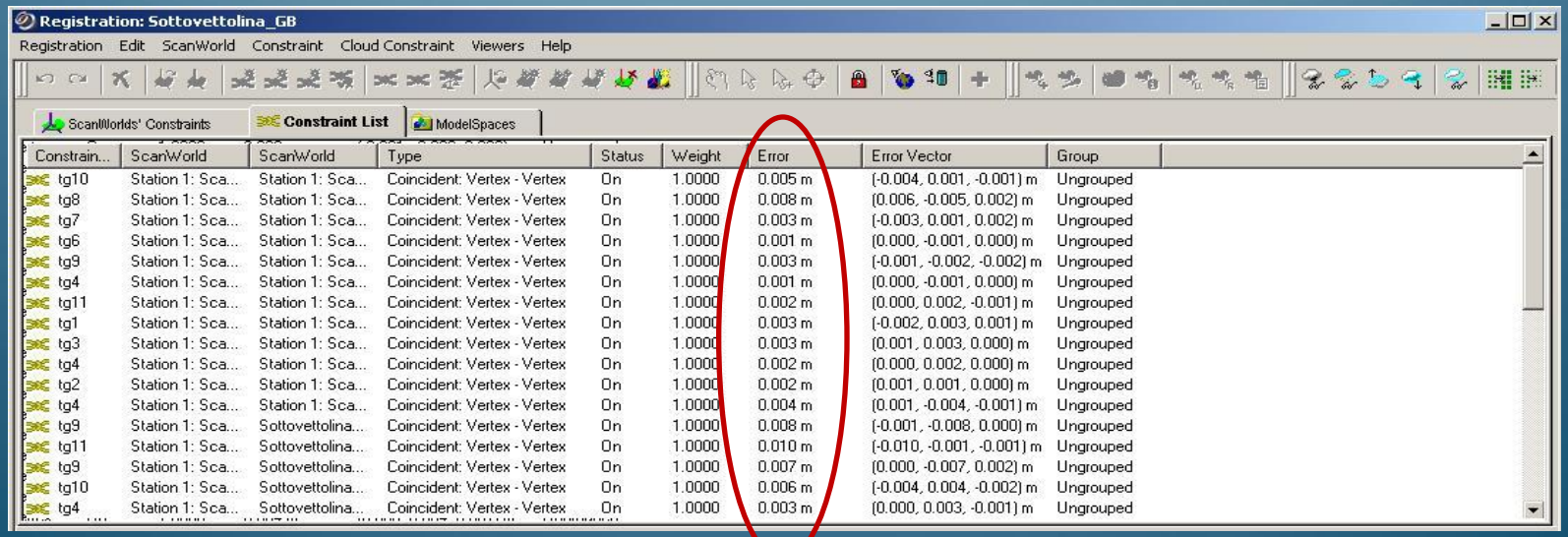
Post-processing in Leica Geo Office software

- Post-processing of differential GPS measurements allowed to provide sub-cm results.

DATA PROCESSING

Through the Total Station survey the point clouds were referred to a unique reference system by applying a spatial trasformation (**roto-traslation**) using the targets as system constraints (Registration).

Target-based Registration reported a millimetric accuracy.



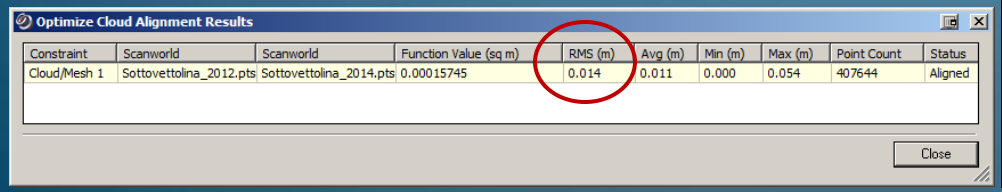
Constrain...	ScanWorld	ScanWorld	Type	Status	Weight	Error	Error Vector	Group
tg10	Station 1: Sca...	Station 1: Sca...	Coincident: Vertex - Vertex	On	1.0000	0.005 m	(-0.004, 0.001, -0.001) m	Ungrouped
tg8	Station 1: Sca...	Station 1: Sca...	Coincident: Vertex - Vertex	On	1.0000	0.008 m	(0.006, -0.005, 0.002) m	Ungrouped
tg7	Station 1: Sca...	Station 1: Sca...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(-0.003, 0.001, 0.002) m	Ungrouped
tg6	Station 1: Sca...	Station 1: Sca...	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(0.000, -0.001, 0.000) m	Ungrouped
tg9	Station 1: Sca...	Station 1: Sca...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(-0.001, -0.002, -0.002) m	Ungrouped
tg4	Station 1: Sca...	Station 1: Sca...	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(0.000, -0.001, 0.000) m	Ungrouped
tg11	Station 1: Sca...	Station 1: Sca...	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.000, 0.002, -0.001) m	Ungrouped
tg1	Station 1: Sca...	Station 1: Sca...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(-0.002, 0.003, 0.001) m	Ungrouped
tg3	Station 1: Sca...	Station 1: Sca...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.001, 0.003, 0.000) m	Ungrouped
tg4	Station 1: Sca...	Station 1: Sca...	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.000, 0.002, 0.000) m	Ungrouped
tg2	Station 1: Sca...	Station 1: Sca...	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.001, 0.001, 0.000) m	Ungrouped
tg4	Station 1: Sca...	Station 1: Sca...	Coincident: Vertex - Vertex	On	1.0000	0.004 m	(0.001, -0.004, -0.001) m	Ungrouped
tg9	Station 1: Sca...	Sottovettolina...	Coincident: Vertex - Vertex	On	1.0000	0.008 m	(-0.001, -0.008, 0.000) m	Ungrouped
tg11	Station 1: Sca...	Sottovettolina...	Coincident: Vertex - Vertex	On	1.0000	0.010 m	(-0.010, -0.001, -0.001) m	Ungrouped
tg9	Station 1: Sca...	Sottovettolina...	Coincident: Vertex - Vertex	On	1.0000	0.007 m	(0.000, -0.007, 0.002) m	Ungrouped
tg10	Station 1: Sca...	Sottovettolina...	Coincident: Vertex - Vertex	On	1.0000	0.006 m	(-0.004, 0.004, -0.002) m	Ungrouped
tg4	Station 1: Sca...	Sottovettolina...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, 0.003, -0.001) m	Ungrouped

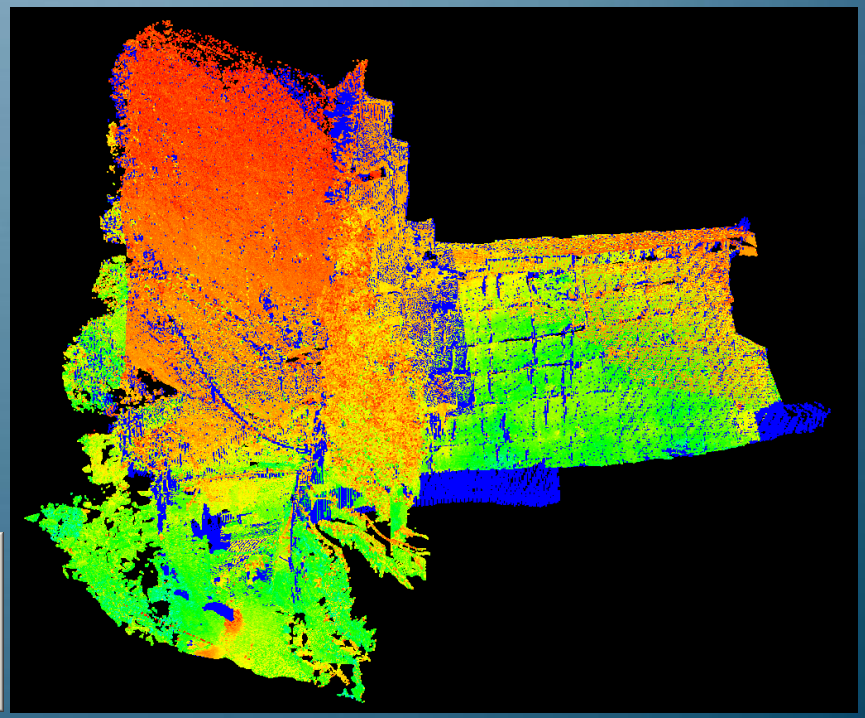
Target-based Registration in Leica™ Cyclone 9.0 software

MULTI-TEMPORAL DATA PROCESSING

Both the point clouds were georeferenced in the Italian National Reference System Gauss-Boaga (Transverse Mercator Projection, Hayford ellipsoid, Rome 1940 datum, Zone 1).

Co-registration of the two point clouds relative to the years 2012 and 2014 in Leica™ Cyclone 9.0 software provided a few centimetres accuracy. Iterative Closest Point alghrotim (ICP, Besl & Mckay, 1992) was used.





Co-registration in Leica™ Cyclone 9.0 software

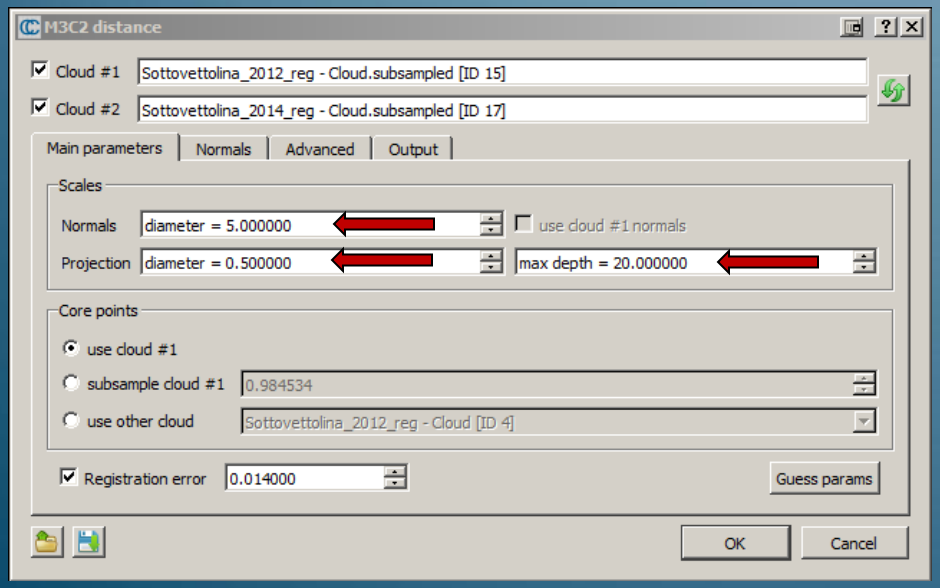
MULTI-TEMPORAL POINT CLOUDS COMPARISON

3D point clouds were processed using the Open Source CloudCompare software and, in particular, the Multi scale Model to Model Comparison (M3C2) plugin (Lague et al., 2013) which enables point cloud analysis.

This approach consists in performing a direct comparison of point clouds computing distances in 3D and using search cylinders to find corresponding points between the two clouds.

MULTI-TEMPORAL POINT CLOUDS COMPARISON

The **normal scale** is the diameter of the spherical neighborhood extracted around each core point to compute a local normal. This normal is used to orient a cylinder inside which equivalent points in the other cloud will be searched for.



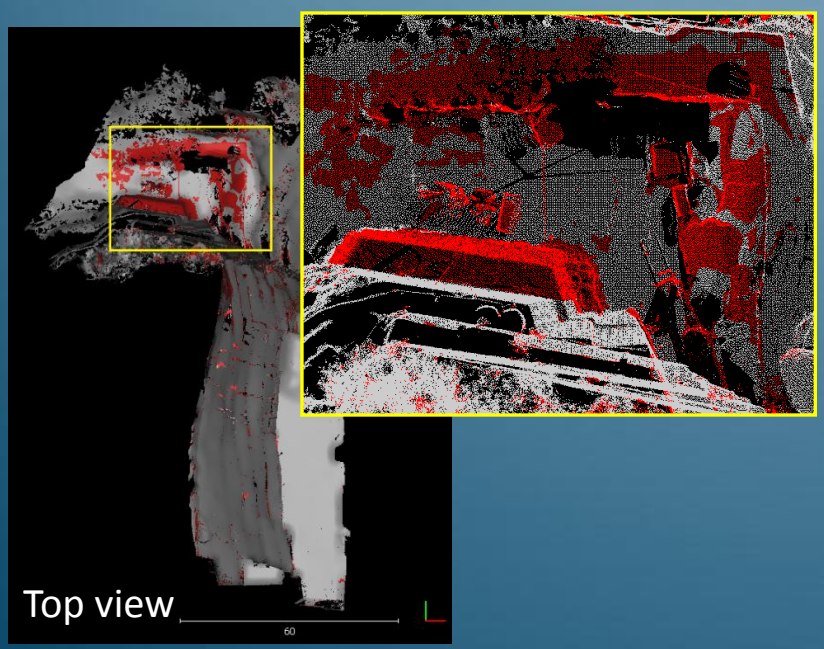
M3C2 distance plugin in CloudCompare software

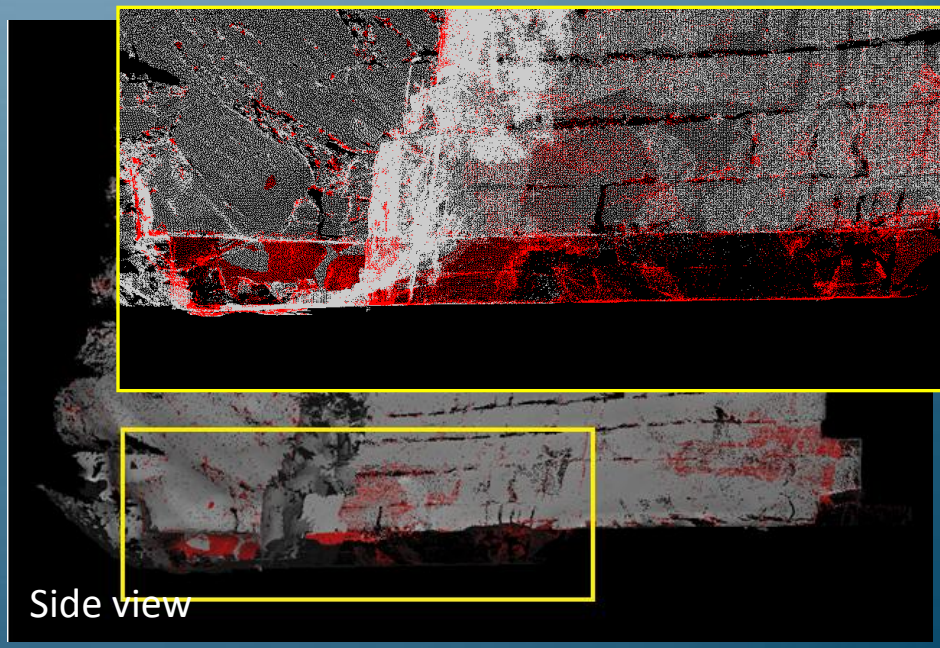
The **projection scale** is the diameter of the above cylinder.

The **max depth** parameter corresponds to the cylinder height (in both directions).

MULTI-TEMPORAL POINT CLOUDS COMPARISON

Thanks to the direct comparison of the point clouds, without the need of surface meshing or Digital Elevation Model (DEM) generation, this method can produce **accurate results** without introducing errors due to interpolation process.



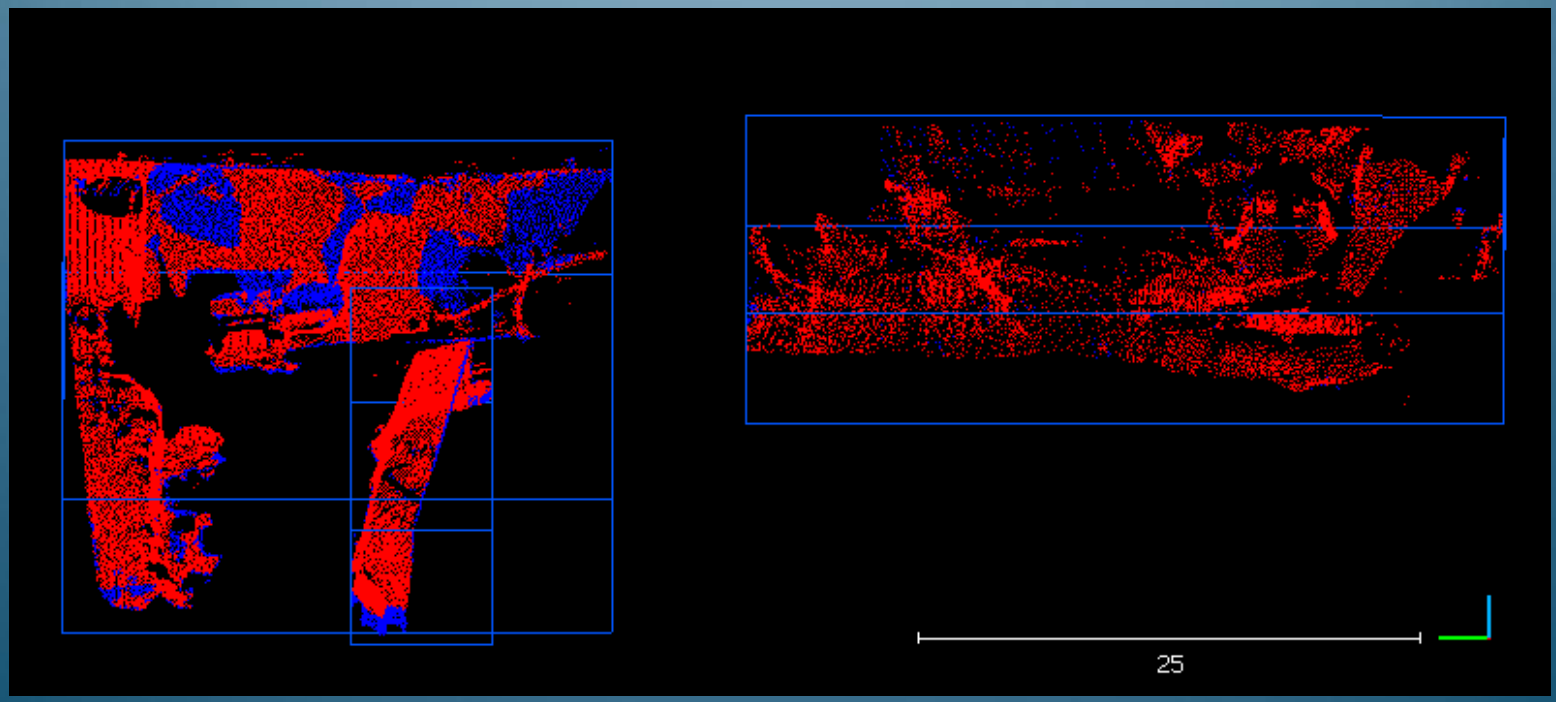


M3C2 Significant Change (in red)

VOLUME CALCULATION

CloudCompare allows to estimate volume differences.

The volume of the extracted material is roughly the sum of the segmented red areas which correspond to the changes.



Segmented areas in CloudCompare

VOLUME CALCULATION

By the sum of the segmented red areas, the calculated volume is almost 2,500 cubic metres in 19 months corresponding to 6,750 tons (355 tons per month).

Calculated volume refers to the total extracted material.
This underground marble quarry has a declared yield of about 30% in terms of blocks; the extracted ornamental stone corresponds roughly to 100 tons per month.

CONCLUSIONS

- TLS represents an ideal method for **modelling the excavation surfaces** generating dense point clouds, rapidly supplying accurate and detailed geometrical information.
- 3D point clouds can be processed using **Open Source software**.
- This approach allows direct comparison of point clouds computing distances in 3D enabling **change detection analysis** with point clouds belonging to different time periods.
- Furthermore, it allows quarry workers to gain information about the **morphological differences of extracted material** and **possible rock fall zones.**
- Allowing reliable evaluation of productivity, this approach can be used to **correctly plan future excavation activities**.

THANK YOU
FOR YOUR ATTENTION