

## THE APPLICATION OF TERRESTRIAL LASER SCANNING TO MONITORING THE CRICOVA UNDERGROUND MINE IN THE REPUBLIC OF MOLDOVA

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**Abstract:** *Terrestrial laser scanning is an advanced technique for mapping and monitoring the Earth's surface that can be successfully used in the monitoring of underground mines, especially in determining the geometric parameters of mine gallery structures. This article presents the use of terrestrial laser scanning technology in the Cricova underground mine in the Republic of Moldova to identify changes and potential risks for the safety of future works. Using the Leica BLK 360 scanner (BLK Edition), control measurements were conducted to determine the verticality and flatness of the underground mine walls located at a depth of 10 meters. After processing the data using specific specialized software, a 3D model was created, deviations from the mine walls compared to the reference project were highlighted, and final reports were developed for evaluation, analysis, and decision-making.*

**Keywords:** *terrestrial laser scanning, 3D modeling, underground mine, point cloud, monitoring of displacement.*

### 1. Introduction

Currently, one of the modern technologies of terrestrial measurements is Terrestrial Laser Scanning (TLS) technology, which has become an efficient tool in numerous fields of activity. The application areas of this technique continues to expand as it has proven to be more advantageous than the traditional methods in terms of operability, reliability, and time and cost efficiency [1].

In the 3D scanning process, exceptionally fast, accurate, complex, and safe spatial data of objects on the Earth's surface or underground are obtained. The scanned object is then visualized by specialized software as a cloud of points, and subsequently, it is possible to perform a wide range of analytical tasks and also to generate object models [2].

Specifically in mining, TLS has the potential to be used for a wide range of applications: monitoring and documenting the progress of underground mining works, assessing the stability and hence worker health and safety at mining sites, monitoring deformation and convergence, calculating volumes, providing supplementary evidence (e.g. in the case of accidents or damage), aiding security and protection of mining sites, etc. [3] Monitoring underground movements is important as increasing rate of movements can be

indicative of failure and also provide operators with a better understanding of when to install roof and wall support [4].

In this paper, an applied study of TLS was conducted to determine the deformations of the underground walls of the Cricova mine located in the proximity of the city of Chişinău in the Republic of Moldova (fig.1). This study is concerned with determining the accuracy and precision of laser scanning measurements for the purposes of measuring underground mine deformation, especially determining the verticality and flatness of the walls in the mine. The mine that was explored has a length of approximately 2 km and a depth ranging from 10 to 70 meters.

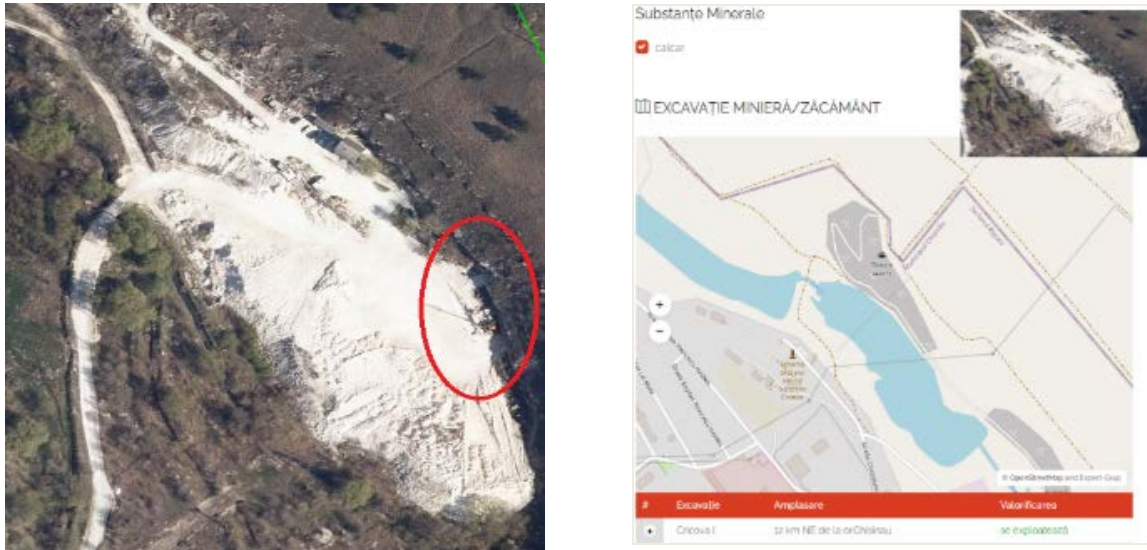


Fig.1.The location of the Cricova underground mine[5], [6]

## 2. Materials and Methods

Terrestrial laser scanning was performed using the Leica BLK 360 on a section of the mine, where 22 stations were established. The enclosed LiDAR sensor in the BLK360 captures point clouds at a rate of 360,000 points per second and completes a scan with images in less than 3 minutes[7].

Primary applications in underground mines, such as localization, convergence monitoring, structure mapping, change detection and deformation tracking, require globally referenced point clouds (georeferencing). Attachment of a global coordinate system (usually earth-fixed) of point clouds, is difficult in underground mines due to the absence of a spatial positioning framework. Instead, point clouds in underground mines are indirectly georeferenced by transferring datum from a GNSS-aided environment through a total station survey using ground control tags [8].

For georeferencing in the MOLDREF99[9] national system, it was necessary to materialize two reference points near the mine entrance (fig. 2). The coordinates of these two points were determined using the CHCNAV I50 GNSS receiver in the MOLDPOS positioning system [10]. Subsequently, a traverse was conducted with the Leica Viva TS15 total station to transmit the coordinates to the targets fixed on the walls of the underground mine (fig. 3). The 3D scanning was conducted by TLS by setting the instrument over georeferenced targets. These targets are identified subsequently in the point cloud, either

manually or through automated algorithms, for conversion from the local coordinate system to the national coordinate system[8].



Fig. 2. Measurements with CHCNAV I50 GNSS receiver



Fig. 3. Measurements with Leica Viva TS15 total station

Analyzing the study area, the optimal locations for the scanning stations and targets were determined in order to achieve maximum precision (fig. 4, fig. 5). Providing a complete 3D model requires complete coverage of the project area and measurement of all the desired features. Firstly, the devices are displaced in order to eliminate the remaining left-behind areas and the shadows created in the model. So, the device must be located at points that best cover the areas not captured at the previous stations. Changing the location of a laserscanner significantly increases the surveying time as well as the data processing time.[11]



Fig. 4. One of the optimal stations of the Leica BLK 360 scanner.

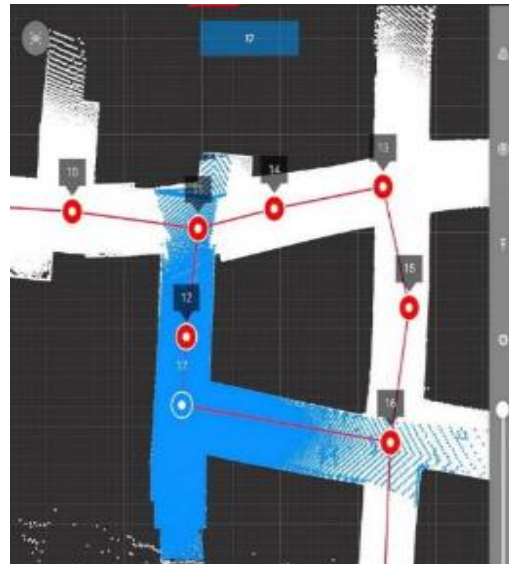


Fig. 5. Station 17 of the scanner (view from the Leica Cyclone Field 360 control panel)

Static scan positions are determined by using survey-type resection techniques based on target positions. A minimum of three targets is needed to tie or register one scan position to another, but maximizing the number of targets and their geometric placement helps to increase the accuracy of the collected data.[12].

For the case study, multiple targets were set along the mining gallery. During the scanning process, the targets were within clear line of sight of the scanning position to allow registration.

The scanning process can take anywhere from 2 minutes to 6.50 minutes, depending on the targeted area and selected resolution. For the given case, a high precision was set, and the scanning period lasted 6.50 minutes. In the beginning, the starting point was identified, and then it proceeded directly to collecting the data points. These points can be visualized and stored directly on the control panel, having an internet connection.

After completing this process, it is necessary for the data to be processed and then modeled in 3D. This process can be performed directly from the scanner connected to a computer, through a connection using the Leica Cyclone REGISTER 360 (BLK Edition) software [7].

After importing the data into the software (fig. 6), we can perform several options such as optimization, modeling, editing, scanning error detection, and deletion of erroneous points. Additionally, we also have access to the option of georeferencing the job in MOLDREF 99 (fig. 7).

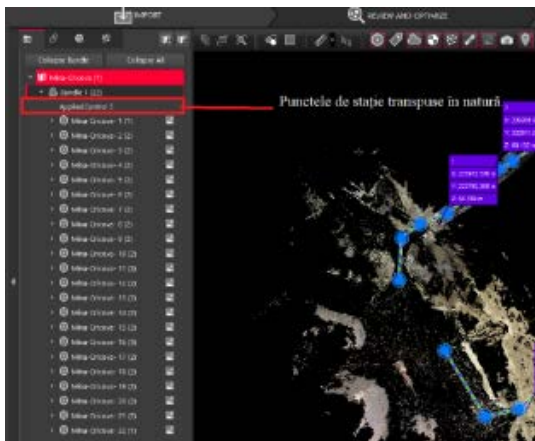


Fig. 6. Importing points into the Leica Cyclone REGISTER 360 software.

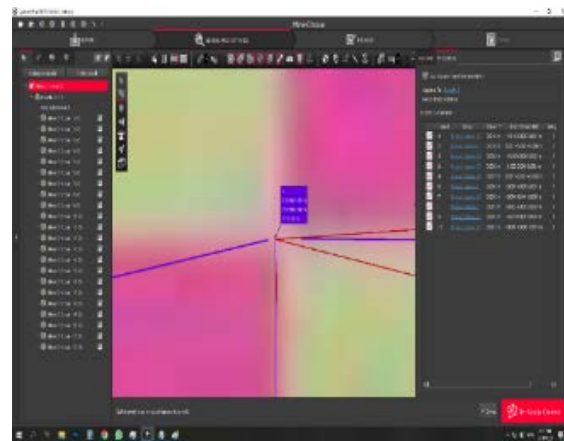
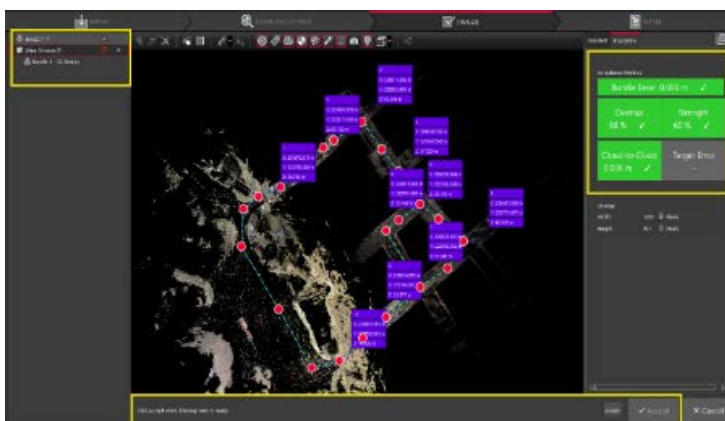


Fig. 7. Georeferencing in the MOLDREF 99 coordinate system.

After performing all the options of editing, modeling, creation, and removal of objects that do not have to be scanned, the final optimization of all data was performed and an evaluation report was generated (fig. 8).



Overall Quality	
<b>Error Results for Bundle 1</b>	
Setup Count: 22	<b>Bundle Error 0.006 m ✓</b>
Link Count: 23	<b>Overlap 68 % ✓</b>
Strength: 60 %	<b>Strength 60 % ✓</b>
Overlap: 68 %	<b>Cloud-to-Cloud 0.006 m ✓</b>
	<b>Target Error --</b>
<span style="color: green;">■</span> Max error of 0.005 m. <span style="color: yellow;">■</span> Max error of 0.000 m. <span style="color: red;">■</span> Error greater than 0.020 m.	

Fig. 8. Creation of final optimization and error report



A precision of results evaluation can be observed through a performance of the classifiers, which can be analyzed by creating a coverage report of the object that was scanned using point clouds.

Data accuracy is calculated by the ratio between the coverage /set of correctly labeled common points and the total number of data, while the error rate results from the ratio between the number of incorrectly labeled data and the total data number [14]. The Fig. 8 shows the report of results that were determined following the application of a three-dimensional classification for the case study, which reached a maximum error of 6 mm.

### **3. Analysis and results**

The analysis and description of the results is the final and most important stage of a study to actually present the reality. To obtain the 3D model of the underground mine, point cloud processing was performed using Cyclone 3DR 2022.1 software.

Using the Cyclone 3DR software, we can create final deliverables directly from the Leica Geosystems 3D laser scanner to expedite and streamline the data capture and BIM (Building Information Modeling) workflow processes. 3D mesh models are one of the high-value deliverables that Cyclone 3DR enables us to generate, and the latest version includes new features to make the creation and customization of textured mesh more accessible to everyone. [7]

The mine model was created using a single function. The idea is to sequentially access each flat surface to extract the walls and ceilings of the mine gallery. The function will automatically join the surfaces and create an accurate model of the mine, specifically by selecting the point cloud and initiating the *Building Extractor* command.

The function automatically processes the point cloud to find the best extraction tolerance that is possible to be observed, but also to modify this value to extract certain planes as needed (fig. 9, fig. 10).

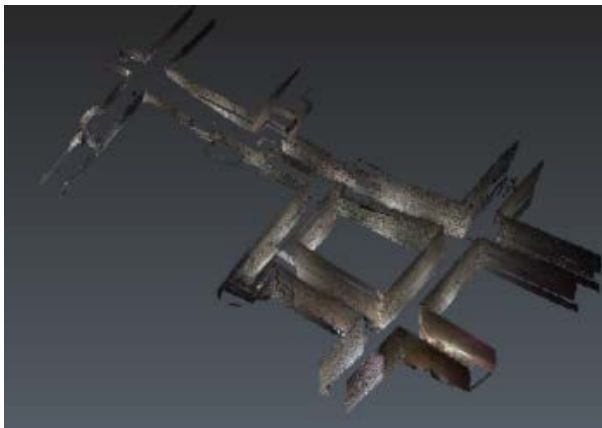


Fig. 9. Extraction of mine walls

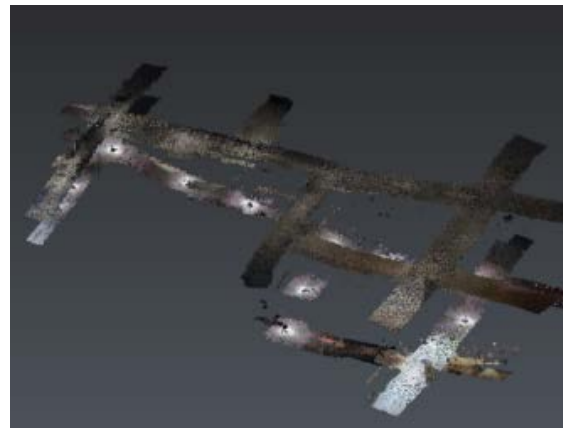


Fig. 10. Extraction of mine ceilings

The 3D comparison of two models or two contours to determine the deviations between them requires an important theoretical geometric verification with the appropriately measured model, or when there is a need to compare two objects at different moments, for example, with a surface represented by BIM technology. With data from the BIM model, correction or maintenance projects can be planned and managed to bring underground mines into compliance with verticality and flatness requirements. To achieve the objective, the two models must be placed in the same coordinate system to be compared.

This process consists of the following steps:[15]

- reading the model "as it is built" as a cloud of points from digitization;
- aligning or registering the scan data to the theoretical model;
- distance calculation and color texture mapping;
- adding labels;
- editing or exporting the 3D verification report.

This is the reason why manual alignment or prepositioning registration should be performed first, followed by the utilization of the most appropriate calculation for achieving the final registration (Fig. 11, Fig. 12).

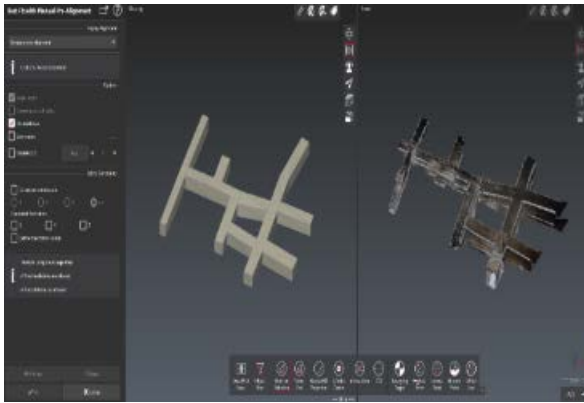


Fig. 11. Prepositioning BIM vs CAD

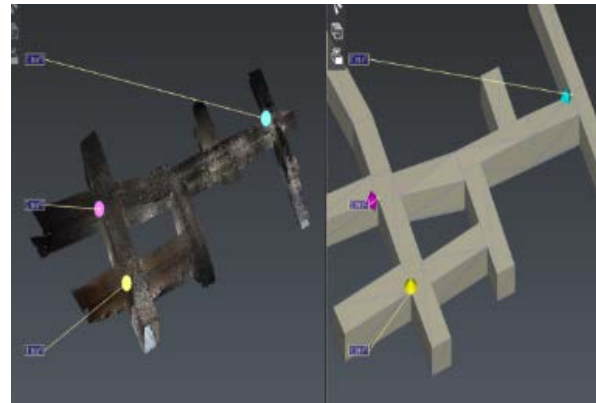


Fig. 12. Alignment between BIM vs Cloud

The comparison of the two objects is based on the first entity selected and which is considered as the reference object. The main steps in this case are [15]:

- applying the color to the *Reference*;
- checking the maximum distance and setting 0.72;
- unchecking the other options;
- clicking on *Preview*(as different values are possible (fig.13), depending on the cleaned points);
- color map applied to the mesh to see deviations.

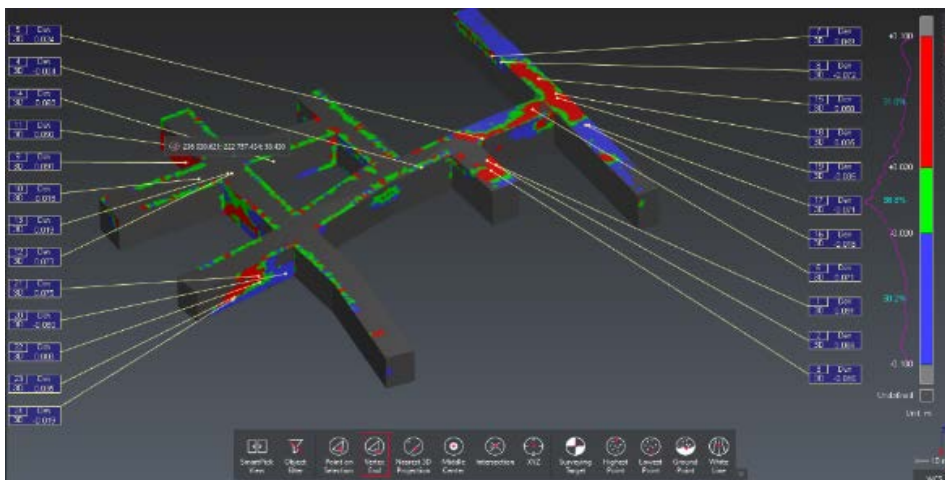


Fig. 13. Deviations between BIMvsCloud

In this way, we have the possibility to determine the flatness and verticality of the walls of the mining galleries by simply access using the Surface flatness and Surface levelness commands (fig. 14, fig. 15).

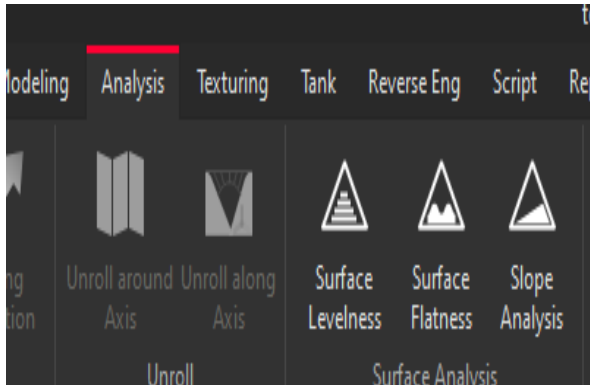


Fig. 14. Cyclone 3DR menu with analysis option

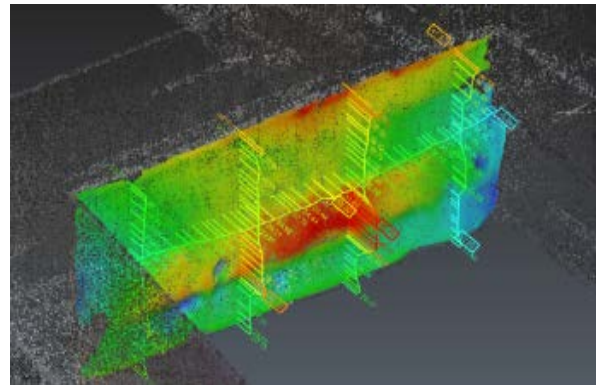


Fig. 15. Deviations from the reference project

Performing a final analysis of the results obtained according to Table 1 and Figure 16, we can mention that the deviations of the mine walls are quite significant, indicating a neglect of the project during the extraction of mineral deposits.

Table 1. Deviations of the mine walls on X, Y, Z coordinates and the 3D displacement vector

Label number	Meas X	Meas Y	Meas Z	Ref X	Ref Y	Ref Z	Dev X	Dev Y	Dev Z	Dev 3D
1	236 032.740	222 812.664	61.557	236 032.797	222 812.593	61.556	-0.057	0.071	0.001	0.091
2	236 030.058	222 810.526	60.274	236 030.110	222 810.461	60.273	-0.053	0.066	0.001	0.084
3	236 031.268	222 811.391	58.440	236 031.257	222 811.404	58.441	0.010	-0.013	-0.000	-0.016
4	236 029.110	222 796.582	56.272	236 029.106	222 796.579	56.272	0.003	0.003	0.000	-0.004
5	236 019.138	222 808.361	57.138	236 019.157	222 808.377	57.138	-0.019	-0.016	-0.000	0.024
6	236 014.497	222 818.454	62.671	236 014.499	222 818.454	62.600	-0.002	-0.000	0.071	0.071
7	235 994.985	222 808.031	60.529	235 994.956	222 808.070	60.530	0.030	-0.039	-0.001	0.049
8	235 997.866	222 810.350	61.511	235 997.909	222 810.293	61.510	-0.043	0.057	0.001	-0.072
9	236 030.656	222 747.144	54.805	236 030.602	222 747.215	54.806	0.054	-0.072	-0.001	0.090
10	236 036.763	222 750.602	55.564	236 036.748	222 750.592	55.564	0.015	0.010	0.000	-0.018
11	236 030.546	222 757.384	58.430	236 030.621	222 757.434	58.430	-0.075	-0.050	-0.000	0.090
12	236 030.942	222 756.871	52.750	236 031.003	222 756.911	52.751	-0.061	-0.040	-0.000	0.073
13	236 030.643	222 756.091	52.386	236 030.655	222 756.075	52.385	-0.012	0.015	0.000	0.019
14	236 025.622	222 765.178	52.314	236 025.565	222 765.141	52.314	0.057	0.038	0.000	-0.068
15	236 000.255	222 818.434	59.281	236 000.285	222 818.394	59.280	-0.030	0.040	0.001	0.050
16	236 015.401	222 829.736	59.602	236 015.392	222 829.749	59.603	0.009	-0.013	-0.000	-0.016
17	236 018.927	222 830.751	62.717	236 018.927	222 830.750	62.787	0.001	0.001	-0.071	-0.071
18	236 005.758	222 822.572	60.020	236 005.779	222 822.543	60.020	-0.021	0.028	0.000	0.035
19	236 006.272	222 822.886	59.105	236 006.251	222 822.913	59.105	0.021	-0.028	-0.000	-0.035
20	236 064.643	222 771.457	53.558	236 064.701	222 771.511	53.558	-0.059	-0.054	-0.001	-0.080
21	236 069.535	222 766.331	56.550	236 069.480	222 766.280	56.549	0.055	0.051	0.001	0.075
22	236 069.314	222 766.494	54.627	236 069.308	222 766.488	54.627	0.006	0.006	0.000	0.008
23	236 073.785	222 761.679	53.702	236 073.759	222 761.655	53.702	0.026	0.024	0.000	0.035
24	236 074.047	222 761.318	53.154	236 074.062	222 761.331	53.155	-0.014	-0.013	-0.000	-0.019

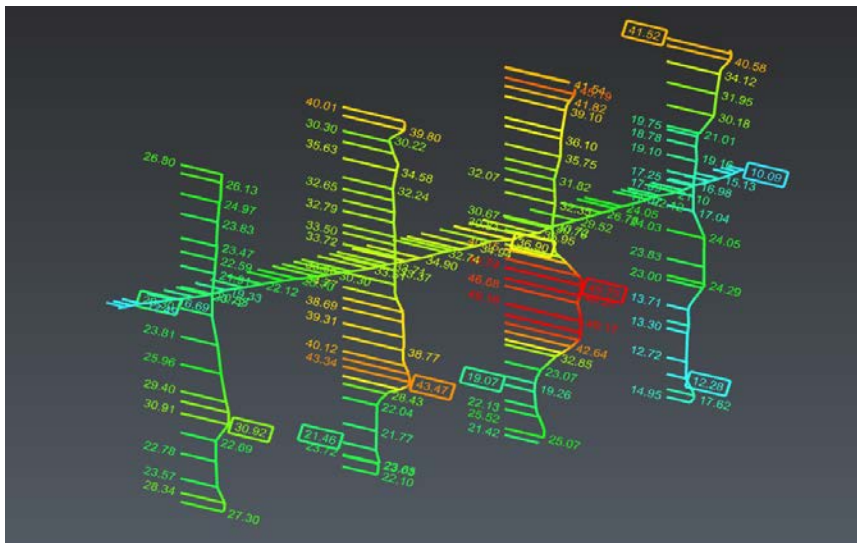


Fig. 16. Values of mine wall deviations

With the Cyclone 3DR software, it is possible to create automated reports with all the data included, using the option of exporting the executions that were carried out separately on easily readable layers. Complete and personalized reports can be exported as 2D or 3D PDF files for a better demonstration of the study results (fig. 17, fig. 18, fig. 19).

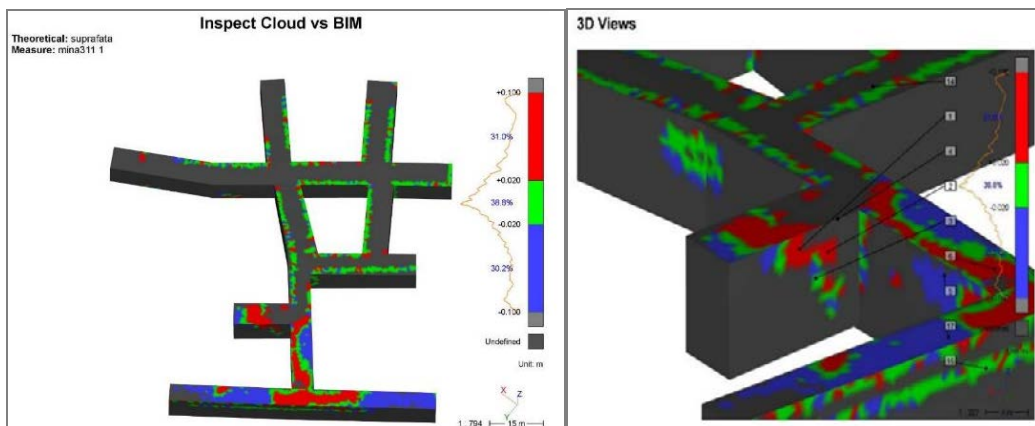


Fig. 17. Inspect Cloud vs BIM

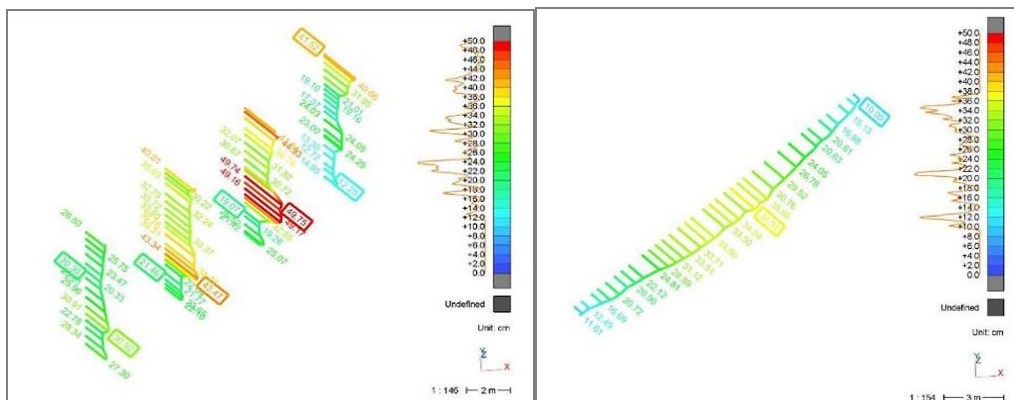


Fig. 18. Sections of the mine wall deviation flatness



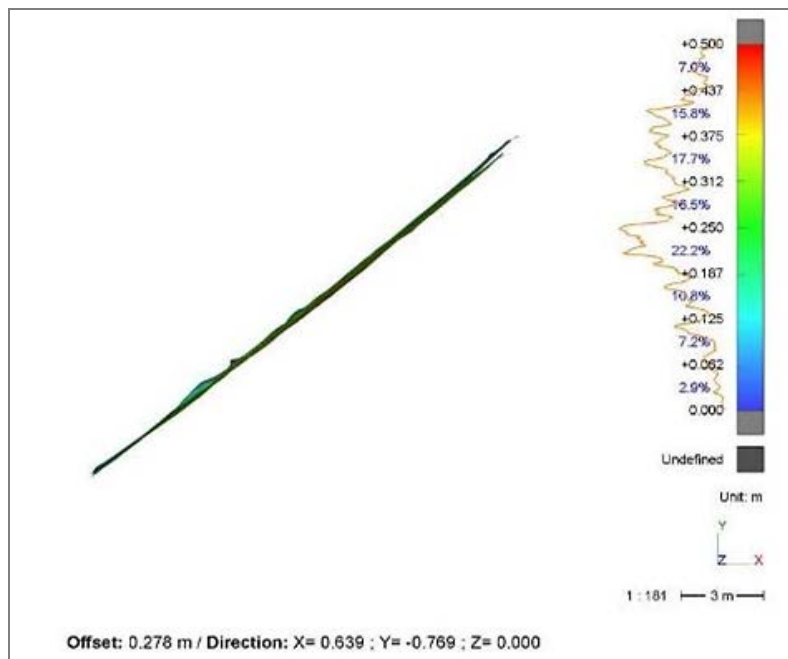


Fig. 19. Surfacelevelness

#### 4. Conclusions

Terrestrial laser scanning technologies, in addition to providing a fast solution for digitizing real-world objects, offer a complete set of easily interpretable data, not only due to the point cloud but also to the recorded images. These technologies offer many advantages compared to traditional deformation monitoring and analysis techniques. TLS has become increasingly vital for mine integrity verification, providing early information about potential collapses and instabilities of walls, and allowing for early intervention to significantly improve miners' safety and reduce economic losses caused by equipment damage and infrastructure loss.

The present study was focused on determining the flatness and verticality of the Cricova mine galleries in the Republic of Moldova using TLS technology. By integrating with other topo-geodetic measurements (real-time GNSS receivers and total stations) for georeferencing the data into a coordinate system, the point cloud data were easily used for the accurate spatial positioning of the studied object.

Analyzing the final report of the laser scanning and data processing and modeling through Cyclone 3DR software and BIM technology, a maximum deviation of approximately 50 cm in wall verticality from the reference project was detected in a section of the mine. This proves the need for ongoing monitoring and the implementation of measures in future excavation works.

Following the study, it can be noted that terrestrial laser scanning and BIM modeling are two complementary technologies that can be used together to obtain a detailed and comprehensive image of an underground mine. They are important tools for assessing and managing the verticality and flatness of underground mines. These technologies provide accurate data, detailed analysis, and a management platform to ensure optimal safety and operation conditions of the underground mine.

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