RELIABILITY OF VOLUME DETERMINATION OF EXTRACTED RAW MATERIAL DEPOSITS IN SURFACE QUARRIES CONSIDERING THE DENSITY OF MEASURED POINTS: EXAMPLED BY GEODETIC MEASUREMENTS IN THE STONE QUARRY TREBEJOV, SLOVAK REPUBLIC

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Abstract: Contemporary development in measurement technology enables more effective and detailed collection of data for determination of the shape and dimensions of natural or artificial objects. The paper presents the equipment and surveying procedures necessary for geodetic measurement of the stone-pit wall before and after mineral extraction. Terrestrial laser scanning – TLS was the main measuring method. The paper describes also the phase of preparing and processing measured data into the digital terrain model, as well as determination of the volume of extracted material. Final part presents results and comparisons of volume determinations gained by different measuring methods and at different density of measured points.

Key words: terrestrial laser scanning, extracted stocks volume, digital terrain model

Introduction

Organization conducting mining activities in accordance with Act of the National Council of Slovak Republic Nr. 44/1988 Coll. on the protection and use of mineral resources, as amended (the Mining Act) shall lead documentation and records stock of exclusive deposit and its amendments. To ensure these tasks, several geodetic methods and technologies may be used, which differ mainly accuracy, detail and speed. For surface mining and quarrying, classical methods of polar method with trigonometric determination of heights using the total stations (TS) and the method of Global Navigation Satellite Systems (GNSS) are suitable. Among modern methods is particularly appropriate terrestrial laser scanning method using terrestrial laser scanners (TLS).

1. Locality

The results of measurements at multiple locations for the purpose of presenting the conclusions in this article, the quarry Carmeuse Slovakia, Ltd. in the administrative area Trebejov near Košice, Slovak Republic was chosen. It is located 13 km north of Kosice, extracted mineral is dolomite. The maximum length of the bearing reaches 440 meters, maximum thickness is 113 meters at an altitude 275-406 meters above sea level. Mining operations in the quarry began in 1959 and the proposed date of extraction completion in 2055 is estimated at an annual extraction of 450000 tons per year. The bearing is open and mined as five-horizon wall quarry with a height of walls 16.20 meters up to 25 meters. The measurements were carried out on the third horizon which is accessible by technological path (Fig. 1).

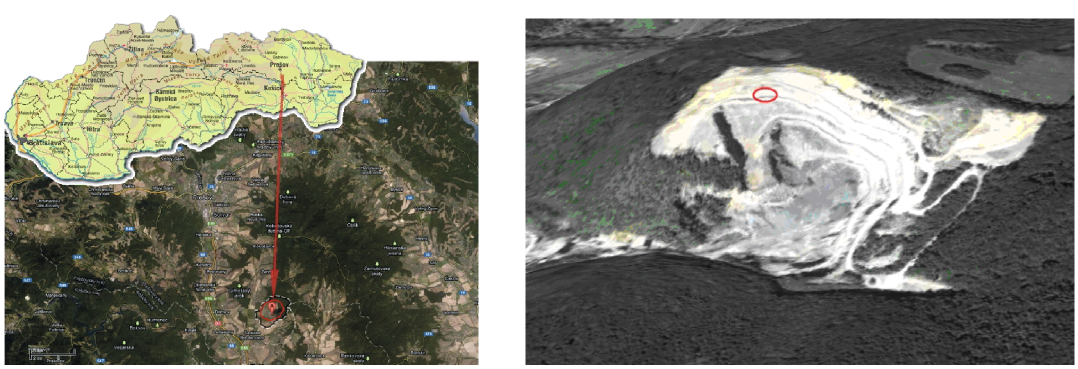


Fig. 1: Localization of the object

2. Objectives and methods of measurement

The main objective of this article was to determine the optimal method of geodetic measurements and subsequent processing of the measured data with respect to the density of the measured points considering the resulting level of details at the irregular surface of extraction walls and also the time and financial demands of the process. The density of measured points was determined indirectly from differences between surfaces and using volumes subsequently calculated

- measuring the shape of the same mining wall by different devices with different density of points
- measuring the shape of the mining wall before and after material blasting by the same apparatus and methods.

Active mining wall ready for raw material blasting with dimensions approximately 55 meters x 21 meters represents the object of measurement (Fig. 2)

Fig. 2: Object of measurement

The measurements were performed by three instruments:

- polar method with trigonometric measurement of heights using Leica TS02 total station (Fig. 3a) - in both stages about 500 detailed points in the approximately horizontal sections were focused. Vertical distance of these sections was approximately 25cm, horizontal distance of points was varied, the points were chosen in locations that best match the shape of the mining wall. Measurement time was approximately two hours,
- using a similar method by Trimble VX Spatial Station (Fig. 3b) in the automatic scan mode - in both stages 30000 points were measured. Horizontal and vertical distance of measured points with

respect to the distance of the object from the standpoint was set to 25 cm. Measurement time was approximately three hours,

- terrestrial laser scanning method with TLS Leica ScanStation C10 (Fig.3c) - in both stages about 3 million points were measured. Horizontal and vertical distance of measured points with respect to the distance of the object from the standpoint was set to 2cm. Measurement time was approximately 20 minutes.

Fig. 3a: Total station Leica TS02 *Fig. 3b: Trimble VX Spatial Station* *Fig. 3c: TLS Leica Scanstation C10*

Auxiliary measuring points used as standpoints and orientational points due to the operation in the quarry and because of the considerable time interval between measurements were stabilized only temporarily. Coordinates and heights of these points were determined by RTK GNSS observation with the period at one point 10 minutes using the same transformation key in both stages of the measurement. Using the same method, with a shorter observation time also points on the upper bounding face were targeted - upper plateau. Due to approximately regular shape of the wall, the horizontal distance between points was chosen equally at each 3m.

3. Processing of measured data

Difficulty of data processing and modeling naturally depends on the amount of input data and chosen modeling method (Blišťan, 2005), (Blišťan & Kovanič, 2012), (Gergeľová et al., 2013). In our case, the measured data were previously adjusted to a text file in the structure of Y, X, Z - dimensional rectangular coordinates of measured points, I - intensity of the reflected signal, R, G, B - color scale (Tab. 1) and then imported into the selected software.

Tab 1: Structure of the list of measured points coordinates in the text form

Y	X	Z	I	R	G	B
264253.23	1226666.361	349.990	82	114	107	65

The main software tool creating of surfaces and determining the volume was the Trimble RealWorks 6.5 especially equiped by the software possibility to work with a large point clouds. To create surfaces and subsequent comparison, the polyline with sufficient overlaid and designed circuit area of interest was used. According to this area all files have been cut off (Fig. 4). Points on the upper bounding face were measured by RTK GNSS, theese points have been added to all files of measured points measured by TLS Leica ScanStation C10, Trimble VX Spatial Station and Leica TS02 total station.

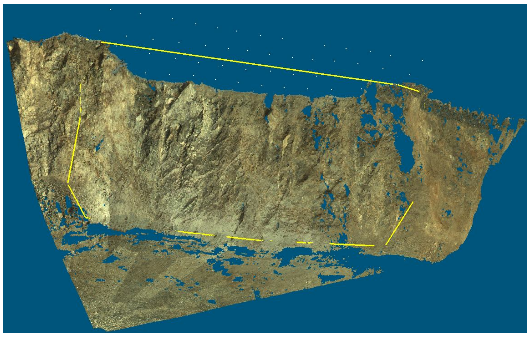


Fig. 4: Determination of measured area perimeter

This way obtained basic set with 100% of the measured data points measured by TLS method have been by "Spatial Sampling" command further reduced to 50%, 10% and 1% of the initial number of points. The data obtained by devices Trimble VX Spatial Station and Leica TS02 total station has been cut by analogy with the original density points. Data sets, quantity and spatial distance between points are shown in Tab. 2.

Tab 2: Point sets, amount and spatial distance between points

	approximate number of measured points	spatial distance of measured points
TLS Leica Scanstation C10 - **100% points**	3 millions	2cm
TLS Leica Scanstation C10 - **50% points**	1,5 million	4cm
TLS Leica Scanstation C10 - **10% points**	300 000	10cm
TLS Leica Scanstation C10 - **1% points**	30 000	20cm
Trimble VX **Spatial Station** - **100% points**	20 000	25cm
Leica **TS02** total station - **100% points**	500	150cm

Since the measurement was carried out in two stages - before blasting, after blasting and material extraction, all the point cloud files were similarly edited with approximately same parameters in the resulting files. From the processed point clouds, 3D surfaces - Mesh (Fig. 5) were created, which were used to determine the volumes between them. Trimble Realworks 6.5 software allows to determine the volumes directly between point cloud, and results are almost the same as using mesh surfaces.

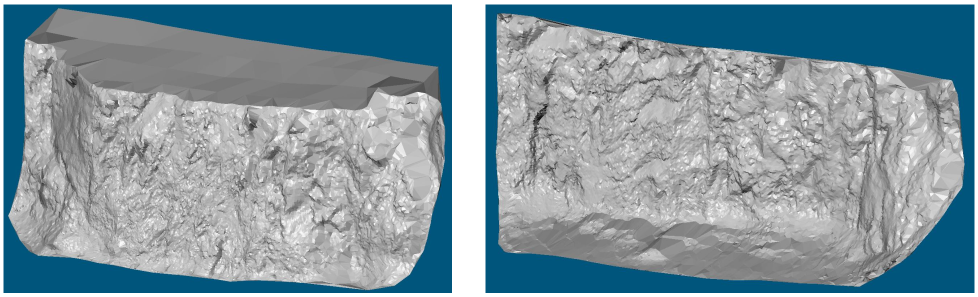


Fig. 5: Mesh of extraction wall before and after blasting with raw material extraction

Volumes were determined as differences of individual surfaces. Fig. 6 displays both surfaces - before blasting as a point cloud and after blasting with extraction of raw material in the form of mesh and the volume of extraction.

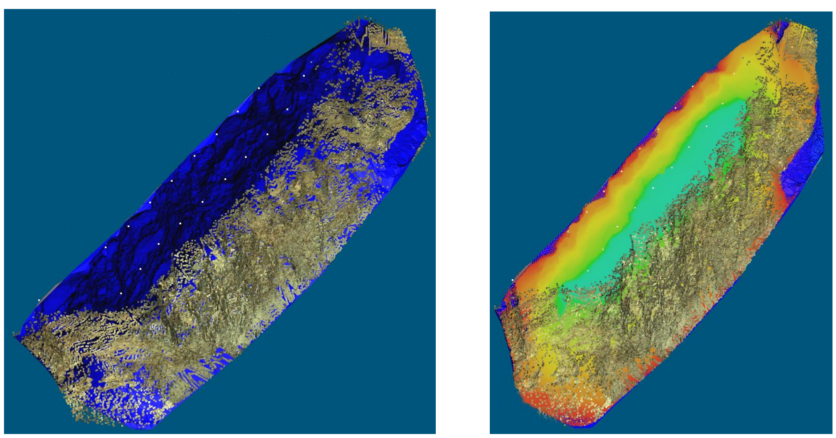


Fig. 6: Surfaces of extraction wall before and after blast, and after raw material extraction together with graphic presentation of the extracted material volume

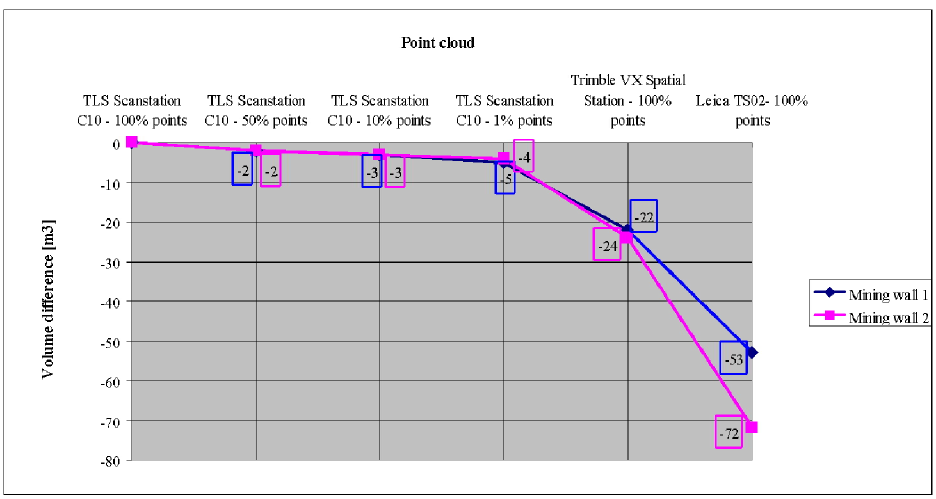
4. Results of measurements and data processing

4.1 Volume difference determination from the measurements of same mining wall by different devices with different density of points

As an object of interest, the mining wall whose shape have been measured before blasting (marked as mining wall 1) was chosen, and separately after the blast and material extraction (marked as mining wall 2). Each stage was measured and evaluated separately. Point clouds were processed separately in text form according to Tab. 2. The result is a reconciliation of the difference of the individual surfaces reflected by differences of volumes. As the basic reference surface we considered the file measured by TLS Leica ScanStation C10 with 100% of used points. Tab. 3 and graph 1 reflect the differences in comparisons of volumes – current surfaces to the basic reference surface.

Tab. 3, graph 1: Differences of determined volumes comparing the current surface with the baseline surface

	Mining wall 1 – Volume difference compared with the basic surface [m^3]	Mining wall 2 – Volume difference compared with the basic surface [m^3]
TLS Leica Scanstation C10 - **100% points**	0	0
TLS Leica Scanstation C10 - **50% points**	-2	-2
TLS Leica Scanstation C10 - **10% points**	-3	-3
TLS Leica Scanstation C10 - **1% points**	-5	-4
Trimble VX **Spatial Station - 100% points**	-22	-24
Leica **TS02** total station **- 100% points**	-53	-72

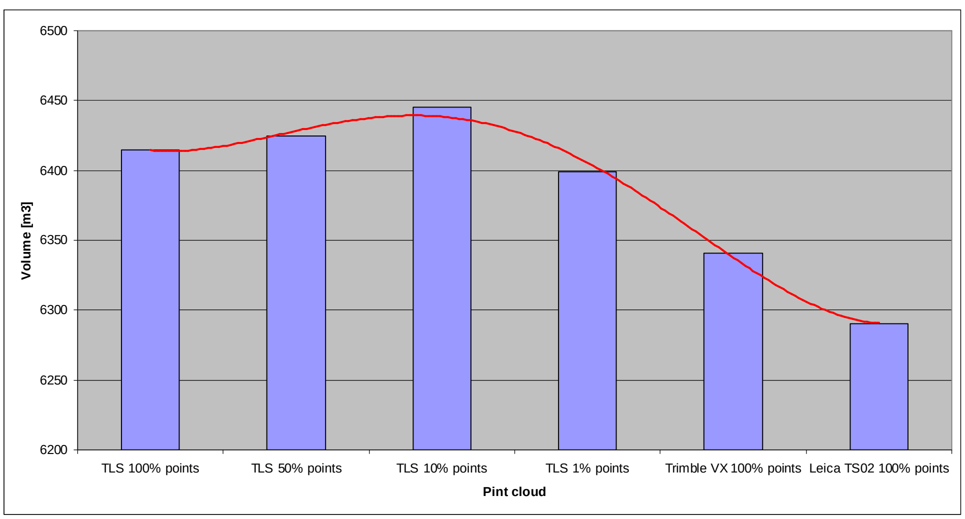


4.2 Volume difference determination from measurements of the mining wall before blasting and after material extraction

Point measurement of mining wall before blasting and after material extraction was performed by devices with the parameters set according to Tab. 2. Extracted material volume was calculated by Trimble Realworks software as the difference of the surfaces using the similar procedure as described in previous section. Volumes determined from individual files, their differences and differences in the percentages are expressed numerically and graphically in Tab. 4 and graph 2.

Tab. 4, graph 2: Volumes of extracted material calculated in theTrimble RealWorks software

Point quantity	TLS 100% points [m^3]	TLS 50% points [m^3]	TLS 10% points [m^3]	TLS 1% points [m^3]	Trimble VX 100% points [m^3]	Leica TS02 100% points [m^3]
Volume [m^3]	6415	6425	6445	6399	6341	6290
Volume difference [m^3]	-	+10	+30	-16	-74	-125
Volume difference [%]	-	+0,15	+0,47	-0,25	-1,15	-1,95



Extracted material volume was determined through horizontal cuts created by software Trimble Realworks 6.5 using “Cutting Plane Tool” command (Fig. 7). Slice interval of 25 cm was chosen. In this way we created 82 horizontal slices, which were exported to the format "dwg" and their area was determined by software Microstation V8 (Fig. 8)

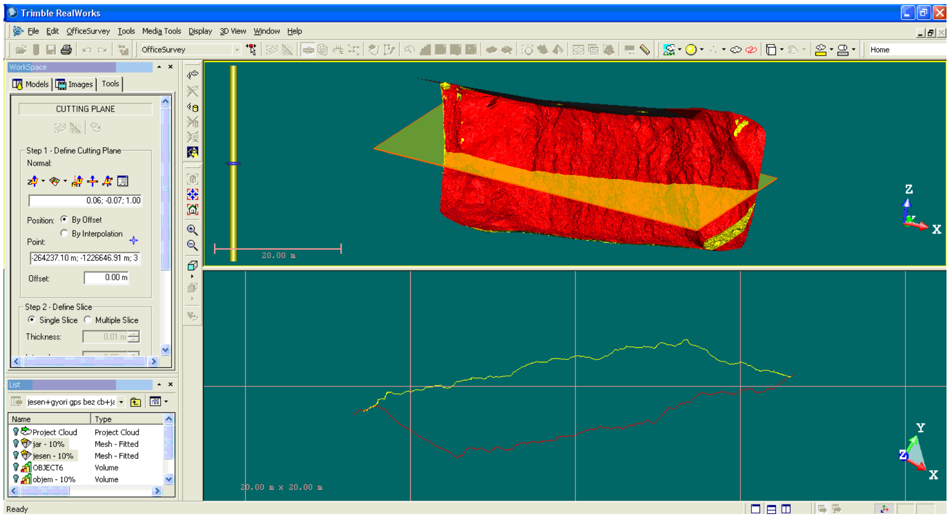


Fig. 7: Horizontal cuts creation for determination of extracted material volumes

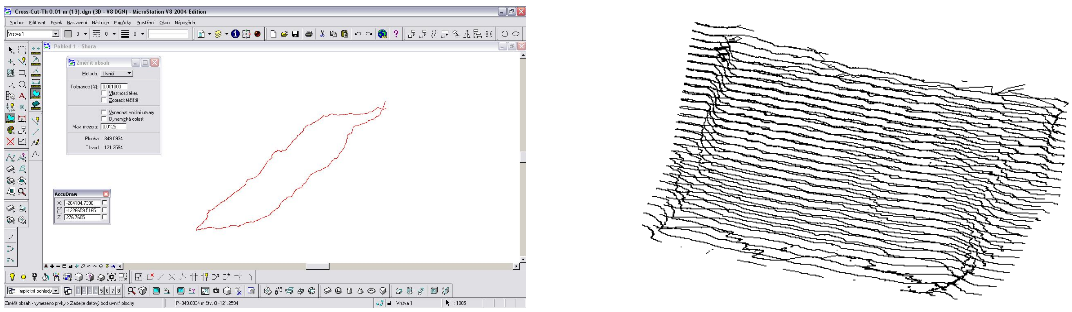
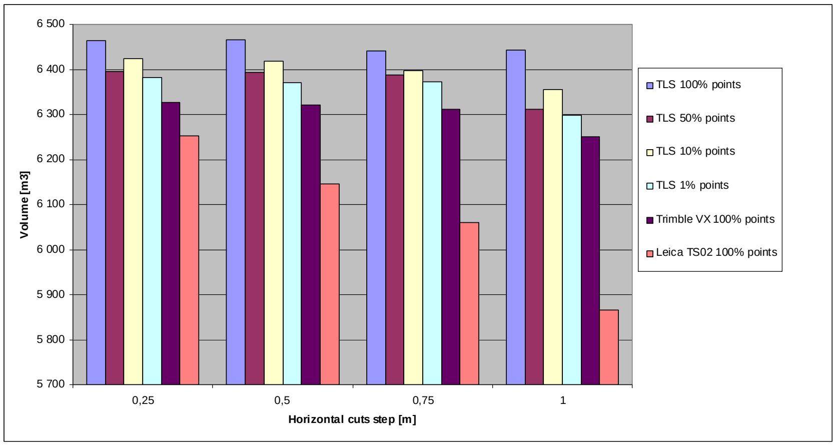


Fig. 8: Horizontal cuts area computation

This way obtained section volumes were determined for the horizontal cuts step 25cm 50cm, 75 cm and 100 cm. Volumes determined from these files are expressed numerically and graphically in Tab. 5 and graph 3.

Tab. 5, graph 3: Extracted raw material volumes determined using horizontal cuts

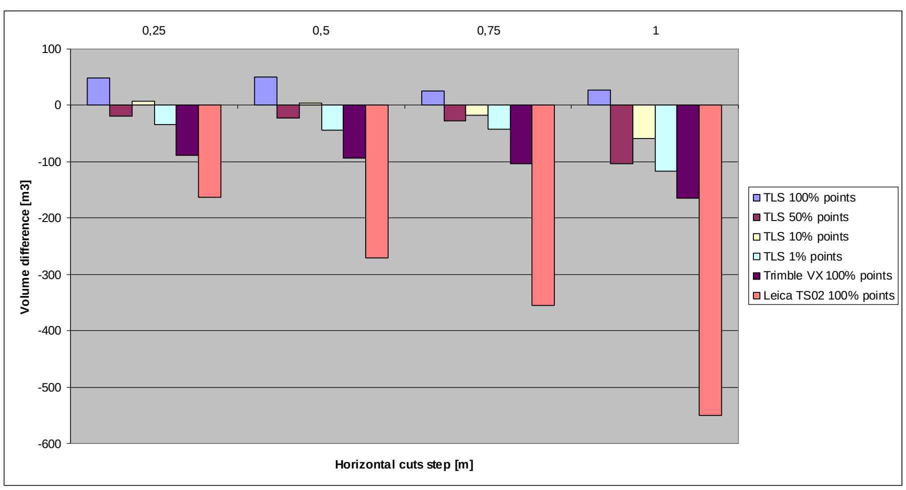
Horizontal cuts step [m]	TLS 100% points [m^3]	TLS 50% points [m^3]	TLS 10% points [m^3]	TLS 1% points [m^3]	Trimble VX 100% points [m^3]	Leica TS02 100% points [m^3]
0,25	6 463	6 396	6 423	6 381	6 326	6252
0,5	6 465	6 393	6 419	6 371	6 321	6145
0,75	6 441	6 388	6 398	6 373	6 311	6060
1	6 442	6 311	6 356	6 298	6 250	5865



Volumes obtained from horizontal cuts with different intervals between them were compared with the basic volume, which was calculated using TIN models with points measured by TLS and 100% of the measured points. This volume we consider to be the most accurate because it was created on the largest quantity of measured points. Volume differences determined from these files are expressed numerically and graphically in Tab. 6 and graph 4.

Tab. 6, graph 4: Extracted raw material volume differences on the basis of horizontal cuts compared with the volume calculated in TIN model on the basis of points measured by TLS at 100% quantity of measured points

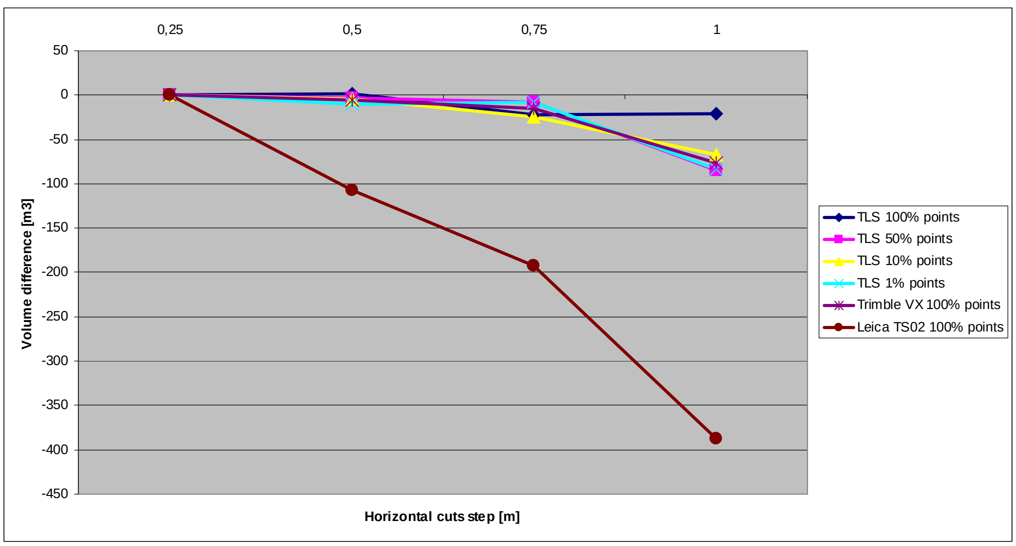
Horiztal cuts step [m]	TLS 100% points [m^3]/[%]	TLS 50% points [m^3]/[%]	TLS 10% points [m^3]/[%]	TLS 1% points [m^3]/[%]	Trimble VX 100% points [m^3]/[%]	Leica TS02 100% points [m^3]/[%]
0,25	48 / +0,75	-19 / -0,30	8 / +0,12	-34 / -0,53	-89 / -1,39	-163 / -2,54
0,5	50 / +0,78	-22 / -0,34	4 / +0,06	-44 / -0,69	-94 / -1,47	-270 / -4,21
0,75	26 / +0,41	-27 / -0,42	-17 / -0,27	-42 / -0,65	-104 / -1,62	-355 / -5,53
1	27 / +0,42	-104 / -1,62	-59 / -0,92	-117 / -1,82	-165 / -2,57	-550 / -8,57



Volumes obtained from horizontal slices created from the point files measured by different devices with varying quantity of points were for the optimal horizontal cuts step determination compared by individual methods. Volumes comparison for the different methods with respect to the horizontal slice step is expressed numerically and graphically in Tab. 7 and graph 5.

Tab. 7, graph 5: Volume differences determined by specific methods with focus on the step of horizontal cuts

Horiztal cuts step [m]	TLS 100% points [m^3]/[%]	TLS 50% points [m^3]/[%]	TLS 10% points [m^3]/[%]	TLS 1% points [m^3]/[%]	Trimble VX 100% points [m^3]/[%]	UMS Leica TS02 100% points [m^3]/[%]
0,25	0 / 0,00	0 / 0,00	0 / 0,00	0 / 0,00	0 / 0,00	0 / 0,00
0,5	+2 / +0,03	-3 / -0,05	-4 / -0,06	-10 / -0,16	-5 / -0,08	-107 / -1,71
0,75	-22 / -0,34	-8 / -0,13	-25 / -0,39	-8 / -0,13	-15 / -0,24	-192 / -3,07
1	-21 / -0,32	-85 / -1,33	-67 / -1,04	-83 / -1,30	-76 / -1,20	-387 / -6,19



5. Conclusion

The aim of this article was to determine the optimal method of geodetic measurements and subsequent processing of the measured data with respect to the density of the measured points and the desired resulting detail level of mining irregular walls surface and also the time and financial requirements of the process. We used modern surveying technologies designed for spatial data collection with automatic scanning (TLS) and also common devices – total stations with laser distancemeter.

Their main distinguishing characteristic is the detailed points density with respect to the measurement speed. From the surveyor point of view TLS are most effective, but financially demanded. TLS are ready to obtain large amounts of spatial data in short time, but subsequent data processing is time consuming and requires powerful hardware and suitable software. Total stations allow lower measured points density, surveying time in the field is longer, but data processing is easier. Therefore, the accuracy of the volumes determination is lower than using TLS.

Analysis confirms that recommended optimal spatial distance of measured detailed points using TLS is up to 20cm, because of volume difference determination is within 1% in opposite to reference volume what is neglible in comparison to the total amount of extracted raw material.

The results are presented in tables and graphs in absolute and percentage changes in determined volumes and demonstrate the TLS method suitability for data processing in the form of 3D models showing only small results values differences in comparison with total stations methods.

In the cut method of volume determination, when the high quantity of detailed points is measured, cuts step up to 0.5m should be selected, when resulting volumes differences are negligible. As to data measured by total stations with a small quantity of points, the difference in volume determination with horizontal cuts step 1m ranges up to 6%.

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