ENVIRONMENTAL MONITORING MANAGEMENT OF WASTE FROM LARGE EXCAVATIONS DUE TO INFRASTRUCTURE BUILDINGS

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ABSTRACT:

Large infrastructure building like the Florence Railway Station designed for high-speed rails requires a proper management of the huge quantity of waste originating from excavation activities. Such waste amounts require large areas for disposals, making abandoned areas or exhausted quarries and mines ideal sites for hosting the excavated wastes.
A rectangular area of 500x70m delimiting the railway station has been excavated in two steps causing the removal of a 10m-thick soil layer per step: excavated earth and rocks would then be used for the environmental restoration of an area of 400x350m located near a former exhausted lignite quarry) in the proximity of the Santa Barbara village near Cavriglia (Arezzo).
The Tuscan Regional Environmental Agency (ARPAT) have been involved in monitoring both the terrain transportation and disposals' operations according to the approved management plan: the Environmental Regional Information System Office (SIRA) was asked to evaluate volume balancing between all the waste management cycle, with included: (a) waste extraction from railway station site building, and (b) waste disposal final destination (exhausted Santa Barbara lignite quarry).
Terrestrial Laser Scanner (TLS), Simultaneous Localization and Mapping System (SLAM) systems and Remotely Piloted Aircraft Systems (RPAS) surveys have been used to track earth and rocks excavation and disposal activities in the aforementioned sites: while RPAS systems cannot be used in underground site surveys, their usage must be recommended in open space surveys due to the ese of use if sub-centimetric precisions are not required.
Multiple TLS scans alignment can result in a quite challenging task if automatic alignment software is not available, requiring manual rough alignment's operations that can be very time consuming: two open-source solutions based on different algorithms have been evaluated.
The selected survey technologies – RPAS, TLS, SLAM – have shown a great potential in earth and rocks monitoring: each technology has its own strengths and weakness, which can vary on the basis of both hardware and software technical progresses.

1. INTRODUCTION

1.1 Excavation Earth and Rocks in large transportation infrastructures

Proper environmental management of excavation materials from large transportation infrastructures is addressed by compliance to national regulations, and specifically with DPR 120/17, Art. 9 and 18, for volumes over 6.000m^3 or projects requiring Environmental Impact Assessment (EIA). Excavated materials can be classified as Earth and Rocks instead of waste while following these rules: (a) physical/chemical composition as reported in Dlgs 152/2006, and (b) disposal is done according to a management plan.
Compliance controls of excavated earth and rocks to these requirements are in charge to Italian Regional Environmental Agencies: a specific department – Environmental Evaluation Office – is responsible of the overall control activities, i.e materials' sampling, their transfer to analysis laboratory, volume tracking between excavation and final destination sites.
In complex worksites volume tracking activities could require topographic support for precise evaluation of excavated volumes in both sites: both Remotely Piloted Aircraft Systems (RPAS) and terrestrial laser scanner (TLS) instruments can be used for precise 3D survey of wide areas.

1.2 RPAS and TLS characteristics

Both RPAS and TLS are widely used techniques for precise 3D surveys in many industrial and environmental applications, from mining management to environmental monitoring. Compared to TLS, RPAS have shown great speeding up survey capabilities; on-site survey activities – except for GCP surveying – are usually limited to half an hour for about 500x500m areas by using the most diffused RPAS devices (quadricopters).

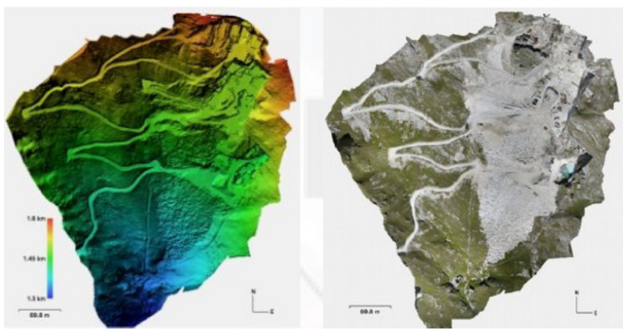

Figure 1. RPAS 3D Point Cloud of a marble quarry.

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On the other hand, RPAS 3D Surveys cannot be used in underground working areas or other contexts where extreme precision is required, due to local centimetric distortions coming from the triangulation process.
TLS surveys allow acquisition of precise measurements obtained as target-to-sensor distances coming from time of flight or phase differences between emitted and received laser signals. TLS surveys are more expensive than RPAS ones both in term of Return of Investment (ROI) and acquisition times, mainly due to the huge number of scans required in wide areas.

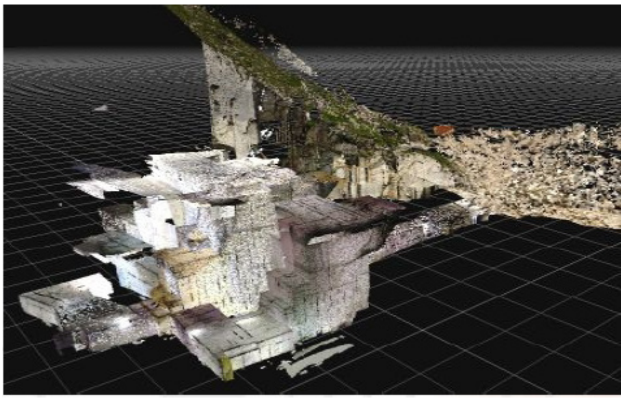

Figure 2. TLS 3D Point Cloud of a marble quarry (underground).

Simultaneous Localization and Mapping System (SLAM) systems can be regarded as an emerging technology whose maturity level is risen in the last years. Artificial intelligence (AI) algorithms included in SLAM hardware allows simultaneous acquisition and real time alignment of point cloud, greatly enhancing surveying capabilities in environments in which a user can follow a path by either walking or driving a bicycle or a car equipped with a SLAM device.

1.3 Earth and Rocks Management Tracking

Earth and Rocks management plan of the new high speed railway station of Florence issued by Italferr S.p.a. has been verified by volume balances evaluation between original excavation site and final disposal's destination: both RPAS and TLS surveys have been used due to the characteristics of the two sites, extending the first at most underground and the latter an exhausted lignite open-pit mine. Two-pass surveys have been performed in both sites to assess initial and final soil levels: excavated and/or disposed earth and rocks' volumes have been evaluated as volume differences between initial and final 3D point clouds, taking into account expansion and compression factors due to materials' excavation and disposition processes.

2. MATERIALS AND METHODS

2.1 Area of study

The new high speed Florence railway station (site 1) is located about 700m north east to the central Florence railway station: the whole excavation area is enclosed in the box [11°14'26" 43°47'23", 11°14'36" 43°47'07"]. Excavated earth and rocks come from a rectangular area about 500x70m wide: the removal process provides two working stages in which volumes extending to 10m of height have to be excavated.

Figure 3. High speed Florence railway station as in June 2019 aerial image freely available by OGC WMS Services managed by Regional Enviromental and Soil Information System of Tuscany – SITA Office)

Excavated earth and rocks are intended to be used in environmental restoration of part of an abandoned open pit lignite mine near to the thermoelectric central of Santa Barbara (site 2), located in the municipality of Cavriglia, 52022, Arezzo. Disposal area is about 400x350m wide and enclosed in a box [11°28'08" 43°33'42", 11°28'32" 43°33'33"].

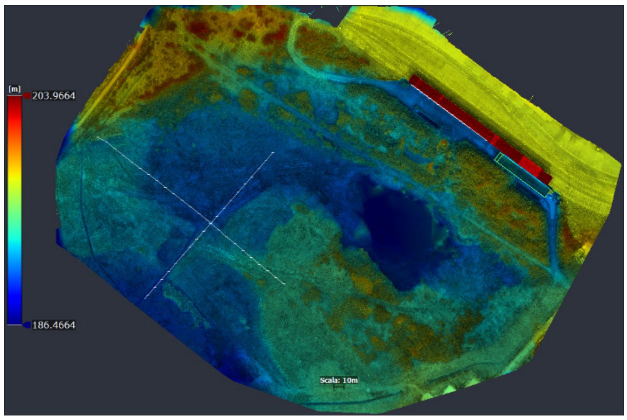

Figure 4. Santa Barbara exhausted mine area subject to environmental restoration (RPAS Survey, 2020).

2.2 Earth and Rocks Management Plan

Italferr S.p.a. management plan provides that Excavated earth and rocks at the railway station are intended to be disposed continuously during excavation activities to the Santa Barbara areas. A dedicated railway line allows earth and rocks transportation to the disposal site, where they have to be disposed over the existing topsoil to create a superimposed regular plan. Disposal site has been divided in five sub areas, each one following a precise time scheduling for materials deposition and compacting operations.

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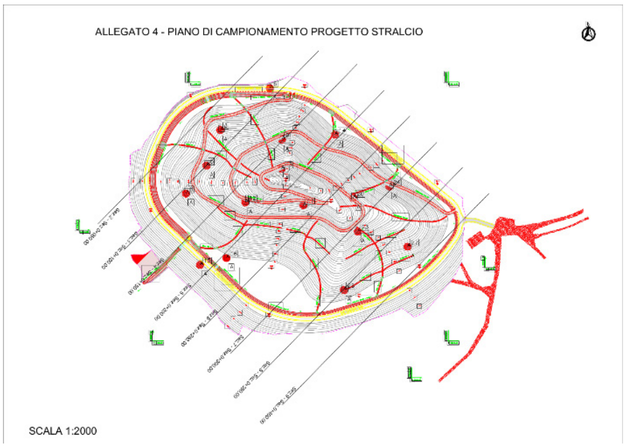

Figure 5. Disposal site cross sections of working stages

On site earth and rocks volumes are typically lesser than excavated ones due to excavation process: disposition process partially reduces the excavation volume increase due to compacting operations, but disposed volumes remain bigger than the excavated ones. Earth and rocks management plan include an estimation of volume increase coefficient: its value has been evaluated following technical regulation prescriptions on soils classification (UNI 11531-1, i.e. UNI EN ISO 14688, UNI EN 13242, UNI EN 13285 application in Italy).

2.3 Survey techniques and sensors

A Phase-difference terrestrial laser scanner Faro Focus S-350 has been used in both sites at the initial working stage: mobile targets have been used for scan alignments, while fixed ones have been used for topographic network materialization. Fixed targets have been removed at the end of each survey campaign.
Site 1 (underground railway station) is characterized by a complex geometry (see Fig. 6): iron columns mask out relevant portions of soil, thus requiring a huge number of scans to get a complete and precise 3D model of topsoil. Required resolution (number of points at 10m) and scene shielding due to the presence of a large number of iron columns suggested to acquire 120 scans in two days of field work at the railway station site.

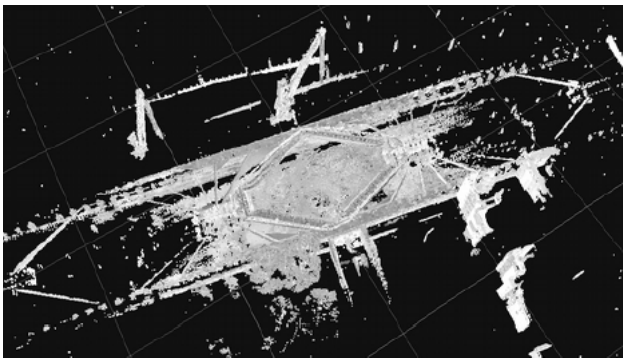

Figure 6. Underground railway station point cloud (partial) – February 2021 survey.

A Leica Total station has been used by Italferr S.p.a. topographers to acquire coordinates of survey network points in the local reference systems in both locations (site 1 and site 2) for the geolocation of terrestrial laser scanner surveys in the local reference system.
A second site survey was required at mid-2022 by comparing Simultaneous Localization and Mapping System (SLAM) to traditional TLS. A Zeb Horizon capturing tool, working up to 100m with 300.000 points per second acquisition rate, was used for the survey of about the entire railway station area: the resulting digital elevation model was then compared in a subarea surveyed with the FARO FOCUS S350 terrestrial laser scanner, covered by 9 scans (Fig. 7). SLAM continuous acquisition mode allows uniform coverage of terrain surface with respect to TLS scans, showing point density decrease with distance from scan points.

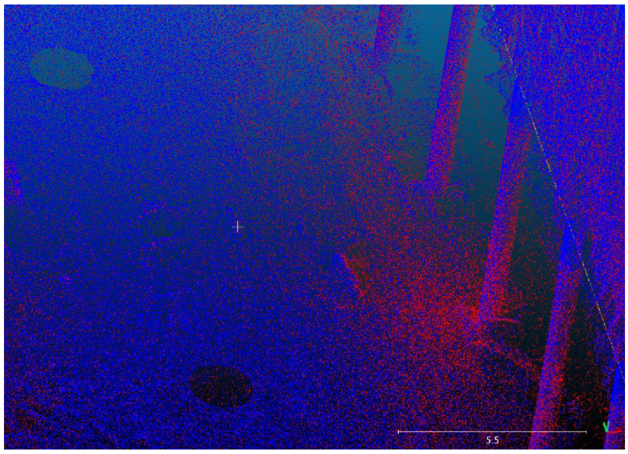

Figure 7. (a) Red: Zeb Horizon Point Cloud of the railway station (partial) (b) Blue: TLS scans – May 2022 survey.

A prior survey with a DJI RPAS RTK at the end of 2020 of Santa Barbara area (site 2) showed a vegetation coverage characterized by small brushes and isolated trees: comparison of the derived digital elevation model (DEM) with 1:2.000 cartography dated. 1999 shows a substantial invariance of the topsoil, except for a limited zone located in the south west of the area characterized by a mean value of height differences of 1m.
Disposal operations in site 2 required prior removal of topsoil vegetation: following the earth and rocks management plan, the complete survey of site 2 required five distinct field works, one for each sub area subjected to surface vegetation removal and subsequent disposal of earth and rocks. Surveys of site 2 consist in single scans distanced about 10m each one: this intermediate survey, i.e. after topsoil removal and before earth and rocks disposal, was made in each subarea with a FARO Focus Terrestrial Laser Scanner (TLS). The TLS Survey has ben used for further assessment of (a) areas subjected to major brushes and trees removal operations (b) absence of earth and rocks disposals after vegetation removal, by comparison with a reference plan extracted from the first RPAS survey using bare soil portions of the surveyed area.

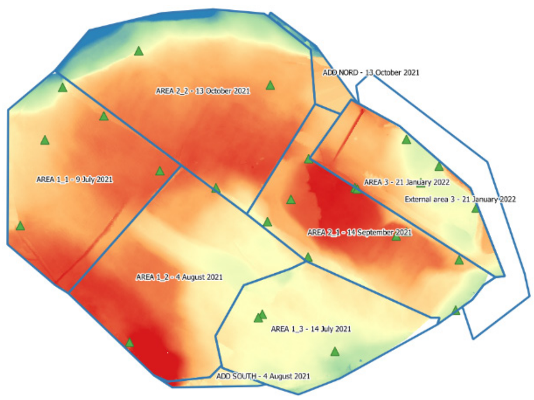

Figure 8. TLS subareas surveyed before vegetation removal stages (2021-2022).

Figure 9. 2020 RPAS survey digital elevation model compared with prior 1:2.000 digital elevation model (1999) for the south west area subjected to negligible height changes between 1999 and 2020.

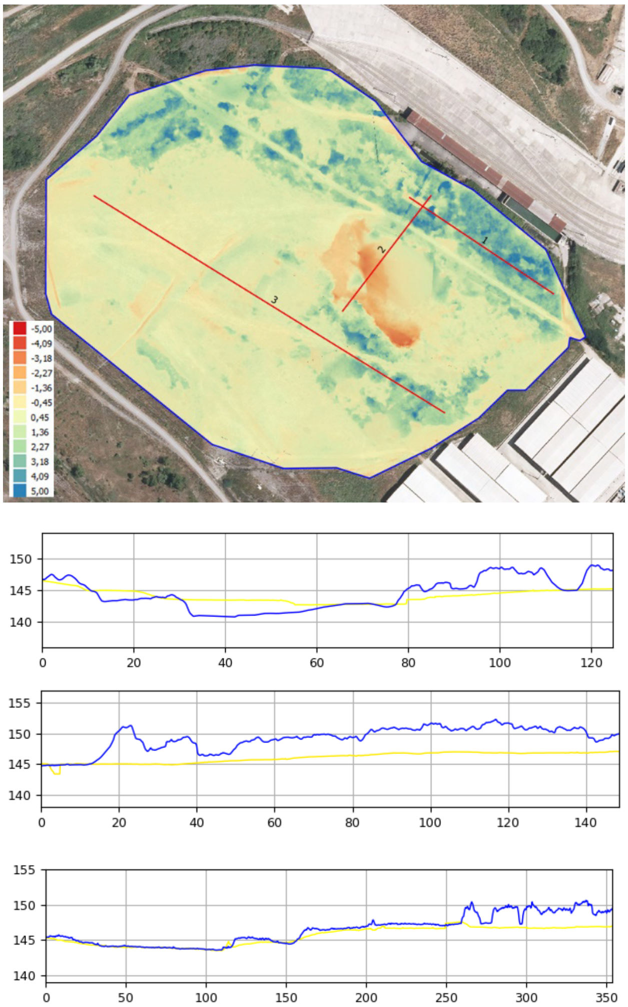

Figure 10. Cross Section of digital elevation models in vegetated areas (yellow: RPAS initial survey before vegetation removal; blue: 1.2000 elevation model dated to 1999).

A DJI Matrix 300 RTK equipped with a LiDAR sensor has been used in assessing disposed volume of earth and rocks coming from the railway station in the first days of June, 2022. Two single RPAS LiDAR surveys of Site 2 area have been done due to area dimensions leading to two digital elevation models, while a single photogrammetric digital elevation model covering the entire area has been obtained.

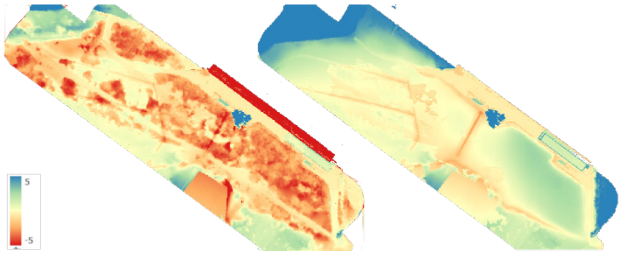

Figure 11. Difference between digital elevation models (RPAS 2020-RPAS LiDAR 2022) in Santa Barbara site (site 2). Left: height difference without vegetation removal of initial survey DEM, right: height difference with vegetation removal.

2.4 Software

Both proprietary and OS software have been used in volume balance evaluation between each working phase: while 3D Zephyr Aerial have been used in RPAS survey triangulation and TLS scans alignment in our agency, additional OS tools have been evaluated to speed up TLS scans alignment.
Since 3D Zephyr Aerial Software require prior rough alignment of each TLS scan by the user, a minimum of three common points between each scan couple have to be identified and imposed as initial condition (manual alignment) for the alignment refinement phase (precise alignment). Another approach allowed by the software is based on initial point clouds mutual alignment by manual roto translations operations: in both cases, the Iterative Closest Point algorithm (ICP) is only used for fine alignment.
Neural Network (NN) based solutions as PointNet and its derivatives (PointNet++) have been proposed for automatic TLS scan alignment (Qi et al, 2017; Jing et al.), 2021, while traditional ICP-derived algorithms are still widely used in many closed and open-source packages. In order to skip the training phase required by NN-based algorithms, a couple of open-source packages supporting auto-alignment of multiple scans has been evaluated: Super 4-points Congruent Sets (Super 4PCS) algorithm (Mellado et al. 2014) and the traditional multi-ICP software package, Point cloud tools for Matlab (Glira et al., 2015). While Point Cloud Library for Matlab is a valuable tool in aligning point clouds coming from close range scanning, Super4PCS software has shown good alignment capabilities, thus requiring pairwise execution over all scans.
Volume balance has been evaluated in QGIS3.x environment by differencing digital surface models (DSMs) in CloudCompare 2.11.3.

3. RESULTS

3.1 DSM precision vs. number of TLS scans in site 1

The central area of the railway station has ben selected to investigate the influence of scan number on the precision of Digital Surface Models (DSMs): two models have been extracted from available scans with (a) 9 full scan set (b) 4-scan set acquired at the angles of the area, and (c) a single scan acquired from the centre of the area. Each digital elevation model has shown a good capability in describing the reference plan of the railway station for each working stage: while a 4-scan digital elevation model has shown a suitable accuracy, a single scan cannot be used in precise reconstructions.

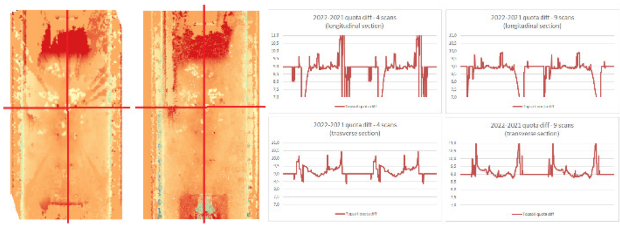

Figure 12. Height differences between full resolution model and (left) 4 scans model (right) 9 scans model.

While both 4 scans and 9 scans derived DSMs are good enough to assess average quota changes between 2021 and 2022, the usage of more TLS scans leads to a less noisy DSM. However, spike filtering can be used to remove quota outliers: as a consequence, the choice of the optimal scan numbers should be related to (a) desired product precision, (b) time for scan acquisitions, and (c) availability of both hardware and software able to handle batch auto-alignment of multiple scans minimizing operator's work.

3.2 Automatic scans alignment

As stated in par. 3.1, the availability of software with batch auto-alignment of multiple scans capability plays a relevant role in survey TLS planning: the greater would be the scan number, the greater would be the time dedicated in mutual alignment and final product refiement.
In this work only a limited test of pairwise point cloud alignment has been done with Point Cloud Library for Matlab version for Windows (command-line) between (a) SLAM-derived point cloud and (b) TLS-derived point cloud acquired in May 2022.

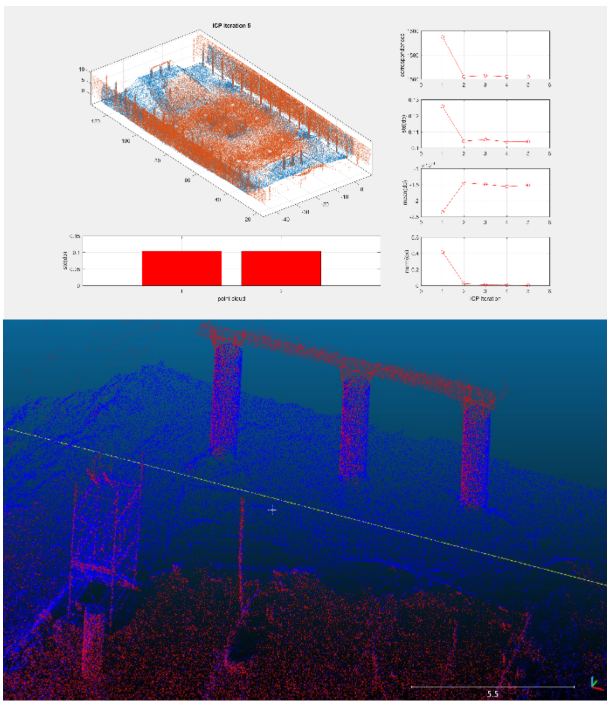

Figure 13. Pairwise scan alignment with Point Cloud Tools for Matlab software. Upper image: Windows command line user interface shows a good agreement after alignment operations between red (TLS-derived) and blue (SLAM-derived) point clouds. Lower image: detail of the aligned point clouds in CloudCompare.

Similar results have been found by using (a) proprietary software 3D Scarlet, and (b) open-source Point Cloud Library for Matlab for scans alignment: while it has been found that execution time of alignment procedures is similar in both cases, solution (b) allows fully scans alignment automation requiring minimal work by operators.

3.3 SLAM vs. TLS precision (TopSoil surface model)

SLAM and TLS May 2022 aligned point clouds have been compared to assess precision of both technologies in surveying actual topsoil surface model: a rough difference of rasterized point clouds shows that, except for boundary areas due to view extent of TLS scans, quota differences are at most behind ±5cm over 4 sections (see Fig. 12).

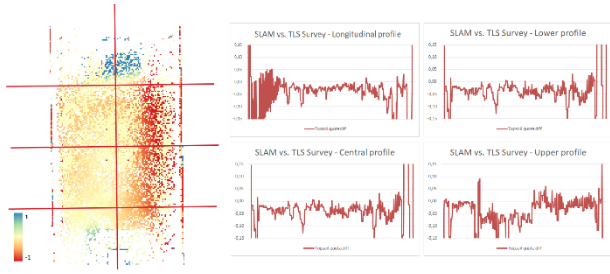

Figure 14. Topsoil quota differences between SLAM and TLS surveys. Left: raster difference and sections, right: quota differences' profiles.

Both SLAM and TLS survey technologies has shown very good precision performances referring to project tolerances: differences between the two reconstructed surface models form point clouds are slightly over scan alignment precision assessed by 3D Zephyr software for TLS scans (about 3 cm). It has been found that SLAM solution, thanks to internal alignment algorithms, in complex contexts like the railway station allows high speed acquisition of very detailed point clouds with very few postprocessing operations, greatly speeding survey procedures at the only cost of accurate planning of acquisition pathways.

4. DISCUSSIONS

As for underground sites in which traditional quadcopter RPAS systems cannot be used, SLAM technology has shown a great ease of use and rapid acquisition times compared to traditional TLS systems: when the maximum available precision (less than 1cm) is not required, like in earth and rocks tracking, this technology has to be preferred.
On the converse, RPAS systems in open space with poor man-made infrastructures and/or buildings are the preferred choice due to lack of reference plans allowing quicker manual rough alignment of multiple scans. Availability of automatic alignment software can help TLS system to close the gap with SLAM and RPAS systems by cutting down alignment times in the presence of reference planes.
All these technologies allow to obtain 3D data suitable in earth and rocks precise tracking application for large infrastructures: each technology has its own strengths and weaknesses, with regard to (a) availability of GPS signal (b) hardware and software equipment/budget availability, and – last but not at least – (c) skills of dedicated personnel.

5. CONCLUSIONS

Terrestrial Laser Scanner (TLS), Simultaneous Localization and Mapping System (SLAM) systems and Remotely Piloted Aircraft Systems (RPAS) have been used since many years in environmental management. All these technologies have been tested to highlight their own strengths and weakness, making

each one suitable on the basis of technical skills and software availability.
It is expected that the three technologies would be used in the near future in environmental monitoring by the Tuscan Regional Agency, aiming to maximize the strength of each one. Investments on automatic alignment software, too, are going to be realized in order to ease TLS, and RPAS technology usage in 3D change detection applications relevant for environmental monitoring.

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