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STEPGRAD
СТЕПГРАД

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LASER SCANNING AT THE LOCATION OF DEVILS' TOWN FOR THE PURPOSE OF DETECTING THE DEGREE OF EROSION OF EARTH PILLARS

Abstract

The detection of erosion was carried out on a characteristic rocky pillar, with the localization and quantification of differences between two surfaces. For this purpose, based on the defined area and spatial configuration of the scanning object, scanner positions, arrangement of control points, and appropriate spatial scanning resolution were planned. The spatial resolution of the point cloud is 1 cm, with a standard deviation of individual points up to 3 mm. Based on the collected data, registration of adjacent scenes was performed using typical scanner signals and the surface matching method. Georeferencing of the second epoch was carried out using the surface matching method. Locations where erosion of the rocky mass occurred were detected, amounting to 0.036 m^3 (36 dm^3).

Keywords: terrestrial laser scanning, 3D modelling, erosion, earth pillars

ЛАСЕРСКО СКЕНИРАЊЕ НА ЛОКАЦИЈИ ЂАВОЉА ВАРОШ ЗА ПОТРЕБЕ ДЕТЕКЦИЈЕ СТЕПЕНА ЕРОЗИЈЕ ЗЕМЉАНИХ ПИРАМИДА

Сажетак

Детекција ерозије спроведена је на једној карактеристичној стјеновитој фигури, са лоцирањем и квантификовањем разлика две површи. За ту сврху, на основу дефинисаног подручја и просторне конфигурације објекта снимања, планирана су стајалишта скенера, распоред контролних тачака и одговарајућа просторна резолуција скенирања. Просторна резолуција облака тачака износи 1 cm, а стандардно одступање појединачне тачке до 3 mm. На основу прикупљених података извршена је регистрација сусједних сцена на основу типских скенерских маркица и методом најбољег уклапања површи. Геореференцирање друге епохе извршено је методом најбољег уклапања површи. Детектована су мјеста на којима је дошло до ерозије стјеновите масе у износу од 0.036 m^3 (36 dm^3).

Кључне ријечи: терестричко ласерско скенирање, 3Д моделовање, ерозија, земљане пирамиде

1. INTRODUCTION

Terrestrial laser scanning (TLS), as one of the technologies applied in geodesy, offers solutions for various tasks within the field of surveying [1, 2]. The TLS method has shown promise in detecting changes and monitoring structural deformations, but improvements in registration, georeferencing, and point cloud processing are necessary for more precise results [3]. By employing TLS monitoring, it is possible to track deformations preceding landslides through routine detection on an annual basis [4]. Additionally, TLS can enhance the characterization and monitoring of rock slopes, enabling precise quantification of rockfalls [5], effectively detecting and analyzing structural damages, providing consistent results, and serving as a virtual sample for testing and post-testing analysis [6]. Yermolaev et al. [7] asserts that TLS offers several advantages: it can register different types of erosion in temporary water streams, enables non-invasive distance measurements without disturbing the surface being studied, and ensures work safety. Furthermore, it facilitates the calculation of morphometric parameters using a high-precision digital topography model. Based on observations in sample areas, the study demonstrates that autumn rains significantly impact soil erosion. Additionally, a study by Li et al. [8] analyzed the erosion and deposition patterns within the gully using two TLS surveys. They found erosion and deposition reserves of 11.0 and 8.2 m^3, respectively, at a DEM resolution of 2 cm. Due to its features, TLS enables data collection and analysis at sites such as "Devils' town". The process of monitoring the geometry of an object involves collecting data about the object (performing geodetic surveying) at different time intervals (epochs) and then comparing the obtained results. Comparison is typically made relative to the zero epoch (initially recorded state), but depending on the required information, subsequent epochs can also be compared. By collecting data in different temporal epochs and comparing them, erosion detection can be conducted. It is necessary to locate the areas where erosion has occurred and determine the degree of erosion by quantifying the differences between the two surfaces. The TLS method is suitable for capturing lateral details of pillars from both the observer's perspective and top-down, from multiple positions [9]. The scanning of the site was conducted in two epochs, the first epoch being in 2017 and the second one year later in 2018. This procedure was carried out within the scope of this study on a characteristic rocky pillar at a site known as "Barjaktar".

2. STUDY AREA

The natural phenomenon consists of Earth pillars, as well as specific relief forms, and two sources of highly acidic water with high mineralization. Devils' town comprises 202 pillars, formed by erosion, of various shapes and dimensions, ranging from 2 to 15 m in height and 0.5 to 3 m in width, with stone caps of various shapes and dimensions at the top (Figure 1). This process has been ongoing for centuries, as the towers form, grow, change, shorten, disappear, and reappear. The earth columns are composed of three layers of different compositions: the base layer is sandstone, up to one meter thick, the middle layer is yellowish clay, up to three meters thick, and above it is the thickest layer of sandstone, covered with andesite plates that protect the loose substrate from destruction and erosion. These specific relief forms were created by the action of rain on the former topographic surface. The site "Devils' town" has been under state protection since 1959, and in 1995, it was declared a natural monument of exceptional importance and placed in the first category of protection [12].

By washing away sand and gravel from underneath smaller or larger stone blocks, pillars in the form of towers and pillars remain. However, external forces (rain, snow, ice, wind) gradually erode the "towers," causing them to collapse, while new ones are formed due to soil washing. Thus, the earth pillars "move," gradually retracting deeper into the interior of the mountain slope [11].

Figure 1. Natural monument Devils' town [9]

This geomorphological phenomenon is unique in our country and very rare in the world. In Europe, there are several similar sites, while in America, the "Garden of the Gods" is known, but in "Devils' town", the pillars are more numerous, larger, and considerably more enduring.

The task of this study is the detection of erosion on characteristic rocky pillars. The pillar whose analysis is presented in this paper is the "Barjaktar" pillar (Figure 2). The name "Barjaktar" comes from the legend associated with "Devils' town", which states that the rocky pillars are petrified wedding guests. "Barjaktar," as the most prominent pillar, has an andesite cap weighing around 3.4 t [7].

Figure 2. Position of "Barjaktar"

3. METHODOLOGY

Terrestrial laser scanning represents a method for collecting spatial data, resulting in a set of 3D points, known as a point cloud. For each point, four pieces of data are collected: three spatial coordinate data and a fourth piece of data representing additional information about the intensity of the return signal. Certain TLS models are designed for high-precision measurements and are applied in the field of engineering geodesy, where the accuracy of 3D point positions needs to exceed 1 cm. The choice of scanner to be used primarily depends on the nature of the specific surveying task, as well as requirements regarding accuracy and scanning speed.

To obtain a unified point cloud of the scanned area, it is necessary to register all point clouds, ensuring the necessary overlap of individual point clouds of the scanned object. Point cloud registration can be performed based on typical signals, morphological details, etc. In this study, registration was performed using typical signals, where the object was marked before scanning. Identifying the typical signal and determining its position requires determining the signal center with satisfactory precision. The precision of determining the center depends on the point density of the terrain [12]. Therefore, data quality is represented by positional accuracy and resolution.

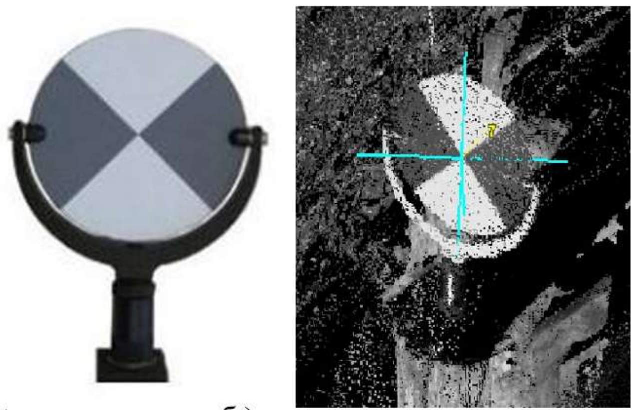
The data processing phase of the collected data is also a complex process and often requires much more time than the data collection itself. Data processing involves several steps, primarily including registration and georeferencing of point clouds obtained through scanning.

3.1. INSTRUMENT AND ACCOMPANYING EQUIPMENT

During scanning, the Leica Scan Station P20 scanner was used (Figure 3). The combination of pulsed time-of-flight distance measurement with Waveform Digitizing (WFD) technology enables high scanning speeds with the Leica P20 scanner (1,000,000 points/s), as well as the capability of distance measurement (up to 120 m), justifying the choice of this scanner to survey the Devils' town site. The declared accuracy of this scanner is 3 mm at 50 m. The laser belongs to Class 2, with a wavelength range from 658 nm (visible) to 808 nm (invisible). The ideal operating temperatures for this scanner range from -20˚C to +50˚C [13].

Figure 3. Leica Scan Station P20 [13]

As accompanying equipment for materializing tie points for registration purposes, Leica standard targets shown in Figure 4 were used.



a.) б.)

Figure 4. a.) Leica standard target b.) Appearance of scanned signal

3.2. LAYOUT OF STATIONS AND SIGNALS

Based on the defined scanning area and the terrain configuration, the stations must be arranged in such a way that the pillar of interest ("Barjaktar") is scanned from all sides to identify areas where erosion has occurred. The scanner stations were selected to ensure the scanner was positioned on a stable surface, in this instance, a wooden platform. Placing the scanner on an unstable surface was avoided due to the significant risk of movement. The layout of standard signals is defined to ensure a sufficient number of signals are captured in each scene for registration to be performed with the required accuracy. All signals are stabilized to prevent their movement until scanning is completed from all stations. In the first epoch, 12 signals were used, and in the second epoch, 9 were used. The smaller number of signals in the second epoch is due to the smaller number of stations (Figures 5 and 6). In both epochs, stations numbered from 2 to 5 are used (Figures 5 and 6), because within those scenes, the "Barjaktar" is scanned.

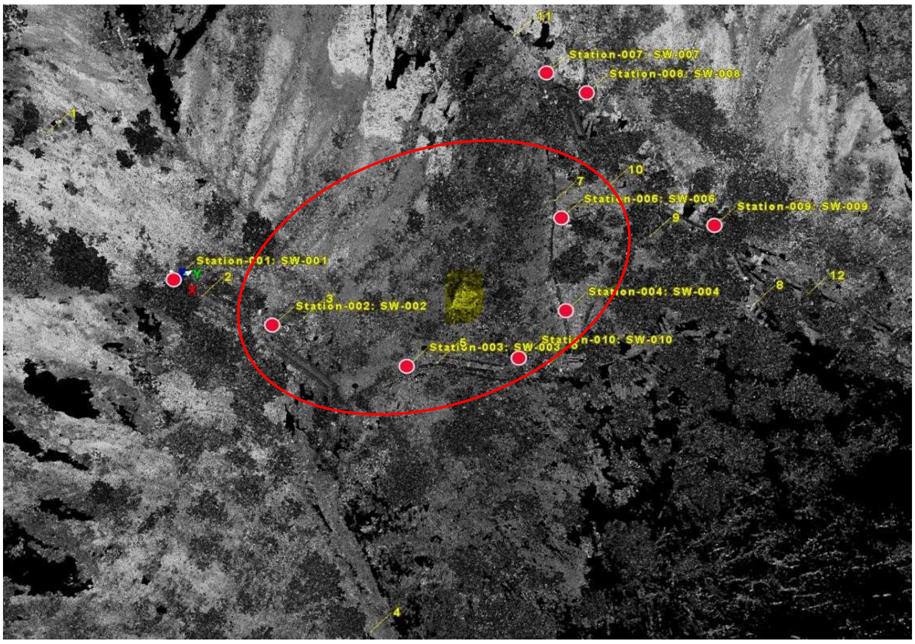


Figure 5. Layout of stations and signals for the first epoch (2017)

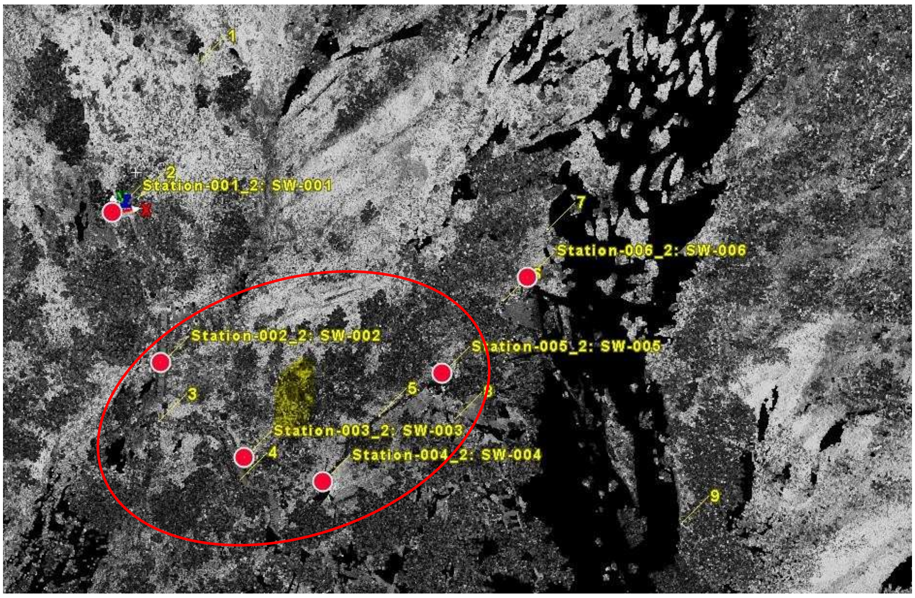


Figure 6. Layout of stations and signals for the first epoch (2018)

3.3. REGISTRATION AND GEOREFERENCING

Data registration was performed using the *Leica Cyclone 9.0* software [14], which enables the manipulation and processing of point clouds.

The method used for registration in both epochs is registration using standard signals. Additionally, an analysis was conducted when both standard signal registration and surface matching were used simultaneously, and it was observed that for this specific case, better accuracy is achieved only with standard signal registration.
Georeferencing was carried out using the surface matching method. The point cloud from the second epoch, which was previously registered, was georeferenced by transforming the coordinate system of the second epoch's point cloud into the coordinate system of the first epoch's point cloud.

4. RESULTS

The recordings were carried out in November 2017 as part of the first epoch and in September 2018 for the second epoch, as part of the pilot project MEĐA, which was realized by a part of the research team in 2017-2018 [7].

Result of the registration for the first epoch:

As a result of the registration, in addition to the merged point cloud, a registration report is obtained. It contains all relevant data about the registration, including accuracy, the number of signals, and the error in their determination. From the analysis of the report, it was concluded that if all signals that can be used for registration between all scenes are included in the registration, its global uncertainty amounts to 9 mm, which is not sufficient in this case. Further analysis revealed that during the scanning of scene number 10, marker number 3 was displaced. This was concluded because the errors in the registration of the 10th scene with all other scenes using that marker (scenes number 1, 2, 3, and 5) were significantly larger (7-9 mm) than the rest (0-4 mm) (Table 1).

Table 1. Errors on marker number 3

No. signal	Scene “i”	Scene “j”	Error (mm)
3	001	010	9
3	002	010	9
3	003	010	9
3	005	010	7

After marker number 3 was excluded from the mentioned scenes and registration was performed again, the accuracy of the registration was 2 mm.

Result of the registration for the second epoch:

The accuracy of the registration in this epoch, when all signals are used, is 7 mm, which, like in the first epoch, is not satisfactory accuracy. Analysis of the report revealed that the error on marker number 4 during registration between scene number 2 and scene number 4 is 7 mm, which is also the largest error. When it is excluded and the registration process is performed again, the accuracy of the registration, like in the first epoch, is 2 mm.
Georeferencing was conducted utilizing the optimal surface matching. The point cloud from another epoch, over which the registration was previously performed, is georeferenced, i.e. the point cloud coordinate system of the second epoch is transformed into the point cloud coordinate system of the first epoch. This entails transforming the coordinate system of the point cloud from the second epoch into that of the first epoch. Following georeferencing, a report indicated that the accuracy of georeferencing is 3 mm.
In addition to the aforementioned georeferencing accuracy of 3 mm, 319 400 overlapping points were used for the transformation process. In this case, a four-parameter transformation was performed. The scanner allows for the compensation of the Z-axis inclination with an accuracy of 1.5", thereby nullifying the parameters of rotation around the X and Y axes. The surface matching method is an iterative process, and according to the report, 7 iterations were performed in this case.

4.2. ANALYSIS OF REGISTRATION USING STANDARD SIGNALS AND THE SURFACE MATCHING

The registration analysis was performed on the registration data of the second epoch (2018). Registration using the standard signals method has a mean absolute error of 2 mm, while registration using both standard signals and the surface matching method has a mean absolute error of 3 mm.

4.3. EROSION DETECTION (LOCATING AND QUANTIFYING DIFFERENCES)

After georeferencing the point cloud of the entire site for both recording epochs, the pillar of interest ("Barjaktar") was "cut out" (Figure 8), and the point cloud resolution was adjusted to 1 cm (using the *Unifi cloud* function) to enable the comparison of two georeferenced point clouds of the same pillar, captured in two epochs.

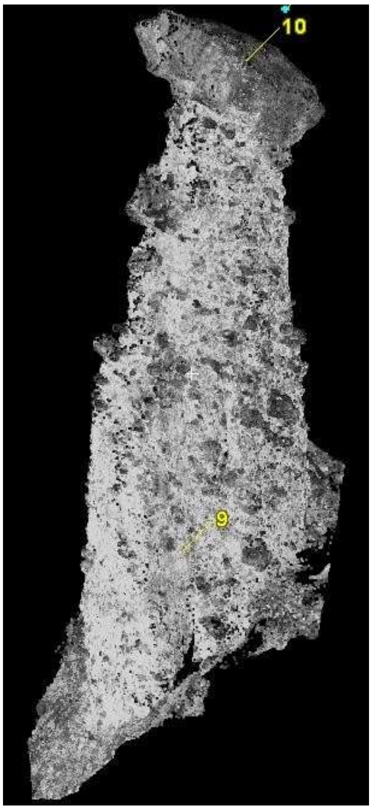


Figure 7. The pillar "Barjaktar" after extraction

For the next analysis, the CloudCompare software [15] (an open-source program) was used. Figure 8 shows the point clouds from the first and second epochs within this program.

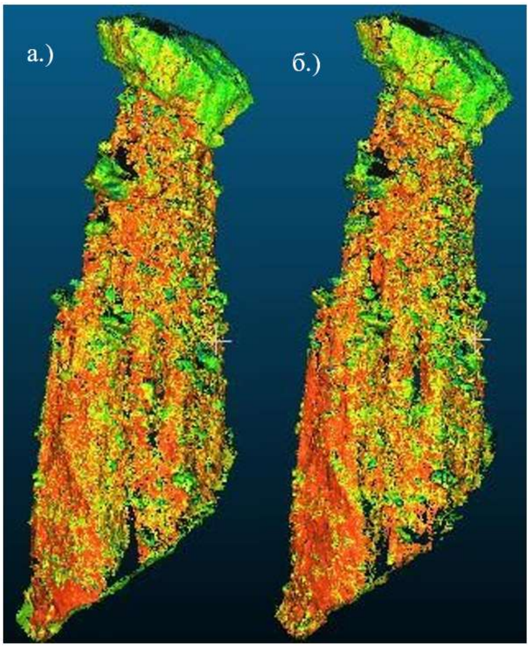


Figure 8. The pillar of "Barjaktar" a) first epoch b) second epoch

After loading both point clouds, the next step involves computing deviations between the two epochs. The Cloud/Cloud Distance function was used for this step. The point cloud from the first epoch serves as the reference for comparison, while the point cloud from the second epoch is the one being compared. The basic idea is to determine distances using the nearest neighbor distance method. Calculating distances using the nearest neighbor method sometimes isn't precise enough if the point cloud isn't dense enough or has gaps. Increasing precision can be achieved by defining local models. When comparing point clouds of interest, the local Height Function model was employed. This choice was made based on the recommendation of the program creators, particularly when dealing with point clouds exhibiting "high curvature" [15]. The result of comparing the two epochs is shown in Figure 9. The figure displays a color scale representing the distance between the epochs.

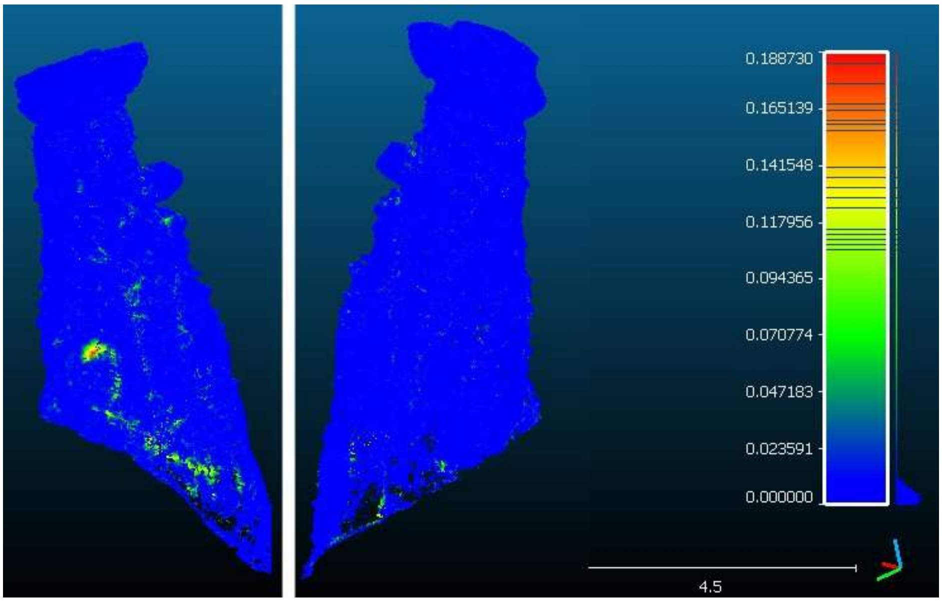


Figure 9. The result of comparing the first and second epochs

Visual inspection and comparison were conducted on areas marked by the color scale ranging from green to red, indicating areas where erosion occurred. As seen in Figure 10, there are areas where erosion has occurred, while the appearance in other places is due to the lack of points from the first recording epoch. These areas were not further considered. The area where erosion occurred is shown in Figure 10 and will be the subject of further consideration.

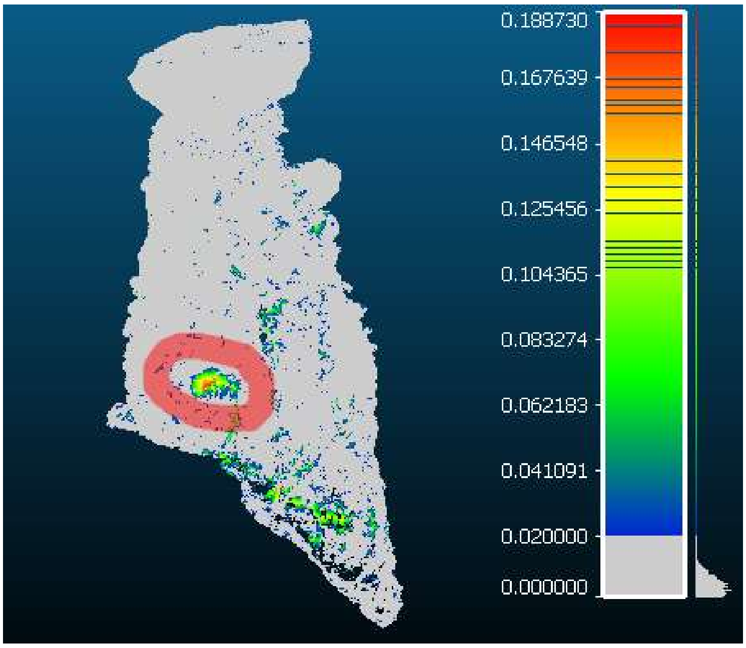


Figure 10. The area (outlined in red) where erosion has occurred

The area of interest has been isolated from the point cloud, and an analysis has been conducted on it. Figure 11 shows the area where the analysis was conducted. One part of the image displays the point cloud from the second epoch, while the other part shows the point cloud where the first epoch recording is also depicted. It is evident here that there was a significantly more rocky mass in the first epoch compared to the second.

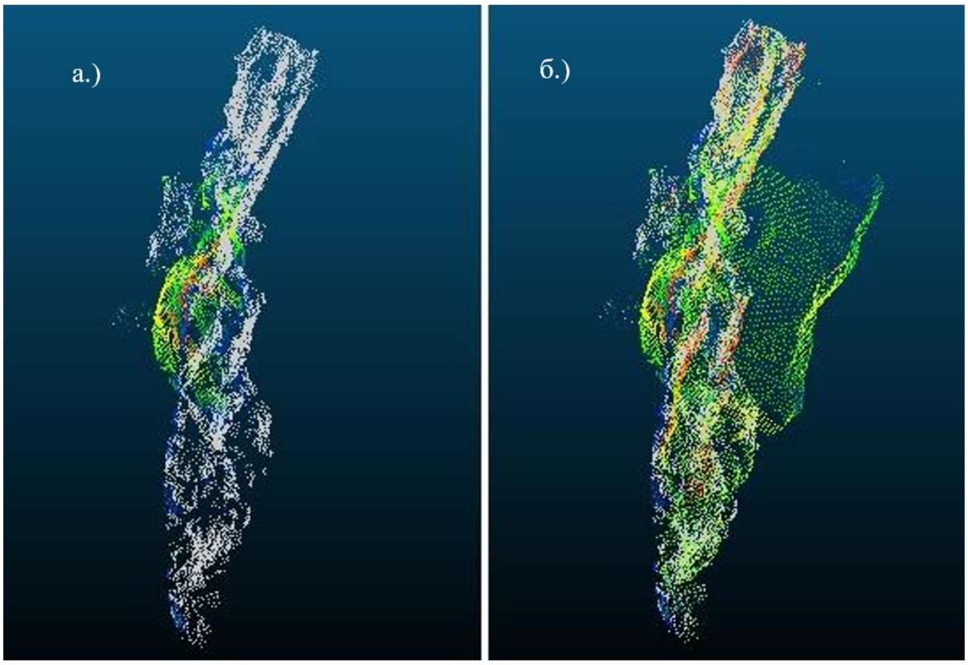


Figure 11. a) Point cloud from the second epoch. b) Point cloud with the first epoch included.

The CloudCompare software [15] offers the ability to calculate volume based on a grid between two point clouds. When initiating the volume calculation function *Compute 2,5D Volume*, it's necessary to input the projection direction value. The function *Compute 2.5D Volume* calculates the volume based on the grid In this specific case, the direction of the Y-axis was used. The appearance of the grid based on which the volume of the landslide was calculated is shown in Figure 12.

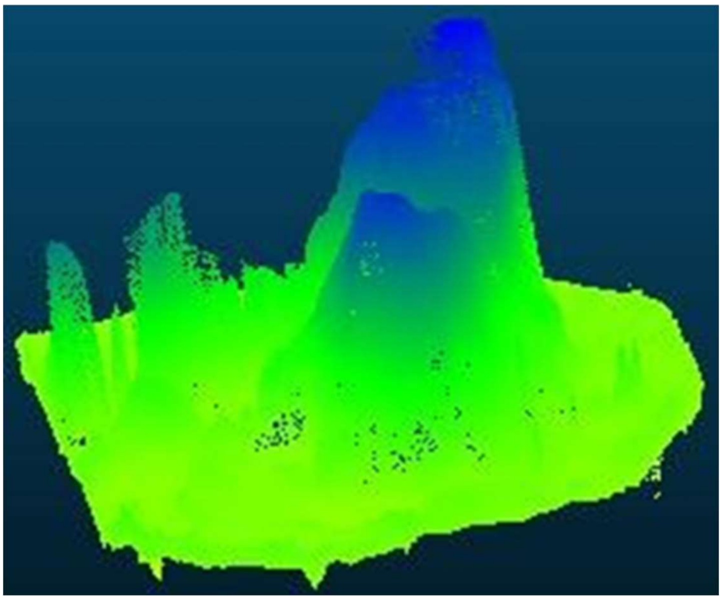


Figure 12. The grid based on which the volume was calculated

The following lines present the volume calculation report. The report indicates that the volume of the landslide material amounts to 0.036 m^3 (36 dm^3).

Volume: -0.036
Surface: 0.641

Added volume: (+)0.001
Removed volume: (-)0.037
Matching cells: 99.2% Non-matching cells:
ground = 0.0%
ceil = 0.8%
Average neighbors per cell: 8.0 / 8.0

5. CONCLUSION

During the detection and quantification of erosion of the rocky pillars, data from two scanning epochs of the "Devils’ town" site were compared. The scans were conducted in November 2017 and September 2018 as part of the "MEĐA" project. Registration and georeferencing processes were performed on each epoch, followed by georeferencing of the second epoch using the surface matching method. After isolating the pillar of interest ("Barjaktar"), a comparison of the pillar from both epochs was conducted using the CloudCompare software. Deviations between the two point clouds were detected and analyzed. It was revealed that erosion of the rocky mass occurred at one location. Through analysis and comparison, it was determined that the quantity of rock mass that eroded amounted to 0.036 m^3 (36 dm^3). This represents the initial phase of research and monitoring changes occurring within the "Devils’ town" site. The presented methodology can be successfully utilized for analysis and comparison within the newly acquired project of the Science Fund DEMONITOR, within which all members of the project "MEĐA" are involved. In the scope of future research, the presented epochs will serve as a baseline for further analyses, and the same methodology can be used for other planned epochs. Within the DEMONITOR project, six site visits are planned to survey the area using TLS and aerial photogrammetry with unmanned aerial vehicles (UAV), where significant results are expected already after the first site visits, considering the seven years.

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