



**Application of terrestrial laser scanning for characterizing
discontinuities in a limestone quarry**

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Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Abstract

The aim of this work was to analyze the possibility to characterize the geometric properties of discontinuities using a laser scanning methodology and to identify the scan configuration that optimizes, from a cost-benefit perspective, the time spent in the field and the positional quality of the results. The equipment used in the field was the Laser-Scanner Faro S70. The activities had place in a limestone quarry, located near the city of Fátima (Portugal).

The work was divided into three main steps: fieldwork survey, data processing and the geometrical characterization of the discontinuities. In the first step several scans were conducted and combined in order to understand the influence of the spatial resolution parameter in the point cloud generation. Also a collection of images were recorded and used for the characterization of the discontinuities. Data processing allowed the combination of scans and three main models were generated and analyzed. The geometric characterization of the discontinuities, for each point cloud model, was focused in strike, dip direction, spacing, persistence, aperture, harshness and filling parameters. All the results were compared in order to identify the scan configuration that most benefits, considering the positional quality and time spent, the acquisition of data during the fieldwork.

The developed work proves the suitability of this methodology for the geometric characterization of the discontinuities, in an open pit mine environment. All the scan configuration offered good results and high accuracy, with noticeable advantages in relation to time spent doing the fieldwork, for the lower scan configuration.

Keywords: laser-scanning; discontinuities; geometric characterization; limestone quarry

Resumo

Este trabalho teve como objetivo avaliar a adequabilidade do método de varrimento laser na caracterização dos parâmetros geométricos das descontinuidades e identificar a configuração do equipamento mais adequada, na perspectiva de minimizar o tempo gasto na operação de campo e maximizar a qualidade posicional dos resultados. O equipamento utilizado foi o Laser- Scanner Faro S70. Os trabalhos foram desenvolvidos numa pedreira de calcário, situada na zona centro de Portugal, no concelho de Fátima.

O trabalho foi dividido em três tarefas principais: o trabalho de campo, o processamento dos dados e a caracterização geométrica das descontinuidades. Relativamente ao trabalho de campo foram testadas várias configurações, incluído o espaçamento e o número de pulsos emitidos, de modo a avaliar o impacto na geração da correspondente nuvem de pontos. Simultaneamente foram recolhidas fotografias que permitiram a indexação de cada ponto ao respetivo nível radiométrico e assim obter uma nuvem de pontos classificada por cor.

O processamento dos dados foi realizado com recuso ao software de livre acesso *Point Cloud* e no final foram construídos e analisados três modelos de nuvens de pontos com diferentes qualidades posicionais, que permitiram a caracterização geométrica das descontinuidades. Assim os parâmetros identificados foram: a direção e inclinação das descontinuidades, a persistência, abertura, rugosidade, preenchimento e o espaçamento. Por último, observaram-se os dados e analisaram-se as diferenças obtidas, com as diferentes configurações, o que permitiu concluir pela utilidade da metodologia e perceber a influência da resolução adotada.

Conclui-se que, para todos os perfis de configuração estudados, os dados mostraram uma boa precisão, com ganho evidentes de tempo na recolha dos dados da configuração de menor resolução. Por último, confirma-se a eficácia da metodologia/procedimento utilizada no estudo das descontinuidades, neste tipo de trabalhos, a céu aberto.

Palavras-chave: Laser-Scanner; caracterização geométrica das descontinuidades, pedreira de calcário

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1. Introduction

In the open pit and quarry exploitation environment it is very important, for safety and ornamental quality purposes, to identify the discontinuities present in the rock mass. The occurrence of discontinuities depends on rock mass lithology and weathering degree. The discontinuities influences the rock mass behaviour, once they introduce anisotropy in deformation, strength and permeability properties and because of this, the excavations stability, depends on the direction of the discontinuities. The ornamental quality of stone depends on the persistence of discontinuities, such as veins, and its colour. Therefore, the process of monitoring and testing of discontinuities should be analysed and classified. To help identify discontinuities and improve the work it is still necessary to find different solutions. Nowadays new technology is emerging in the market and new equipment and tools are being developed to help the researchers to develop specific tool for particular purposes. There are several of them that have wide range of possibilities such as the laser scanner. It can be in use in several fields, from archaeology, architecture to civil engineering practices and in applied geodesy field this technique is doing the first steps. Also the possibility to link this equipment with different data acquisition methods open the door to innovative solutions on which the hybrids such as unmanned aerial vehicles with underslung laser scanner are becoming more popular. Thanks to the high quality of the point cloud, in level of detail and accuracy, the instrument is giving an opportunity to obtain faster and better surveying data. There is still undiscovered potential in it and this project will check one more purpose in the mining field.

1.1 Objective

The project will focus on the use of laser scanner technology to map discontinuities in a limestone quarry. The measurements had place on a quarry near Fatima and concern on joints in the block masses. A final comparison between different options in the settings of the instrument, such as the quality, resolution and time will be performed and identified the best configuration to improve the work.

1.2 Project structure

The work was divided into six main chapters, which were then fragmented into individual phases and descriptions. The first chapter is intended to illustrate, in brief, what the project is about, what tools it uses and explain the final goal. The next section is a theoretical review about concepts that were used in the work. After that, the chapter deals with field work during the data collection. The next chapter presents all phases to transform point cloud in map discontinuities characterization and the last paragraph is devoted to the final analysis and conclusions.

2. State of Art

In this chapter a theoretical background will be provide and all needed concepts will be explain. The first stage was to write a description of the main rock masses and what will be under examine into the area of the research. Further what kind of surveys were exert – basic one and new form. Next subchapter focuses on the other scanning laser applications and the last one shows the used tool.

2.1 Geology – limestone

The Iberian Peninsula, on which coexist two countries - Portugal and Spain, abounds in a number of diverse lithologies. The region where the whole surveys were done is covered by limestone, which belong to the sedimentary types of rocks, from the carboniferous era. The type of the limestone which is located in the excavation region is the “Creme Fatima”. The colour of it is a light beige with thin to medium grain. There can be also visible some of occasional thin lines and some darker brown spots. In terms of hardness, this is a soft limestone with the maximum compression strength of 1366 kg/cm² and with the bending strength of 144 kg/cm². Also the value of the water absorption is 4,35% with the porosity from 3,2% to 8% which have an influence on the abrasion level which is equal to 3,5 mm. The main minerals, that can exist in the limestone, are calcites and aragonites.

2.2 Discontinuities

Rocks discontinuities can be generated by mechanical, chemical, thermal damage, water influence and also fauna and flora impact. By the damage from ring environment rises the shear force, compressive force and also tensile strength the discontinuities are created. This term describe every mechanical continuity break of a rock mass. [9]

2.2.1 Types of discontinuities

Discontinuities include all kinds of mechanical break or plane of weakness in rock mass such as joints, bedding plane, fractures, faults, veins and foliation planes. To know exactly what kind of terms are they, thereafter are explanations of these divisions. [5]

2.2.1.1 Joint

Are the most usual in rock masses. They have fracture surfaces in the rock with no visible displacement. The drawing (Figure 2.1) below represents an open joint which can allow for a water flow.



Figure 2.1 Example of joints, source – WhatTheRocksTellUs.com

2.2.1.2 Bedding plane

These are systematic discontinuities found in sedimentary rocks, they do the separation between layers with different composition (Figure 2.2). There are several types of that planes, depending on the surface: gradational, sharp, wavy and sutured.



Figure 2.2 Example of the bedding planes, source – Geological Engineering

2.2.1.3 Faults

Faults are discontinuities that correspond to fractures planes that show displacement between blocks. The movement, which can be observed in the Figure 2.3, was done by shear. This can reduce the resistance of the rock masses and expose them for further changes and possibilities of breaks.



Figure 2.3 Example of faults, source – Engineering Rocks Mechanics

2.2.1.4 Veins

This term applies to the different type of materials that have the place inside the discontinuities. There are two groups of them, connected with the origin: igneous and sedimentary. The example of the vein is shown of the Figure 2.4.



Figure 2.4 Example of the vein, source – Geocaching.com

2.2.2 Geometrical characterization

To describe discontinuities on a surface it is necessary to describe some of the parameters, which are represented in the following subchapters such as: orientation, spacing, persistence, roughness, aperture and infilling. When the discontinuity is characterized by these factors, they can be provide as a sets, which gives a further information about the whole exanimated area.

2.2.2.1 Strike and dip orientation

To check the orientation of the discontinuities in the block mass it is necessary to know two parameters: the dip direction and dip angle. The dip direction means the steepest line in the plane and the second term is a compass placement of this line, which is measured from North to right. The performances of the surveys are collect and subject them to post-processing in special programs and further analysis. [7]

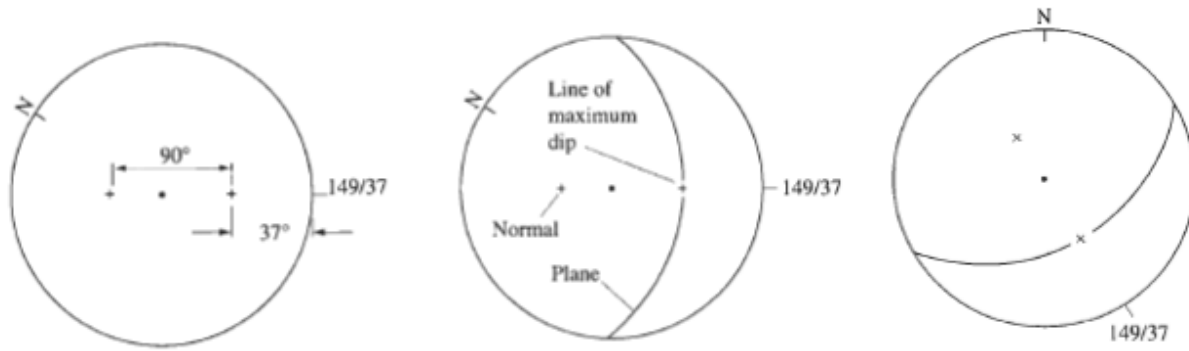


Figure 2.5 Example of the data processing, source - Introduction to Structural Geology

In the Figure 2.5 it can be seen phases of the obtaining manually data. When the information about the strike and dip directions are ready, the first step, showed on the figure above, is to marked point on the tracing paper. After that there is necessary to put the next point in the distance of 90° from previous one in the straight line. The next task is to determine the line between two borders of the circle, which represents the plane of discontinuity. When all of the previous phases is ready the last step is to put the tracing paper in a North position which shows the real position of the data in the surface. [30]

2.2.2.2 Roughness

The concept of roughness is defined as the shorter frequency of real surfaces relative to the troughs and it is a deviation from the perfect area. All of the roughness stretches are reproduced and become classify in degree of universality with the shortcut JRC (Joint Roughness Coefficient). This method compare the previously comprised profiles with the new one and assignment the number of harshness. The roughness is related to several mechanical and hydraulic features of discontinuities.

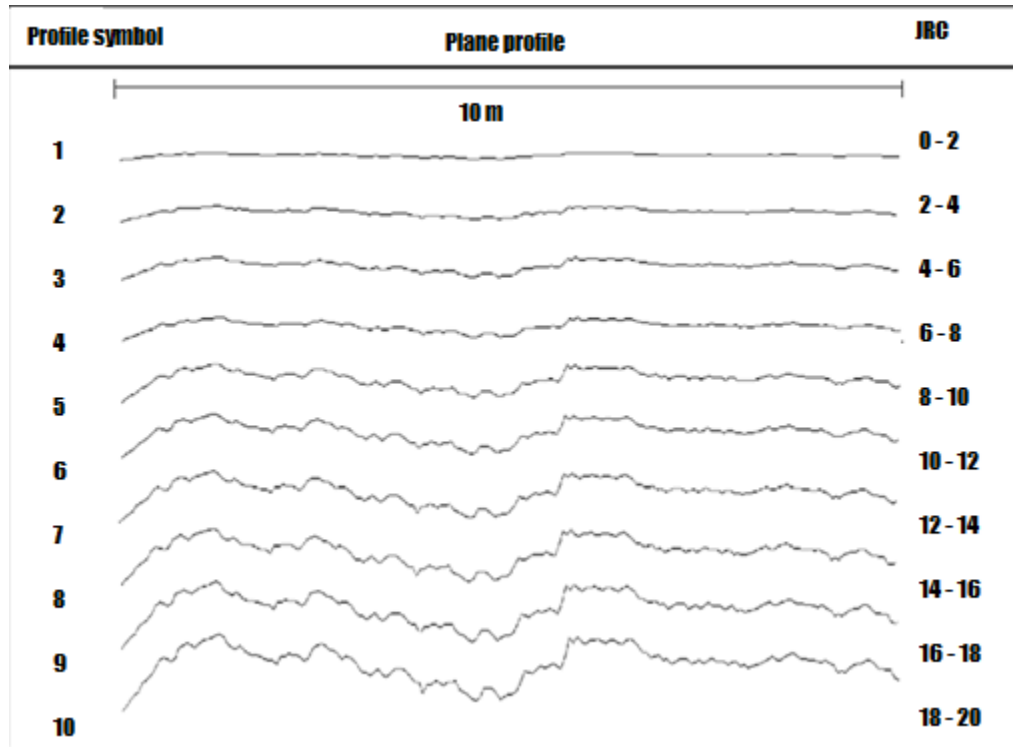


Figure 2.6 Joint Roughness Coefficient (JRC) developed by Barton and Choubey, source – *Engineering Rocks Mechanics*

The chart (Figure 2.6) represents the JRC method classified by Barton and Choubey. Starting from the left it can be observed the number assign to the wave form of line , next is the profile view of the roughness surface with the ending on the right side where represented is the full scale in numbers from 0 to 20.

2.2.2.3 Aperture

This term is used as a description of the distance between adhere walls of a discontinuities. It is possible to forecast the amplitude of asperities from the classification method JRC and length of profile. The differences are not common in the same mass of rocks. When the aperture will be metered on a small area it can be expected in the whole surface. Discontinuity in that case can't be estimated as two similarity planes because of channel flow. It is owing to a bigger apertures. [17]

2.2.2.4 Infilling

It is a parameter that determines the composition of any kind rocks and other materials contained within a discontinuity. The filling has an impact on the forces acting within the gap, strength and the progressing crack degradation process. [29]

2.2.2.5 Persistence

This parameter focuses on the reached sided of the discontinuities planes or the full dimensions of this region. To obtain the results for this factor, there need to be measure one dimension of given discontinuity. The Figure 2.7 is an example of the given term. There are several categories which file the persistence. The first one collects all the examples below 1 m of length and the numeration goes up with the bigger dimensions, and end on the fifth classification process which requires more than 20 m. [6]



Figure 2.7 The example of the persistence, source – Jstore.org

2.2.2.6 Spacing

This term is used to describe the values of geometrical characterization of discontinuity by measure the distances between neighbour joints, cracks and others. To do that it is necessary to conduct surveys of the distance between two interior lines of the closest discontinuities. The for this parameter is show on Figure 2.8.

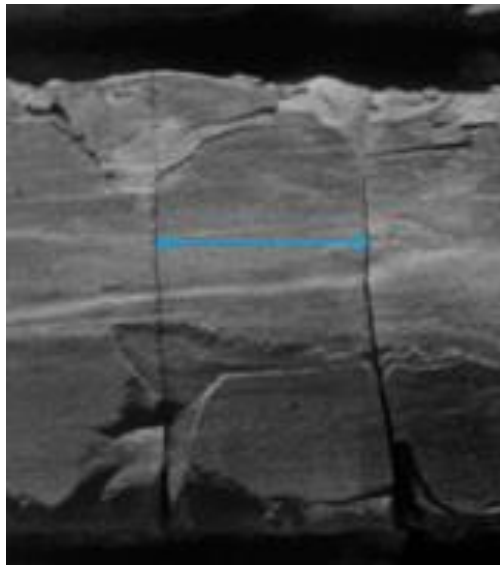


Figure 2.8 The example of spacing, source – Capbridge.org

2.3 Data acquisition common methods

There are several methods that can be used the for the data acquisition. They can be divided in the several groups, according the type of measurements, such as: compass with inclinometer, surveying and indirect methods. All of them are described in the following stages. [10]

2.3.1 Compass and inclinometer

The most common and popular technique for discontinuities measurements is the magnetic one. Several tools such as the compass with the inclinometer or also the geological compass which has

its own inclinometer inside can be in use of this method. The purpose of the measurements is to obtain a list of lengths, directions and slopes of the discontinuities.

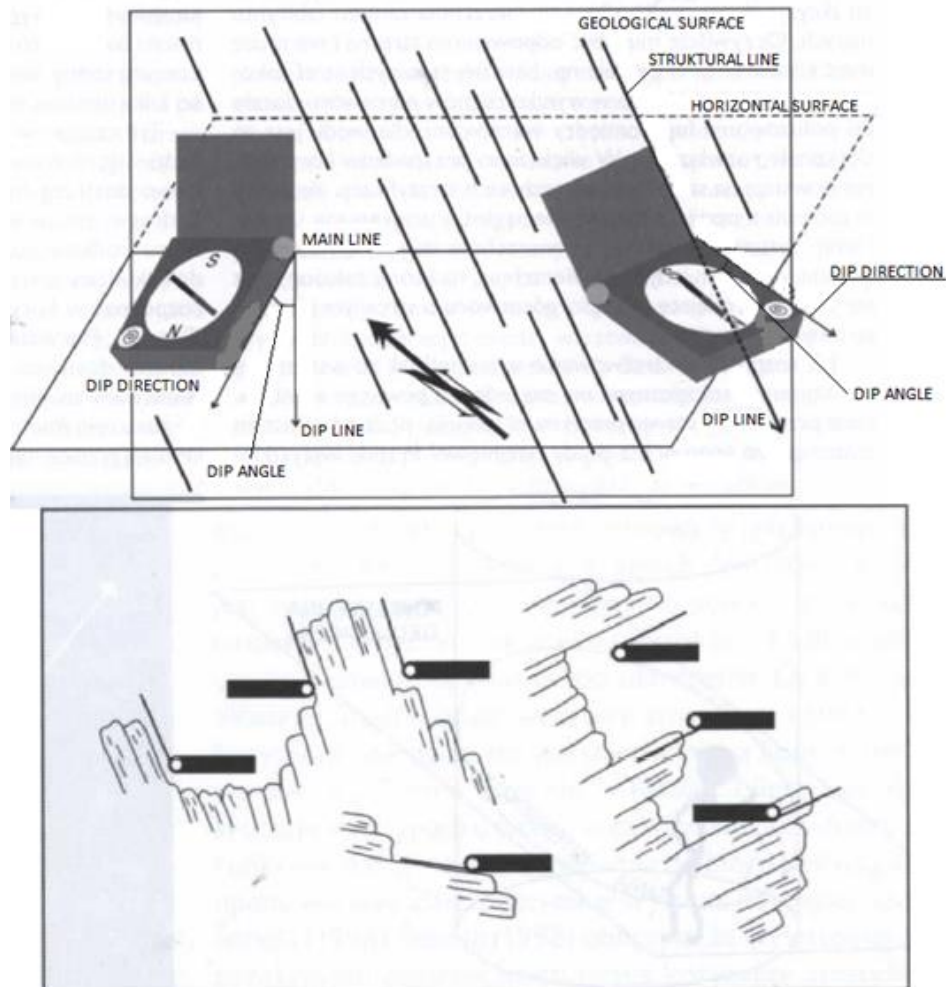


Figure 2.9 Directions, angles and examples in use of compass, source – *Geologia Eksploracyjna*

In the figure 2.9 are presented all the directions and angles necessary to collect from surveys of discontinuities. In the lower figure are examples of compass location based on different surfaces. To start the measurement, the operator must press the clinometer plate to the measured plane. Then level the compass using the vial and release the needle. When the needle stops spinning, lock it. The next step is to read the dip angle from the scale on the side of the inclinometer and the direction of dip from the needle. The receive data need to be written and prepare for further post-processing. The disadvantage of this method is the lack of repeatability compared to other methods. This is due to the fact that the operator using the tool is not able to put it again in exactly the same place after each surveys. It should also be noticed that discontinuities in rock blocks are often difficult to access from ground level. This is due to the different heights of the operating planes and the accumulation of material or other derivatives that prevent the efficient operation of the said method. [18]

2.3.2 Methods using total station scanning

This method is based on the use of a total station (TS) equipment, which is placed on a point of known topographic coordinates, and by measuring angles and distances, will estimate the topographic coordinates of the intended points. Recent TS are equipped with laser beams, which does not require a reflector mirror, as traditional total stations, to allow the measurement of distances between TS and points. TS provides data with high accuracy level, from 2 to 3 mm, according TS configurations. To make possible the use of this method, a point in the field should be identified to place TS from which the visibility to the area will be ensured. The TS (Figure 2.10) is able to obtain the coordinates off all needed points (data location of 25 points per second).



Figure 2.10 Example of the total station, , source – Topcon.com

Despite the fact that the mentioned tool needs much more time to measure a large number of pickets, it is able to do it from large distances - up to 1000 m. When the measurements are completed, it is possible to download automatically the data. [21]

2.3.3 Methods based on image

The methods based on image, also referred in the literature as indirect methods, use image as the basis to estimate point coordinates. Two different approaches can be followed, orthorectification and photogrammetric restitution, providing two different final products: an orthorectification image (in the first approach) and a model in three dimensions (in second approach). In both cases a high quality camera is needed. In order to start the measurements, proper calibration of the camera is necessary, which is associated with long work before the image acquisition. Both processes requires high user skills.

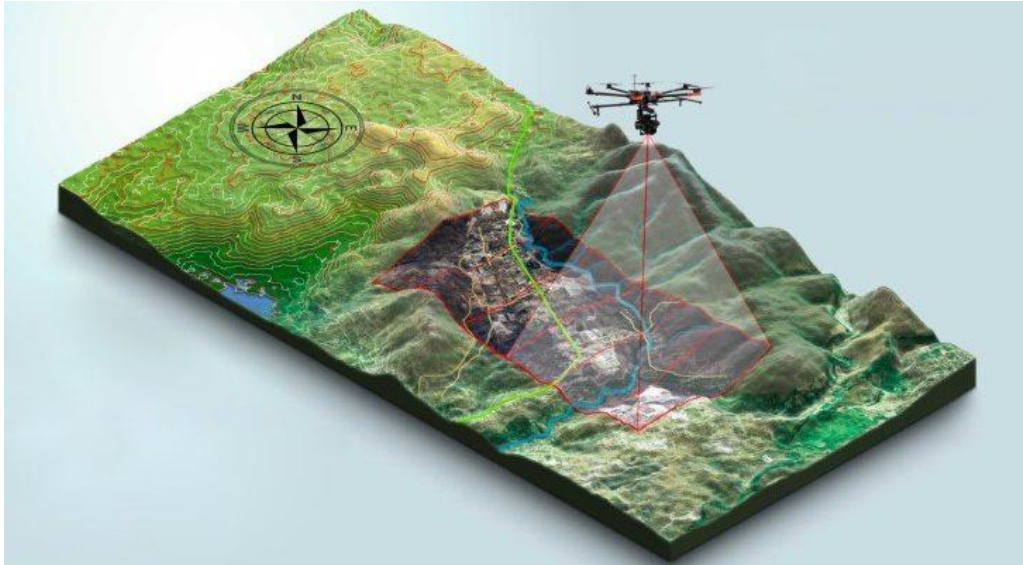


Figure 2.11 Example surveys done by help of digital photos, source – Market-it.com

Methods based on image need to be complemented with the location of control points in the area, for which a total station or a GNSS receiver may be used. As a disadvantage should also be added the fact that all individual photos should be taken approximately at the same distance and at the same level, which can be a source of error. There are two types of photogrammetric restitution: aerial (shown in the example by Figure 2.11) and terrestrial photogrammetry. [1]

2.4 Laser Scanning

In this topic several aspects that are related with the use of Laser – Scanner equipment will be highlighted, starting with a description of other works which were done by help of this tool. After that the hole specification has place and also how all the system works. Follows a brief description on how to position the equipment, how to turn on the GPS coordinate system and a presentation of all steps mandatory to start scanning and collect the point cloud data.

2.4.1 Researches using the Laser Scanner method

In order to carry out the most accurate measurements of discontinuities that occur in limestone rock masses, there was also needed to find and compare similar works available in research platforms. The focus of this literature review will be the use of Laser-Scanning (LS) in open pit mine and quarry mapping activities:

2.4.1.1 Monitoring of mine walls in quarries

In this type of work, the two of the open pit mine were get into consideration. The first one is located in Coc Sau at Quang Ninh in one of the provinces in Vietnam and the second one has place in Cracow. Poland. The main aim of this work was to collect the measurements from both quarries by using the laser scanner technology. The objects of researches in both cases were the walls. In the following work the researches wanted to know what is the best post-processing method for the generated point clouds. In the help of these tool and also the three different systems of final mesh generation the surveys group could ensure higher safe mining. [31]

2.4.1.2 Assessment of technical condition of embankments after floods

The main assumption of the work was to detect crevices, cracks and losses caused by excessive water pressure and its elevated state in the embankments and bridges covering the river. Due to the presence of hard-to-reach places, it was decided to use a laser scanner and also to place specialist signs allowing for later connection of generated point clouds. Structures located at the Vistula River in Krakow were built of stone and irregular sandstone blocks. All objects subject to inventory were then introduced into specialized programs and processed in such a way as accurately as possible.

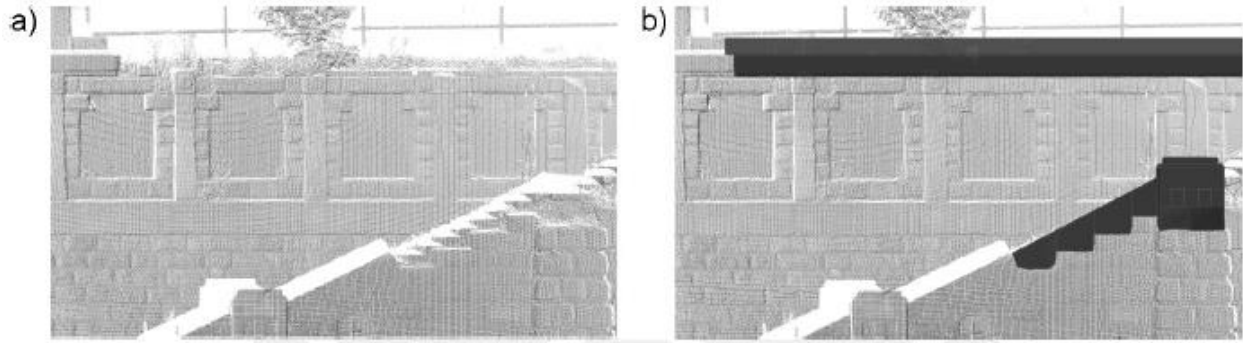


Figure 2.12 The effect of laser scanning of embankments in Cracow, source - *Wykorzystanie geodezyjnych metod inwentaryzacji wałów przeciwpowodziowych na przykładzie bulwarów wiślanych*

During the actual work, a distance of 25 m was used between the measurements. Before performing the scan, the test was repeated at each station and then the proper work was started. The landmarks are arranged between successive positions so that they can be joined together during processing. The density of the measured points was set to no higher than 5 mm. After collecting all the necessary data, they were uploaded to the program and then from the processed and connected point clouds all kinds of discontinuities and losses, visible in Figure 2.12 were chartered. Thanks to this work, it became possible to supplement and repair the damaged shafts. [28]

2.4.1.3 Monitoring dam structures

The subject of the study, which was a huge dam, was located in Valtellina, in the north of Italy. The purpose of the work was periodic monitoring of the dam in terms of possible discontinuities or losses which can be results from the degradation of the structure. It was the first measurement of this type in these areas, therefore, before the actual scanning, the research group implemented on the dam surface permanently stabilized signs that were to help in the subsequent processing of generated point clouds.

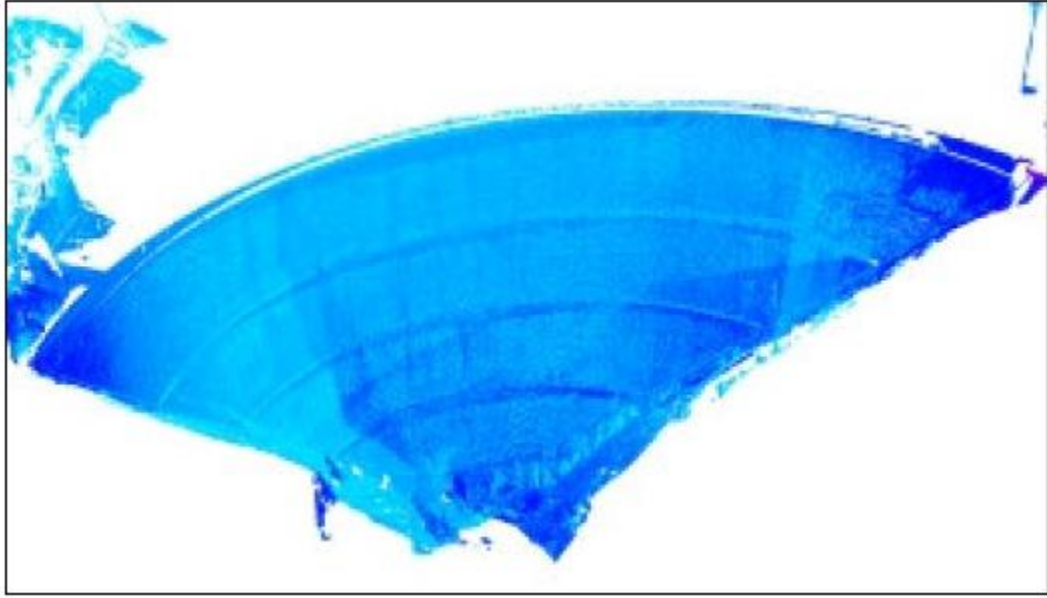


Figure 2.13 The effect of laser scanning during dam monitoring, source - *Structural monitoring of a large dam by terrestrial laser scanning*

Two types of laser scanners were used during the study. The design of the first allowed to collect points occurring no more than 100 m, while the second could measure points located at a distance of up to 1000 m. To find the right places, maps and previous observations of the area were used, which allowed to deploy devices in the most efficient, time and qualitatively places. In this way, the short-range laser was set in four locations at a distance from 50 m to 100 m. In turn, the long-range instrument was spoiled in two places 200 m and 300 m away from the dam. Thanks to the use of a grid of overlapping locations and scanner settings a point cloud was created, which then underwent the post-process which at the end helped with finding the discontinuities on the dam (Figure 2.13). [26]

2.4.1.4 Investigation of the occurrence of the discontinuities in underground mines for the gas storage

In a situation where the seam exploited in underground mines was approaching the level of economic unprofitability and its quantity was beginning to end, the restructuring group, worked in the mining company, decided to transform the entire complex into a gas storage. The research had took place in the Anderleus and Peronneslez-Binche mines located in Belgium. The assumption was to magazine selected material for the needs of nearby urban agglomerations. The works were carried out simultaneously in the laboratory and in the field. The measurement was carried out using a laser scanning technique whose task was to capture cracks and discontinuities that could have resulted in gas escaping to the surface. During the study, points were also used as targets when combining individual scans into a whole. After the post-processing the resources could find the whole of the joints and fill them all. [27]

2.4.2 LS Equipment

The equipment used to do the survey was the FARO Laser Scanner Focus 70 that is enable to capture fast, straight forward and accurate measurements of complex objects and buildings. The

laser has $\pm 1\text{mm}$ resolution at 70 m distance. The scans are recorded to the removable SD memory card, enabling easy and secure transfer to the special program. This scanner can be in work by four and a half of hour on the open air in bad weather conditions. The installed camera can take a photos in HDR quality even in the bad lighting conditions. These HDR images will be mapped onto the point cloud data generated by the laser scanner.



Figure 2.14 FARO Laser Scanner Focus, source – Faro.com

The Figure 2.14 above shows the laser scanner with the legend of the particular parts. The equipment has a touch screen with an specified software where all parameters, that will have an influence in the time of measurements and quality, can be defined. The equipment is installed on a tripod by handle and the main screw. Also on the image can be observed that the laser beam is going from the main box and hits the rotational mirror which allows to measure points. The scanner is able to covers a $360^\circ \times 305^\circ$ field of view, which is shown in the figure below. By this resolution there is only small black hole under the instrument, which can be easily resolve by second scan in different location. [14]

2.4.3 Principle of operation

To measure the distance, the machine uses phase shift technology, where constant waves of infrared light of varying length are projected outward from the scanner (Figure 2.15). Upon contact with an object, they are reflected back to the scanner. The distance from the scanner to the object is accurately determined by measuring the phase shifts in the waves of the infrared light. [23]

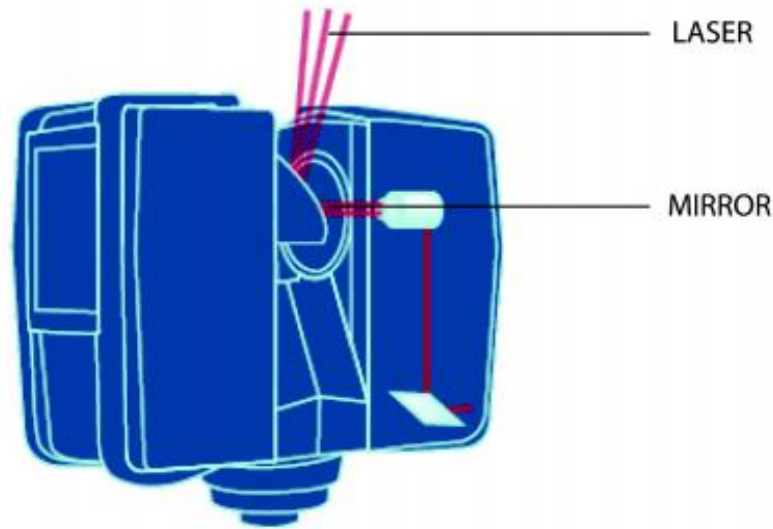


Figure 2.15 Principle of operation LS, source - Faro Focus Laser Scanner User Manual

The x , y , z coordinates of each point are then calculated by using angle encoders to measure the mirror rotation and the horizontal rotation of the Focus. These angles are encoded simultaneously with the distance measurement. Distance, vertical angle and horizontal angle make up a polar coordinate (δ, α, β) , which can be transformed to a Cartesian ones. There is also a different method applied in the LS to establish the coordinates, namely a GNSS receiver. This function is described in the following chapter. Inside the tool there is a GPS receiver which can collect the specified coordinates. The result of the measurements is a Point Cloud, a three-dimensional dataset of the scanner's environment. Depending on the selected resolution each point cloud consists of millions of scan points. [4]

2.4.4 GNSS receiver inside LS

This term is the acronyms of Global Navigation Satellite System. It is a satellite system that is used to pinpoint the geographic location of a receiver anywhere in the world. Six GNSS systems are currently in operation: the United States' Global Positioning System (GPS), the Russian Federation's Global Orbiting Navigation Satellite System (GLONASS), Europe's Galileo, Chinese Satellite System named BeiDou and Japanese one QZSS. Each of these systems employs a constellation of orbiting satellites working in conjunction with a network of ground stations (Figure 2.16). Satellite-based navigation systems use a version of triangulation to locate the user, through calculations involving information from a minimum number of 4 satellites. Each satellite transmits coded signals at precise intervals. The receiver converts signal information into position, velocity, time estimates and corrections for coordinate's estimation. [24]

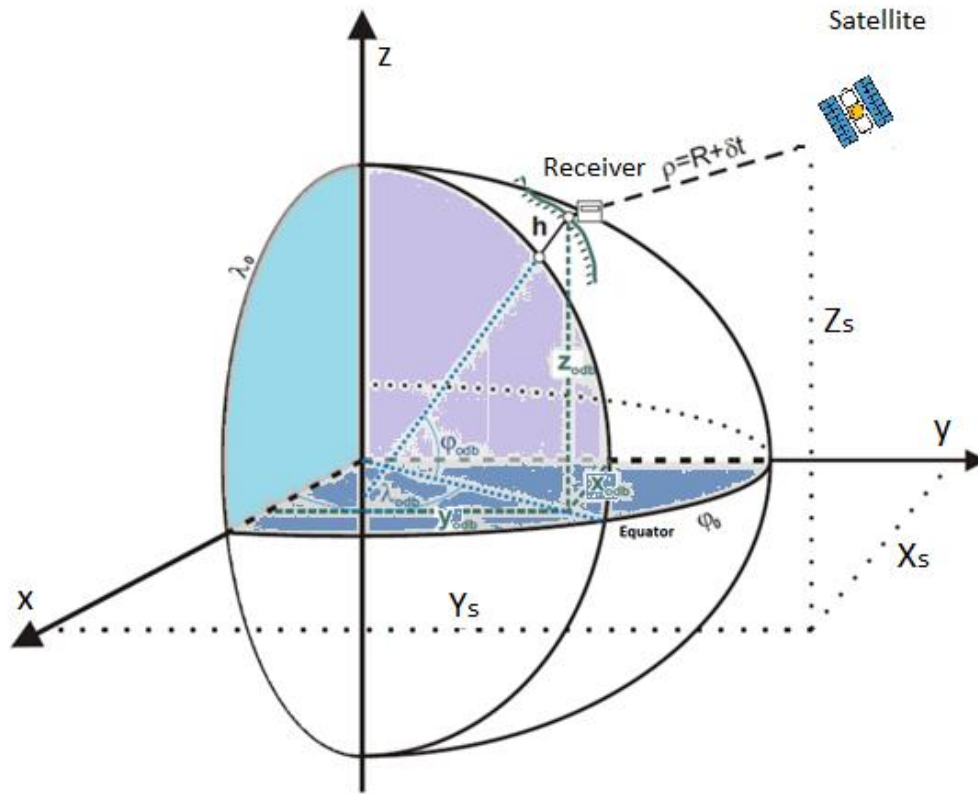


Figure 2.16 Principle operation of GNSS, source - Semanticscholar.org

Rules for setting position of GNSS receiver:

$$\rho = \sqrt{(x_{sat} - x_{rec})^2 + (y_{sat} - y_{rec})^2 + (z_{sat} - z_{rec})^2} + c * \delta t$$

In this equation there are three unknown coordinates x_{rec} , y_{rec} , z_{rec} , corresponding to the global receiver position, and an error term related to time synchronization δt . A minimum set of four satellites is necessary to determine those four unknowns parameters. Additional measures may be adopted to improve the positioning result, up to centimeter level accuracy. Most effective techniques make use of differential observations, provided by an additional base station receiver. Differential observations are combined with the information from the user's receiver, to compute correction of errors affecting the GNSS measurements and also apply alternative precision positioning techniques. Including differential techniques, other strategies may be employed to obtain more accurate positioning results such as [12]:

- A) Static Survey executes the continuous collection of data GNSS at a designated point for a long period of time. Using a postprocessing application, all measurements are combined to obtain determine a single position. When combined with differential techniques, static measurements provide the highest accuracy of GNSS. They are used in the establishment and control of geodetic and geodynamic studies.

- B) Fast Static Survey is a variation of previous method, which, instead of collecting data for long periods, consists on working with data collected over a shorter period of time. It demands for good sky visibility conditions and resorts to differential corrections to achieve position accuracies of few centimeters.
- C) Real Time Kinematic (RTK) is a high accuracy differential positioning technique that tracks the phase of the signal's carrier. It requires differential data from a near base station and at least 5 visible satellites. Usually, RTK fixes take less than a minute to acquire, with a multi-frequency receiver, and characterize by centimeter level accuracy.
- D) Differential GNSS (DGNSS) in this positioning technique, which in term of accuracy stands in between single receiver positioning and RTK positioning. It tracks the codes transmitted by the satellites, so it requires a minimum of four visible satellites. Positioning accuracy decreases inversely with the distance to the base station. Sub-metric positioning is possible for base stations in a radius up to 10 kilometers. This method is used in touristic navigation with single frequency receivers. [11]

3. Field work

In the following chapter all steps that had place in the field work will be presented, including the positioning of laser scanning and the data collection.

3.1 Location of the quarry

The quarry where all the measurements had place is 8 km to the south-east direction from Fátima city. The name of the village is Casal Farto which is connected with the National Park Serras de Aire e Candeeiros. It is a district of Santarem in the half way from Lisbon to Coimbra. The company which is an owner of the open pit mine is Filstone SA (<https://www.filstone.com/pt>).

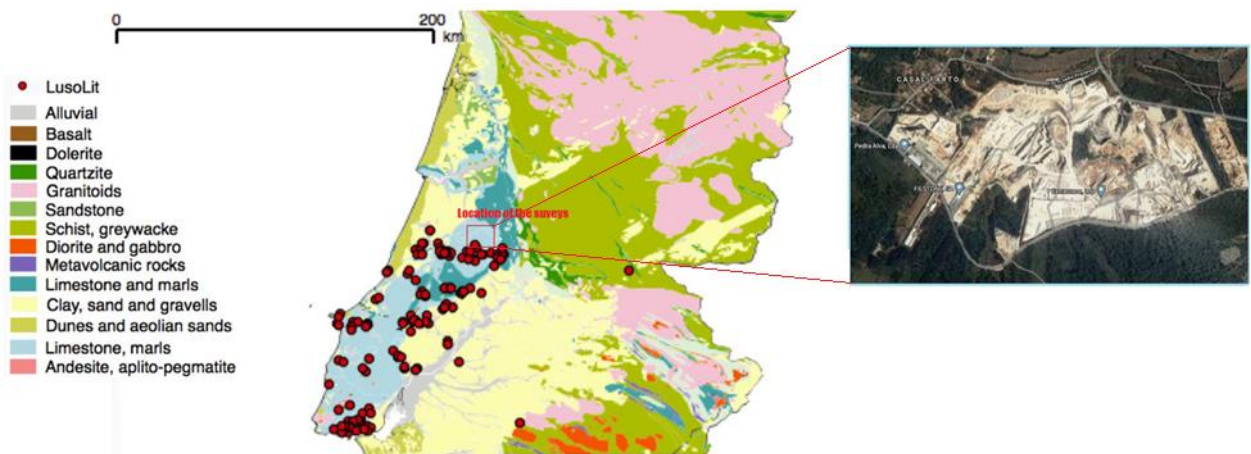


Figure 3.1 Includes a zoom to the location of the quarry, source – Researchgate.com and Googlemaps.com

The Figure 3.1 above shows the location of the quarry. Also there are two more companies that have a concession to operate in this terrain and they are cooperating with each other which provide to increase the profit and improve the work.

3.2 Positioning

Before start working a visit to whole quarry took place in order to identify the best place to do the work. It was chosen the left wing of the open pit mine at the second level of excavation and two positions for the laser scanner were identified. Figure 3.2 presents the coordinates and a map which shows exactly the location of the laser scanner.



Figure 3.2 Map of the exact position of the surveys, source – Googlemaps.com

First position of the scan:	Latitude: 39.5735217° N
	Longitude: -8.6196688° W
	Altitude: 207.30 m
Second position of the scan:	Latitude: 39.5738442° N
	Longitude: -8.6198827° W
	Altitude: 206.80 m

The First step in an accurate positioning is to find horizontally plane. In the field work a tripod on which was mounted on the ground and optically levelled was used. After, when the device was stabilized, it was ready start. Next step was to turn on the tool to check if it is straight in horizontally level. When the main screen appear it was chosen the icon with the name “parameters”, which implemented new screen with several different possibilities of the tool. To check the tilt degree of the scanner it was clicked on the inclinometer which shows spirit level in electronic mode. There are several colours which represents different variation from the horizontal level. On the screen was yellow colour which inform that the scanner is not in the right position and to change the tilt of the level it was necessary to cooperate between the legs of the tripod and dot on the inclinometer. When the point was straight in the middle and the colour changed into the grey, the instrument informed that now it was in the 0° horizontal level. After these changes the next phase of the field work were to scan the benches of the quarry.

3.3 Scans settings

To be able to start scanning, a number of configurations had to be made, since they impact on the quality and time of measurements. The main panel is shown in the illustration on Figure 3.3.



Figure 3.3 Main screen - the LS software, source - Faro Focus Laser Scanner User Manual

The first variable feature that had to be settled was to create and select space on the SD card using the icon called "create folder". In the photo above it is visible at number 1. Thanks to this, it was possible to freely save point clouds whenever the location or scan quality had changed. As the scanner is in constant use, there was no need to change the language, date, time as well as the units of measurement and device name, which is necessary when the scanner would be started first time.

The next step, to start the scan, was pressing the icon marked in the previous figure the 2nd number, which was associated with opening the following screen (Figure 3.4). It contained individual parameters that are responsible for variables closely related to the final result of individual scans. [2]

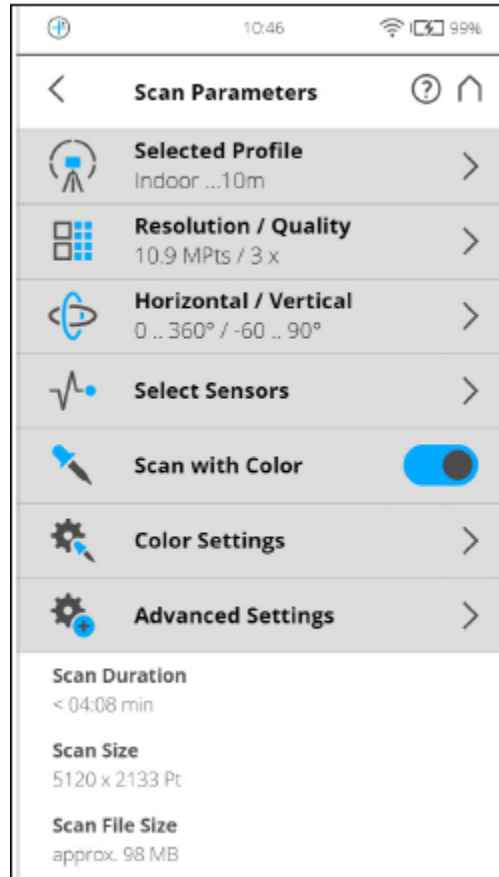


Figure 3.4 Screen with parameters, source - Faro Focus Laser Scanner User Manual

The first icon called "Selected Profile" is responsible for choosing two variables. The first is whether the scan will be carried inside the building or the measurements will be conducted outside. The second one is choosing the length of the area in which the scanner will work.

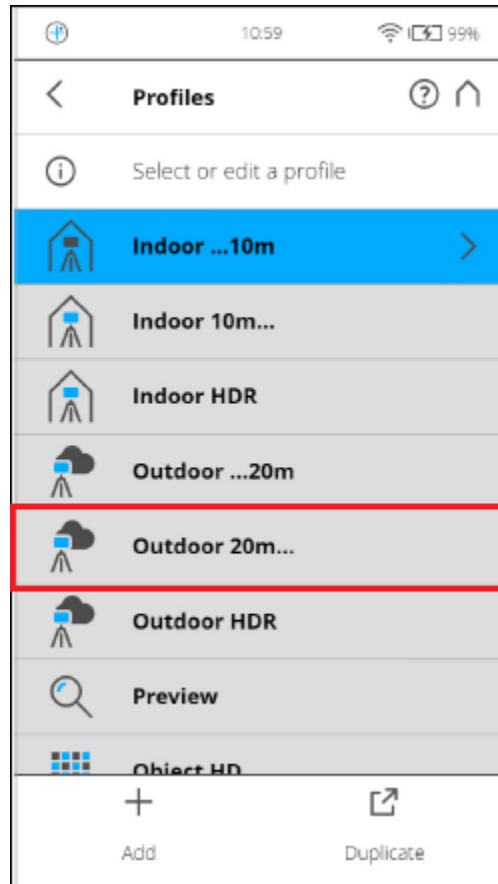


Figure 3.5 Screen with profiles, source - Faro Focus Laser Scanner User Manual

This is related to how far the surface of the scanned area is from the instrument. It is possible to choose a short range up to 20 m and a long range, whether above the indicated value. However, it should be remembered that the scanner class imposes the maximum value to which the laser beam has a chance to reach. In the case of this model it is 70 m. The tests were carried out in the field which was bigger than 20 m, so based on these values, the “Outdoor 20m ...” option was chosen (Figure 3.5). [13]

The next parameter, which is available in the laser scanner software is "Resolution / Quality". It affects several aspects. The first is the length which the instrument will collect data of objects prepared to scan. The higher the resolution and quality, the more time will have place the measurements. Another variable is the number of points collected, which can be translates into the final size of the data and theirs quality. This indicator has two variables. One of them is the resolution that has been classified mathematically, which is in the name of the icon.

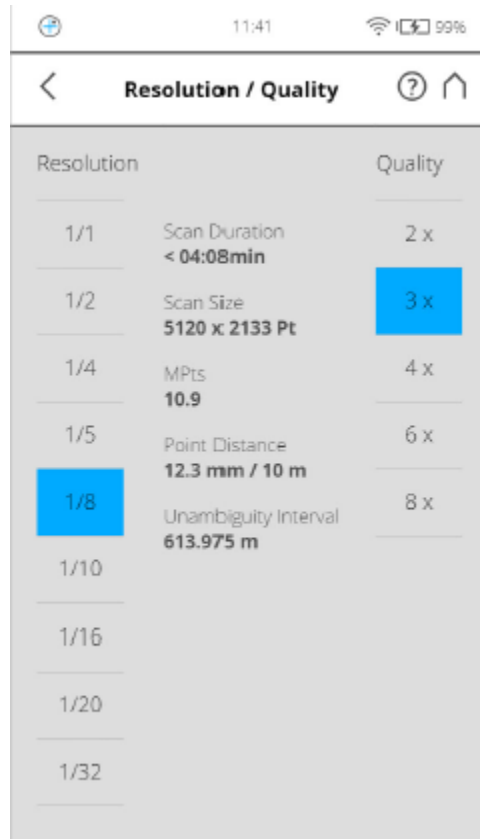


Figure 3.6 Screen with resolution & quality, source - Faro Focus Laser Scanner User Manual

The panel is located on the left side of the Figure 3.6. The identifiers are classified in such a way, that the user can choose from mapping the terrain in the scale of 1 to 1 or less. The lowest possible value is 1 to 32, which results in a smaller point cloud and faster measurement. On the right side there is a parameter describing how much the laser beam will be send to the same place to minimize the risk of errors and improve image quality. For various purposes of using scans, any of these variables can be used, however, with geodetic assumptions, the right description of the panel can't be lower than 3x. The middle column describes five values that respond to the variables applied in these parameters. The first is the time given in minutes, then the size that the collected data will have, the next value is the number of points in the generated cloud. The penultimate variable is the distance between the nearest points. At the end it can be observed a circle of measured length with intervals. Due to the fact that the work involves measurements by entering different configurations, two have been selected and they are described in the named chapter. [25]

Another icon visible on the screen is "Horizontal / Vertical", which allows cutting the rotation angle of the laser scanner in two planes. After selecting this parameter, the window below will be displayed on the screen (Figure 3.7).

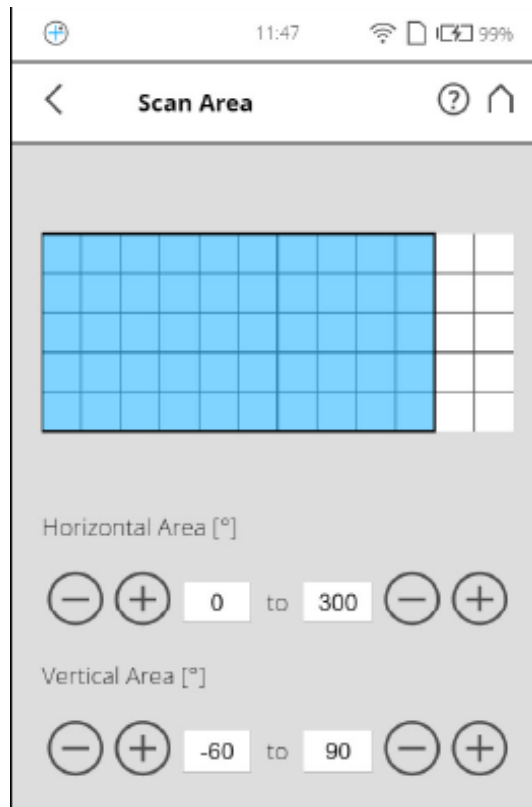


Figure 3.7 Screen with area scan, source - Faro Focus Laser Scanner User Manual

It is responsible for reducing the measurement range of points so as to reduce the time of one scan. To do this, it is necessary to enter the values expressed in degrees into the visible gaps. This will narrow down the scanner and focus on the selected surface. In the illustration, instead of squares, a thumbnail will appear. This helps the user to trim the tested area. The first two windows allows to select a value from 0° to 360° which represents the horizontal value of instrument rotation. Further gaps lets to change the angle of the laser beam in the range of 305° . At the beginning of the tests, a test scan was made, thanks to which, it was determined, from what plane the scanner will start to rotate. Also because of this the full-size photo of the examined surface appears in place of the squares mentioned. Thanks to this it was possible to move the scanner to the right place and to apply variables in the gaps visible in the picture. The vertical angle remains unchanged to capture all visible discontinuities. In turn, the horizontal angle was renamed so the range didn't exceed 270° , which resulted in faster scanning and limitation of the tested planes to three visible walls.

The next parameter has no effect on the scan itself, but has useful and additional options that can be used to overwrite the data obtained during measurements. After selecting the "Select Sensors" icon, the panel shown below appears (Figure 3.8).

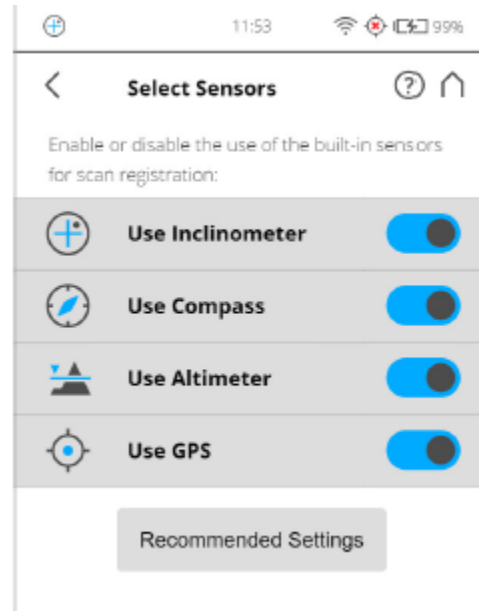


Figure 3.8 Screen with sensors, source - Faro Focus Laser Scanner User Manual

The first of the visible additions is the inclinometer, which was described in the previous chapter when positioning the laser scanner. Another icon shows a compass. The next switch is the altimeter, which when turned on automatically adds altitude to each scan. [19]

The last switch located in the "Select Sensors" folder is GPS. Due to the fact that the receiver was installed by the manufacturer inside the laser scanner, there was no need to use other tools to determine the exact location. When scanning takes place in a clearly visible place, outside it is recommended to enable this option because of the later possibility of entering the examined area on the map. To collect the exact location it is necessary to wait several minutes and the small icon of GPS will appear on the top of main screen. It means that the collecting data is ready. The final coordinates of the point where the instrument was located are visible in latitude and longitude coordinates. Also then information about the number of visible satellites is saved. During the tests, two scanning places were registered, which were presented in the chapter about location.

All switches, during scanning remained in the turn on position, which initiated an increased amount of data received. Each of them was useful in all phases of research. Starting from positioning, through measurements and ending with the data received and post-processing. In the following picture (Figure 3.9) it can be seen the settings and data input. [15]



Figure 3.9 Researches in progress at quarry, own source

The following icon called "scan with colour" is a switch that allows the source codes, responsible for the colours, to be added in the points received on cloud. This process is also supported by photos that the laser scanner takes as the last stage of measurements. During the tests, this function remained active all the time, making all scans performed in colour.

The second to last parameter in the aforementioned tab is "Color Settings". This icon is responsible for a several of functions. The following illustration (Figure 3.10) shows a number of variables that effect on the final view of the point cloud. The first three images representing the laser scanner are designed to improve the quality of the scan by capturing the incident light. [20]

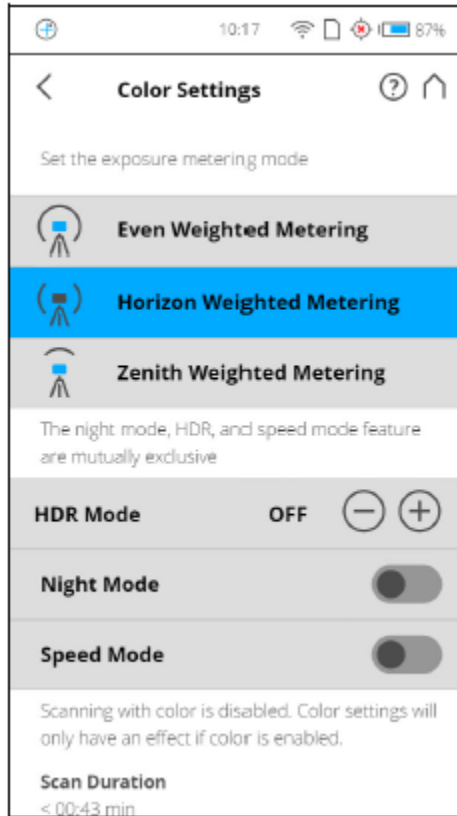


Figure 3.10 Screen with color settings, source - Faro Focus Laser Scanner User Manual

During the researches, the sun in zenith, option was selected. Underneath is a switch to activate or deactivate photos in the HDR system. This increase the time of measurements by twice. For the highest degree of accuracy, this feature has been enabled. The last two parameters are designed to help with facilitate work in heavy and adverse conditions, such as night, low battery or lack of time. In the case of this scans, they remained in the "off" mode.

After completely applying all the necessary functions, the next step was to go to the panel called "Manage". To reach the window, it is required to go to the start screen and press the management button. This helped with check all done variations. When everything was in the position, the next phase of the work could start. [8]

3.4 Scanning

Once all the needed settings were verified and implemented, it was possible to perform scans. To do this, it was necessary to return to the main screen of the device and press the icon with a visible black triangle on a blue background. The scanner started its work and finally, after returning to the starting position, also began to collect photos so as to apply colours to the collected points and create a spherical image. In the Figure 3.11 it can be seen how the scanner worked.



Figure 3.11 Scanning in progress, own source

After scanning in one place, the device was moved to another location and the surveys were repeated. More scans were planned to increase the quality of point clouds, however, rainy weather on that day prevented further measurements. After the work was completed, all the components which have been used were collected and coffer them for safe transportation.

4. Data processing

The following chapter describes all the work that was done concerning the discontinuities identification and characterization. The software used to transfer data from LS equipment was ReCap PRO, from Autodesk. Thanks to this software all the scans were merged. There are include all steps and information how the whole process looks like. [3]

4.1 Used program – ReCap

This is software is provided by Autodesk. The tool has been made available for students in uncharged form in the specified duration in time. Thanks to the free subscription, this program was used during research. In the provided researches ReCap PRO version was used. By this upgraded software it was possible to use a wider range of functions. The main assumption of the program is processing point clouds and connecting them together.

4.2 Scan processing

To start processing the available point clouds the ReCap was turned on. When the main screen appear the first step was to provide the first scan into the program. To do that it was necessary to push the button on the top left corner with the name “New Project”. The panel that was turned on is visible in the attached Figure 4.1.

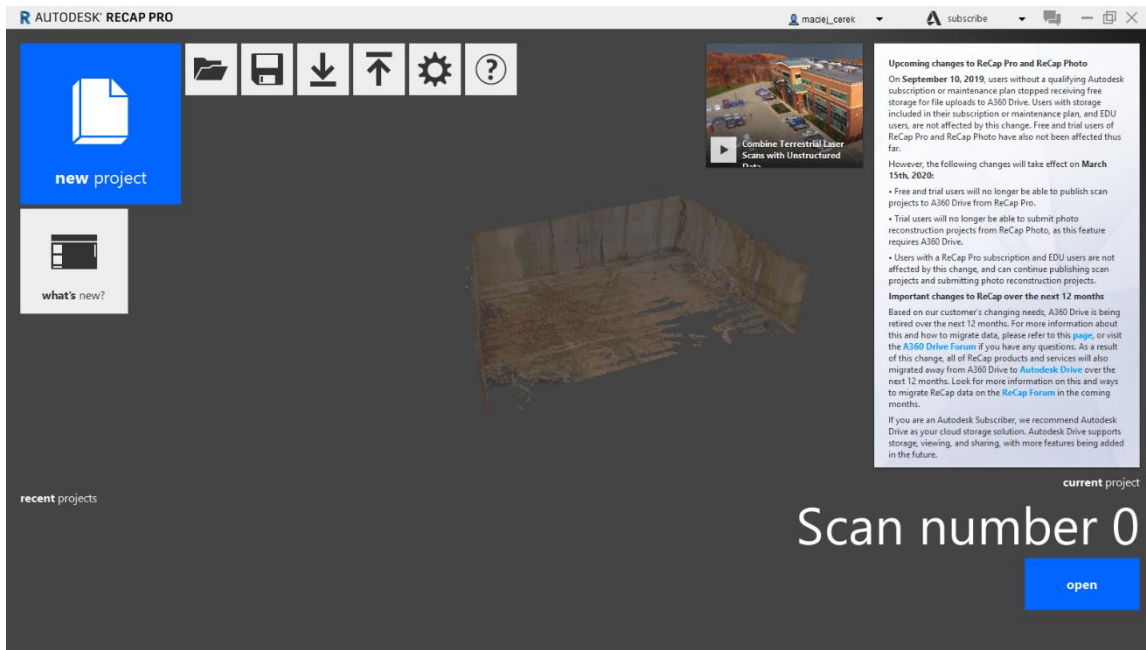


Figure 4.1 Starting new project in ReCap program, own source

From many available options it was necessary to choose settings button (Figure 4.2). The next window displayed. The variables that are in the options are divided into three sections: general, files and advanced.

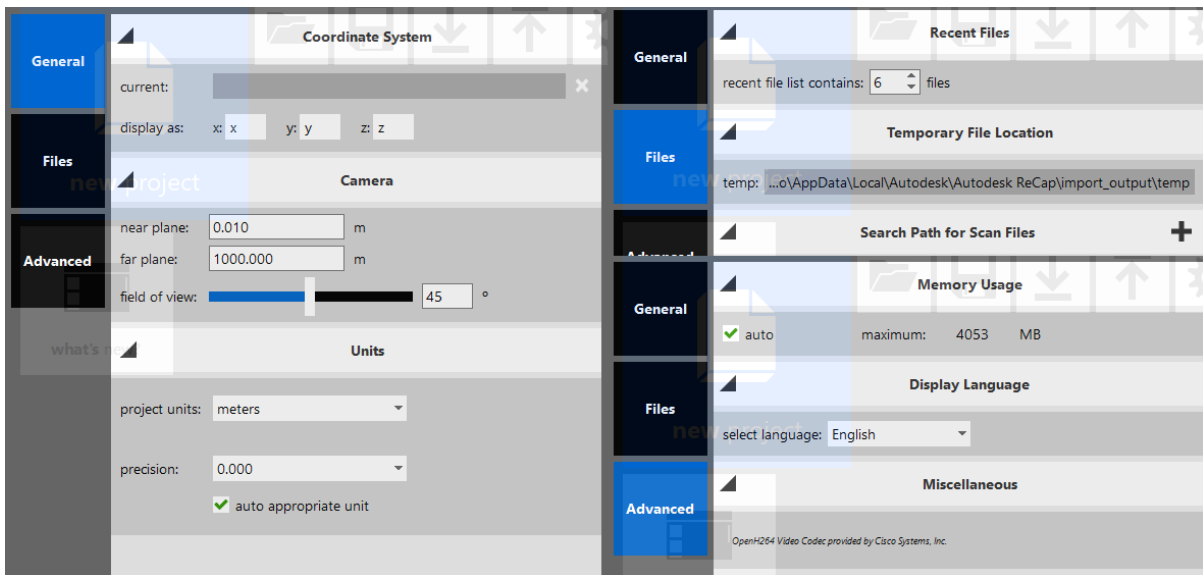


Figure 4.2 Screen with the settings in ReCap, own source

The first of these is responsible for coordinates, camera settings, precision and the measurement system. The next ones allow to change the save path of completed projects, select the language and amount of maximum RAM that program can handle, while making the point cloud. After acquaint with all these settings, they were left in the default way. When the button responsible for creating a new model was pressed, the window with data collection appear. Then it was chosen an option “Import Point Cloud”.

After following the software guidelines and confirming all materials, the next screen was appeared and is documented by the Figure 4.3.

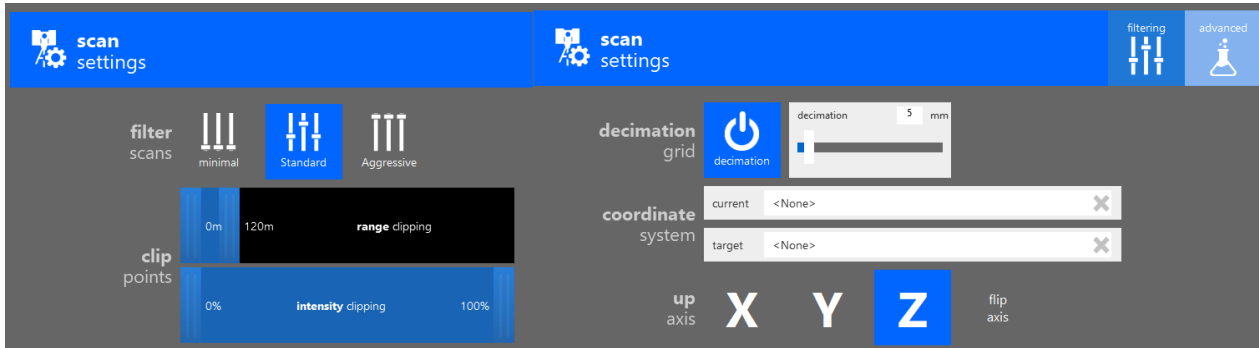


Figure 4.3 Screen with the advanced settings in ReCap, own source

In the options presented, the maximum range to which the program loads the model can be changed. Then it was selected the number of points to be uploaded, expressed as a percentage. When the slider is moved, the areas will be automatically deleted. This option is to ensure greater transparency and shorter processing time of scans, and because of this easier maneuvering. Advanced settings are also available and allows to manually enter values and add coordinates for the scan location and for targets with black and white triangle grids. During the measurements, the GPS receiver automatically collected the coordinate so there were no need to past them into the windows. After analyzing all available information, the initial options are left. After pressing the "Index Scan" button, the uploaded models were implemented and a new screen appeared. This is a window in which are an additional option of uploading scans. As the assumptions of the work, for the first two projects, were to use only one model in each location. There was no need to add and connect point clouds. Then the program created a scan. After generating it, the "Launch project" icon was clicked. The effect of this action can be seen in the window below (Figure 4.4).

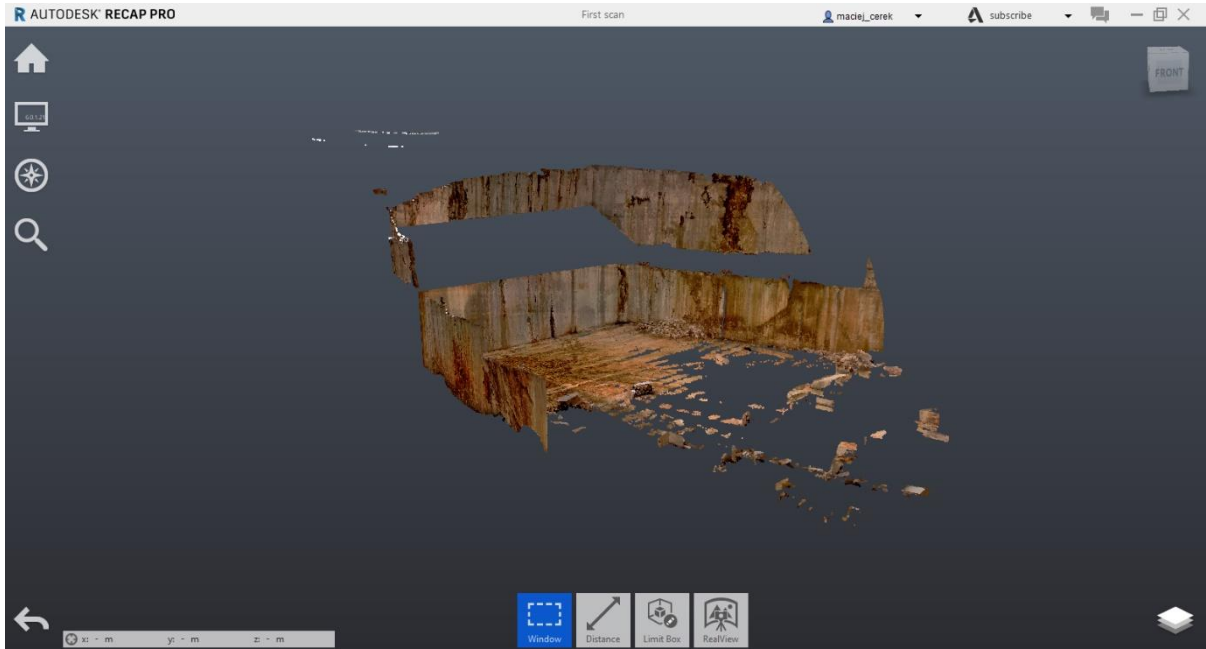


Figure 4.4 First view of the scan, own source

In the foreground a point cloud is visible. The scanner, thanks to the fact that it is able to track points vertically up to 305°, also measured points on the upper wall. The same situation occurs at the back of the excavation, where blocks and rock waste are stored. To ensure greater transparency, the excess of unnecessary points had to be removed. To do this, in the first step, the view of unwanted surfaces is approximated. Then they were selected, which initiated the appearance of an additional window. Everything is documented in the Figure 4.5. [16]

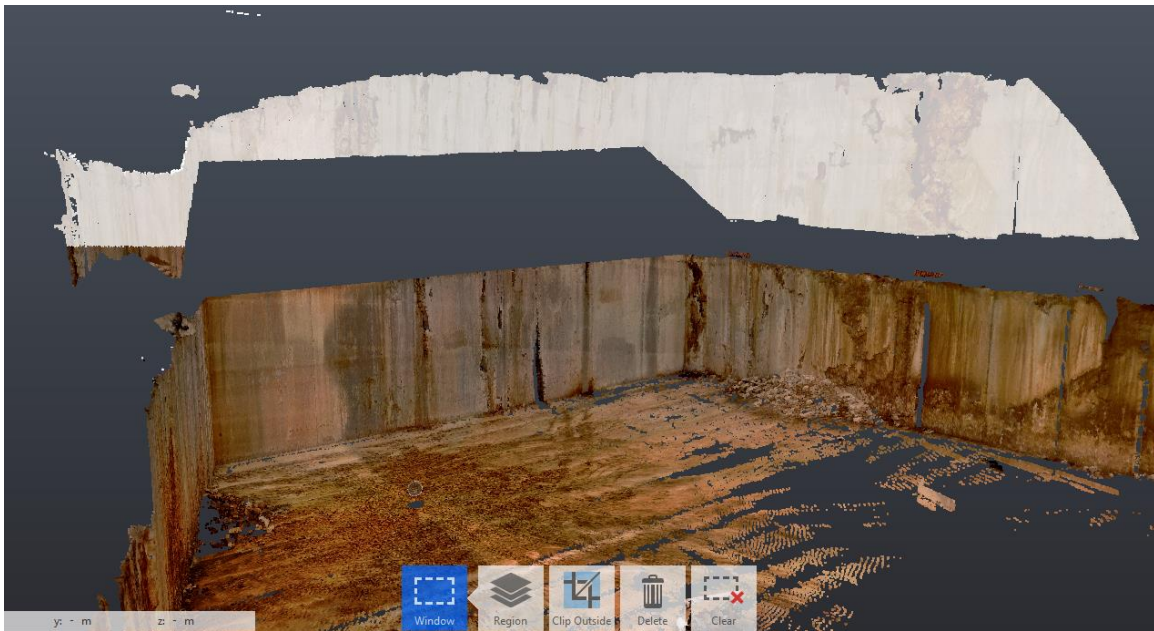


Figure 4.5 Deleting unnecessary points, own source

After deleting needles point there were necessary to check how the projection looks like in different variations. Thanks to the tool offered by ReCap which is able to observe the model in terms of: height, intensity of collected points, differentiation of planes, location of the laser scanner and default view. Below (Figure 4.6) is an image showing all available configurations. They are numbered in the listed order.

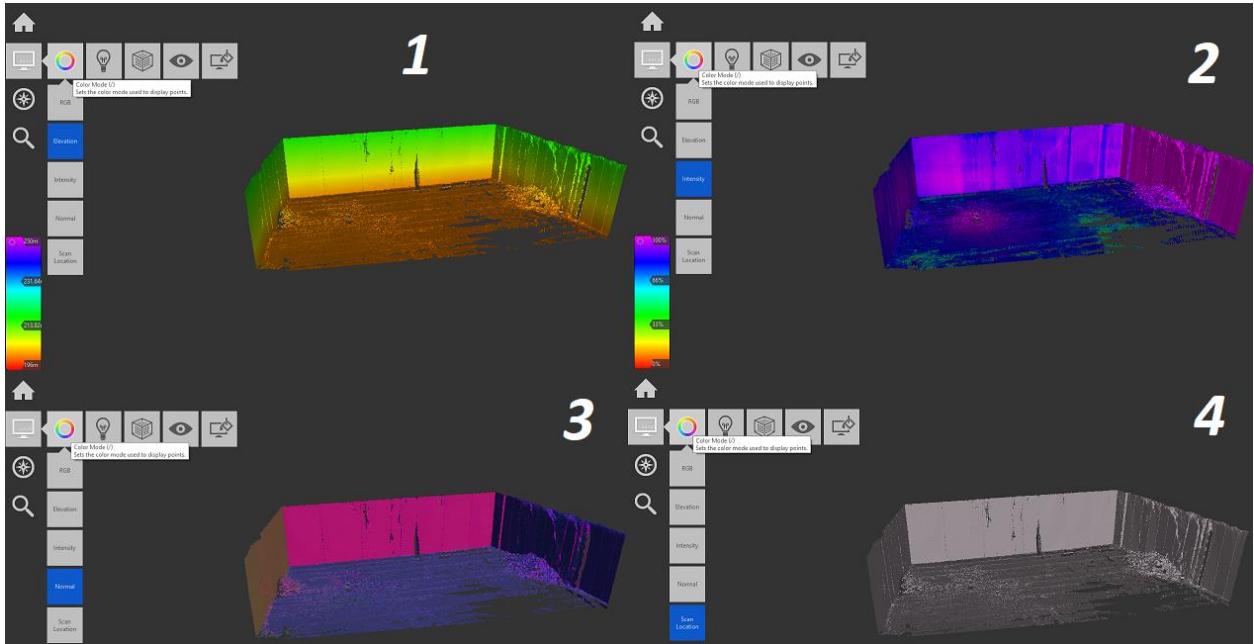


Figure 4.6 Different views of the point clouds, own source

The illustration doesn't include a basic view because it is visible in previous attachments. The first number is intended to show the height of the terrain model. In the lower-left corner there is a map key describing the location of points through colours. A function has been introduced under the second number to check the repeatability of the tested planes. In the settings, the quality was a fourfold measurement of the same value as in the legend means 100%. The lower value is proportional to the quality. The next switch is only used to distinguish all surfaces from each other, which is useful for larger models with different areas. The last function is to help user to find the place where the laser scanner was set.

The quick access bar visible on the left provide several functions that allows to move freely around the model and the ability to search and check the phrase. At the bottom of the screen, supportive measures were used. Thanks to them, it was easier to calculate the distance between selected points, angles among surfaces, write annotations, control the seen area and enter the function of a spherical image.



Figure 4.7 Spherical photo from the LS, own source

The above photo (Figure 4.7) shows a rotating view from the scanned location. These are high-resolution photos which when combined forming a spherical ball. Thanks to this technology, it can be observed the actual measured area and the map of the area, which is located in the upper right corner.

All described functions have been checked for reliability with previously saved values. The obtained results underwent the inspection process, which allowed to generate a scan for further processing. The model process described above focused on the first model. The second point cloud was transformed in the same way. After receiving these two projections, the combination of them create new model and the course is described below.

To start joining two scans into one, again it was necessary to start a new project. All individual options were selected in the same way as described above, except, for uploading two projections instead of one. Changes began to appear when the window with the "Index scans" button appeared. In the form of connecting models rather than the mentioned icon, a new one has come up with the possibility of automatic and manual connection of point clouds. Both options were tested in the researches. The purpose of this, was to analyze the differences between them and choose a scan with a higher percentage of connected points. The first merge was carried out handheld, which is shown in the Figure 4.8.

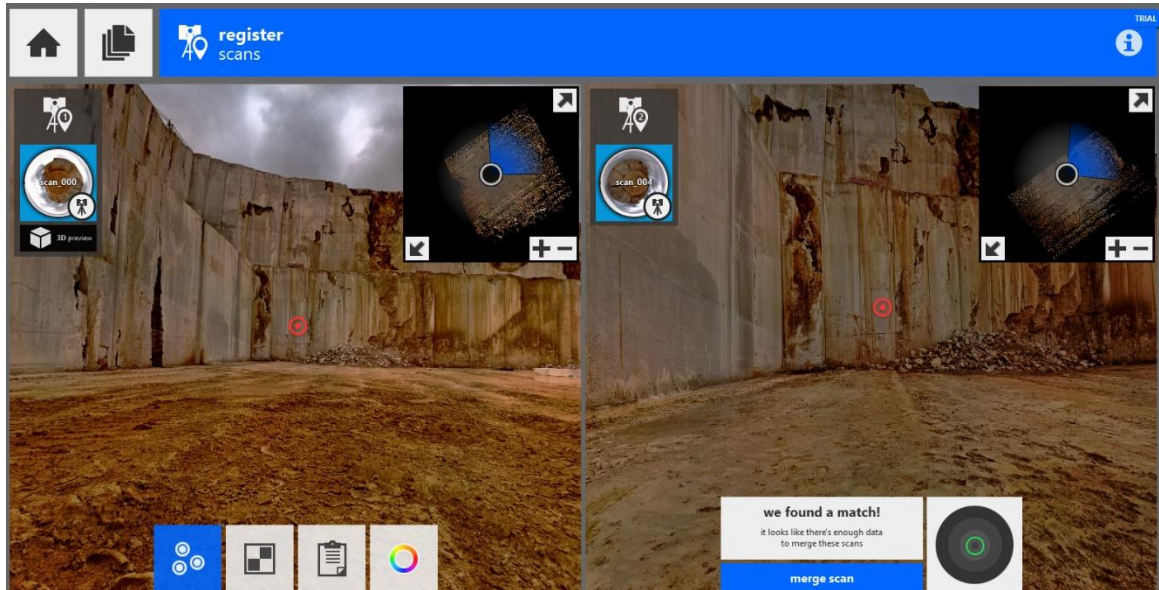


Figure 4.8 The scans linked by manually method, own source

To link models the software has a function that involves finding at least three common areas between point clouds. With the objection, that they must be flat and undeformed. During the research, all three walls were designated and connected. Then the program automatically combined both scans. Finally, a report appeared and it is attached below (Figure 4.9).

scan name	overlap	balance	points < 6mm
scan_004	39.0%	51.3%	94.1%
scan_000	40.2%	51.3%	96.0%

Figure 4.9 Report from manual connecting the scans, own source

Thanks to this information, it can be seen that the number of overlapping points is on average 39.6%. Then the balance between them is exactly 51.3% in both cases. The last data obtained from the report is the percentage of points that were measured with an accuracy of less than 6 mm. Both results are in green colour, which means a high pickets accumulation.

After joining the scans manually and getting the results, the work started with the same projections, but merged using the automatic option. Also in this case it was necessary to start a new project and upload point clouds. The change appeared when the selection of automatic model showed up. Then a new window come up, announcing about the successful completion of the work. Also there was a view of the mine area. The Figure 4.10 has been added below.

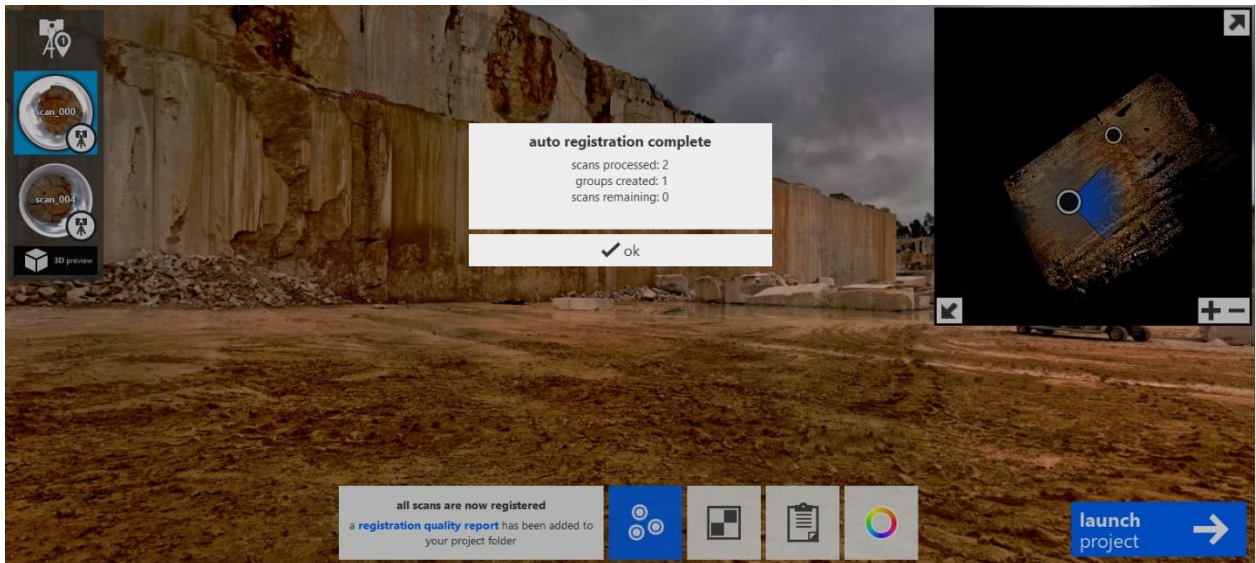


Figure 4.10 The scans linked by automatic method, own source

The next step was to initiate the final merge by pressing the "Launch Project" button. After loading the full projection it was possible to check the report which was in the upper quick access window. The results are shown in the following Figure 4.11.

scan name	overlap	balance	points < 6mm	
scan_004	45.0%	34.9%	97.0%	📄
scan_000	47.7%	34.9%	97.9%	

Figure 4.11 Report from automatic connecting, own source

The information generated in the report after merging have following state: overlapping points are 46.8%, the balance in two scans is similar and theirs amount is 34.9%, in this case the percentage of points distribution below 6 mm is on average 97.4 %.

After analyzing the data provided by the program, it can be seen that higher accuracy occurs after automatic merging. Thanks to this comparison, a self-made scan was selected for the next phase of the project. [22]

4.3 Final view of the scans

After processing in ReCap, three projections were completed. The first scan is marked in the attachment below with the number 1. It is a model made with lower accuracy compared to the second. The next scan was marked with number 2. It was taken from a different place and in higher quality. The last visible point cloud is the combination of these two scans, which automatically puts it in higher classification than the other two in number of points, resolution and level of detail.

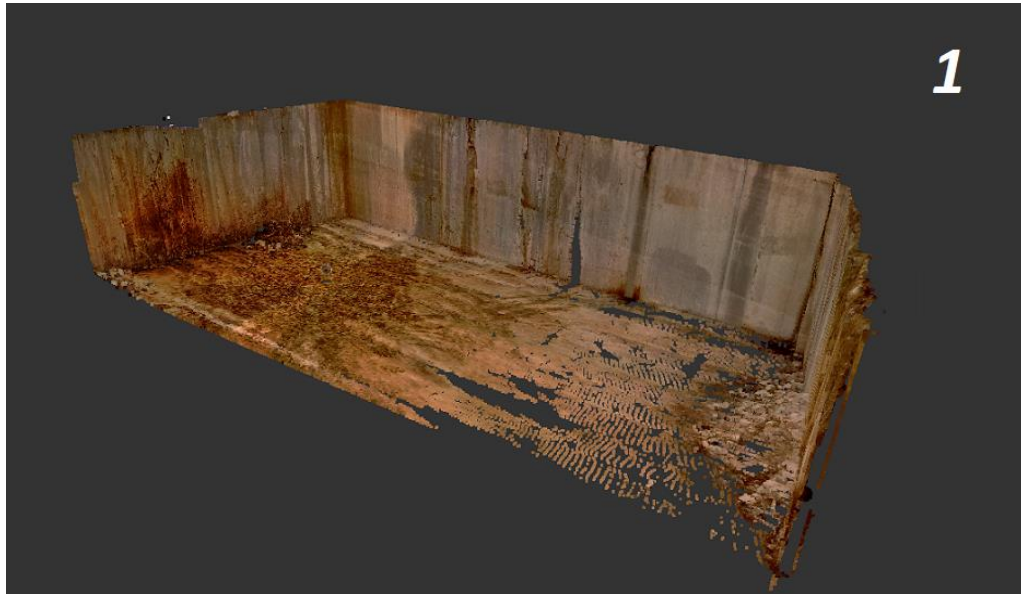


Figure 4.12 First scan, own source

The appearance of the first scan was presented in Figure 4.12. Data about its location is presented at the topic describing the equipment positioning. Below (Table 1) is the configuration selected for the scans.

Table no 1 The first configuration of the scans

Name	Value
Resolution	$\frac{1}{4}$
Quality	4x
Duration of scan	12 ⁵⁹ [min]
Distance between points	$\frac{6,1 [mm]}{10 [m]}$
HDR	2x
Rotation angle	360°

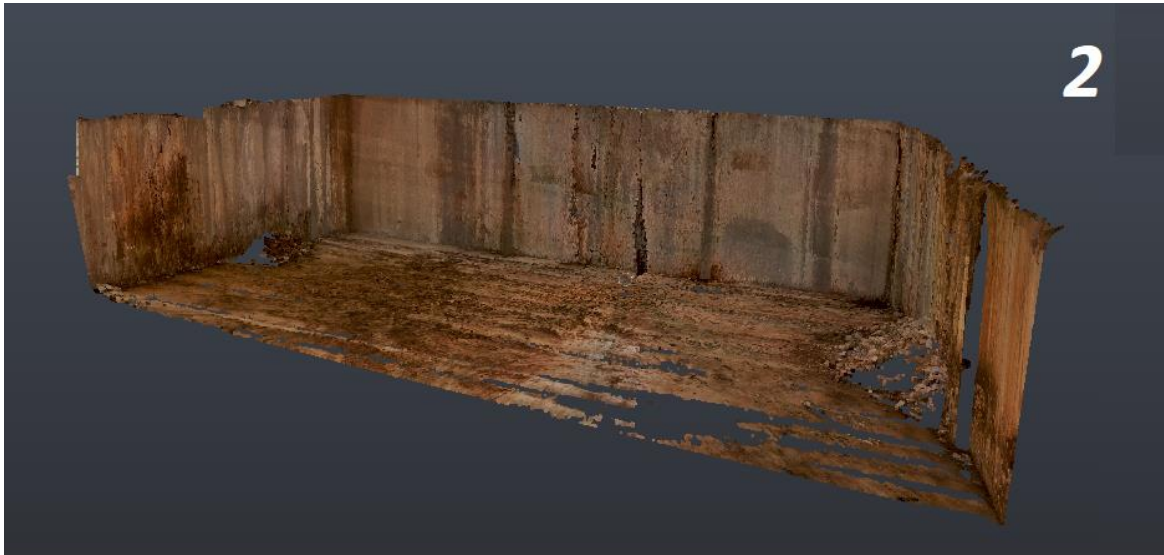


Figure 4.13 Second scan, own source

The Figure 4.13 shows the generated second scan model. As described above, the location of the laser scanner has been documented in the chapter entitled "Positioning". The data describes the settings made before scanning from location number 2nd and they are past below (Table 2).

Table no 2 The second configuration of the scans

Name	Value
Resolution	$\frac{1}{2}$
Quality	4x
Duration of scan	33 ³³ [min]
Distance between points	$\frac{3,1 [mm]}{10 [m]}$
HDR	2x
Rotation angle	270°

The Figure 4.14 in this chapter shows the combined model from two previous scans. It can be seen on each of the final scans that there are no measured points in the lower-right part of the point cloud. This is not a scanning device error, because these deficiencies are repeated in every projection. It is caused by several days of rainfall and leaving large tracts of water in places where machines have previously passed. When the device was sending the laser beam towards the puddle, it was reflected by the water surface and did not return to the scanner. This confused the surface with the sky. However, this doesn't effect on surfaces measured at the later stage.

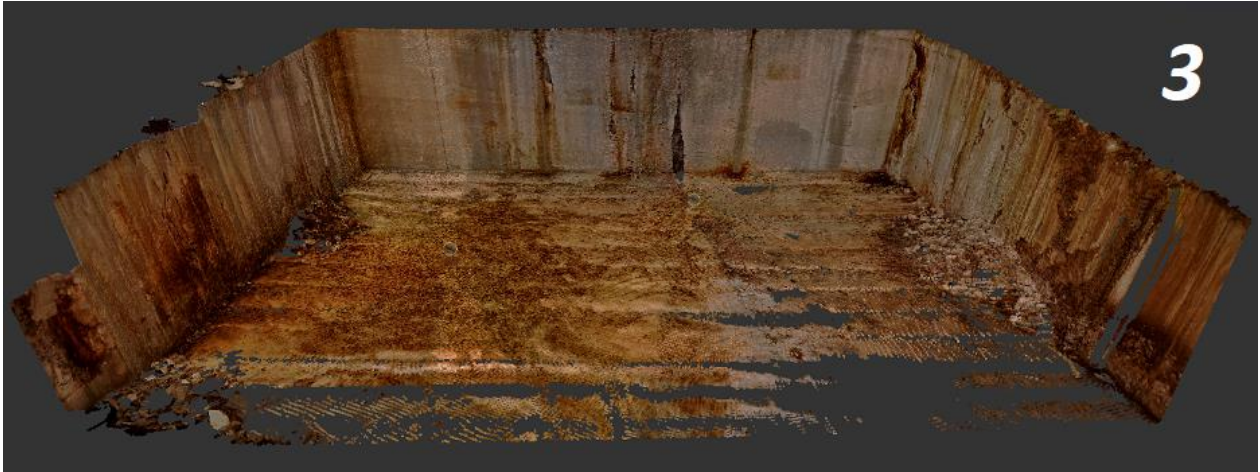


Figure 4.14 Connected scans, own source

The dimensions of an examined area are: South-west wall had a 27.1 m length, North-west wall had a 52.3 m length and the North-east wall had a 25.9 m length. The height each of them is a variable from 14.5 m to 14.8 m which was bring by irregularity of the rock masses.

5. Discontinuities identification and characterization

Thanks to the use of the ReCap program and the associated processing of point clouds presented in the previous chapter, it was possible to study the data in terms of occurring discontinuities in the studied area. The following segment has outlined several tasks, such as: finding joints in the mining walls, then imaging them by adding planes to the generated models, measuring their dimensions and angles, and then entering data into the program that allows their accurate location in space. The individual stages have their place in the following chapter.

5.1 Location and discontinuity display

The first stage in preparing the discontinuities, to obtain the necessary data, such as dimensions, directions and angles, was to locate them. The CloudCompare program, whose specification takes place in the section below, was used for this task. Then, with the help of this tool, figures corresponding to the discontinuities were drawn.

5.1.1 Specification of the program used

The tool that was used during this stage is an open project co-financed by voluntary investors. It is a free program called CloudCompare, which just like the previously used software is apply to change point clouds. It has a number of functions and is compatible with many extensions.



Figure 5.1 Logo of the CloudCompare program, source - Danielgm.net

The Figure 5.1 shows the logo of the mentioned tool. There are the main sponsors and manufacturers. Work on the program began while writing the doctor thesis of Daniel Girardeau-Montaut, who in later cooperation with large companies and financial assistance from the volunteers and firms, was able to create a fully functional tool. Thanks to CloudCompare, the next stage of work was possible, which is illustrated in the next section.

5.1.2 Discontinuities identification in the model with lower accuracy

When all the options described in the previous section were defined, the discontinuity locations were mapped. The first object examined was the SW wall, which is shown in figure 5.2. Two slots marked by symbols D1 and D2 were placed on their surface. The illustration is divided into two views, which results in not only visible of the discontinuities dimensions, but also their angles relative to the horizontal plane.

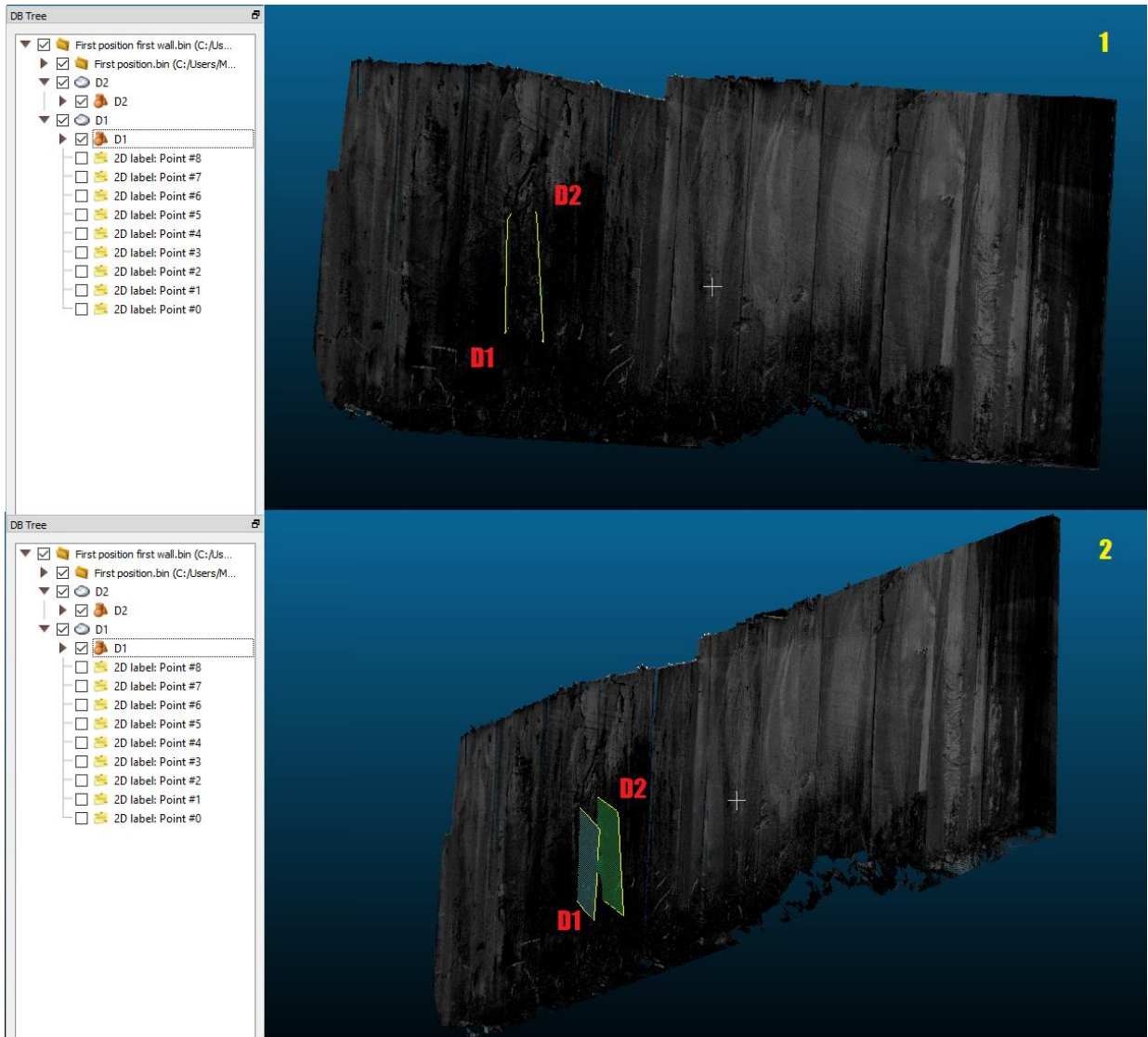


Figure 5.2 Wall SW in the lower resolution of scan, own source

The NW wall, located towards the north-west, was the next object of research in terms of discontinuities occurring in its area. The illustration below (Figure 5.3) shows another nine slots that occur on the selected surface. The slots in the selected shear are represented by symbols from D3 to D11.

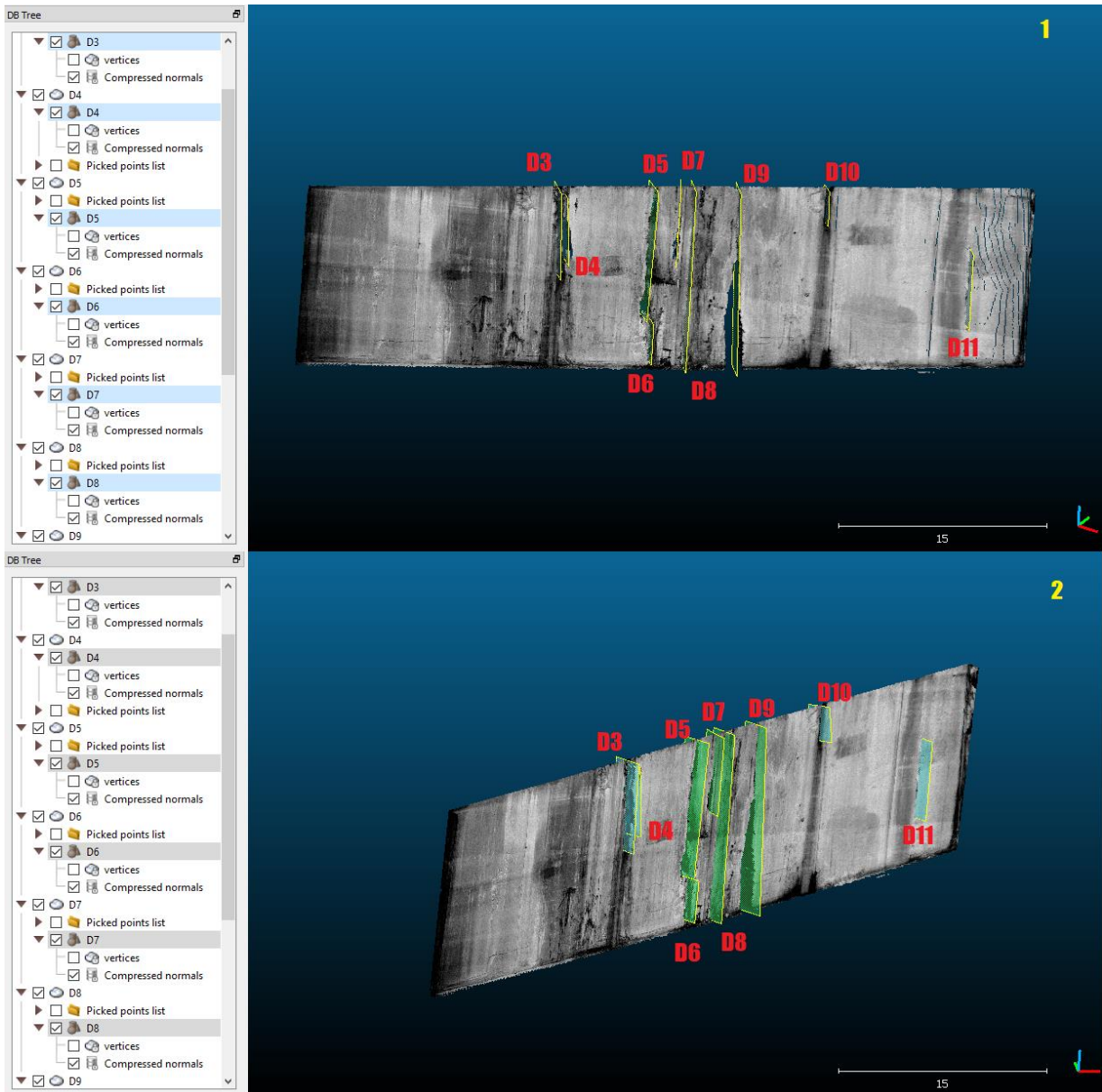


Figure 5.3 Wall NW in the lower resolution of scan, own source

The last plane, with the lower resolution scan examined, was the wall marked with the symbol NE (North-East). Five slots marked with symbols from D12 to D16 were located and research in its area. Figure 5.4 shows the north-eastern wall in two shots, ensuring increased perception of the scanning area.

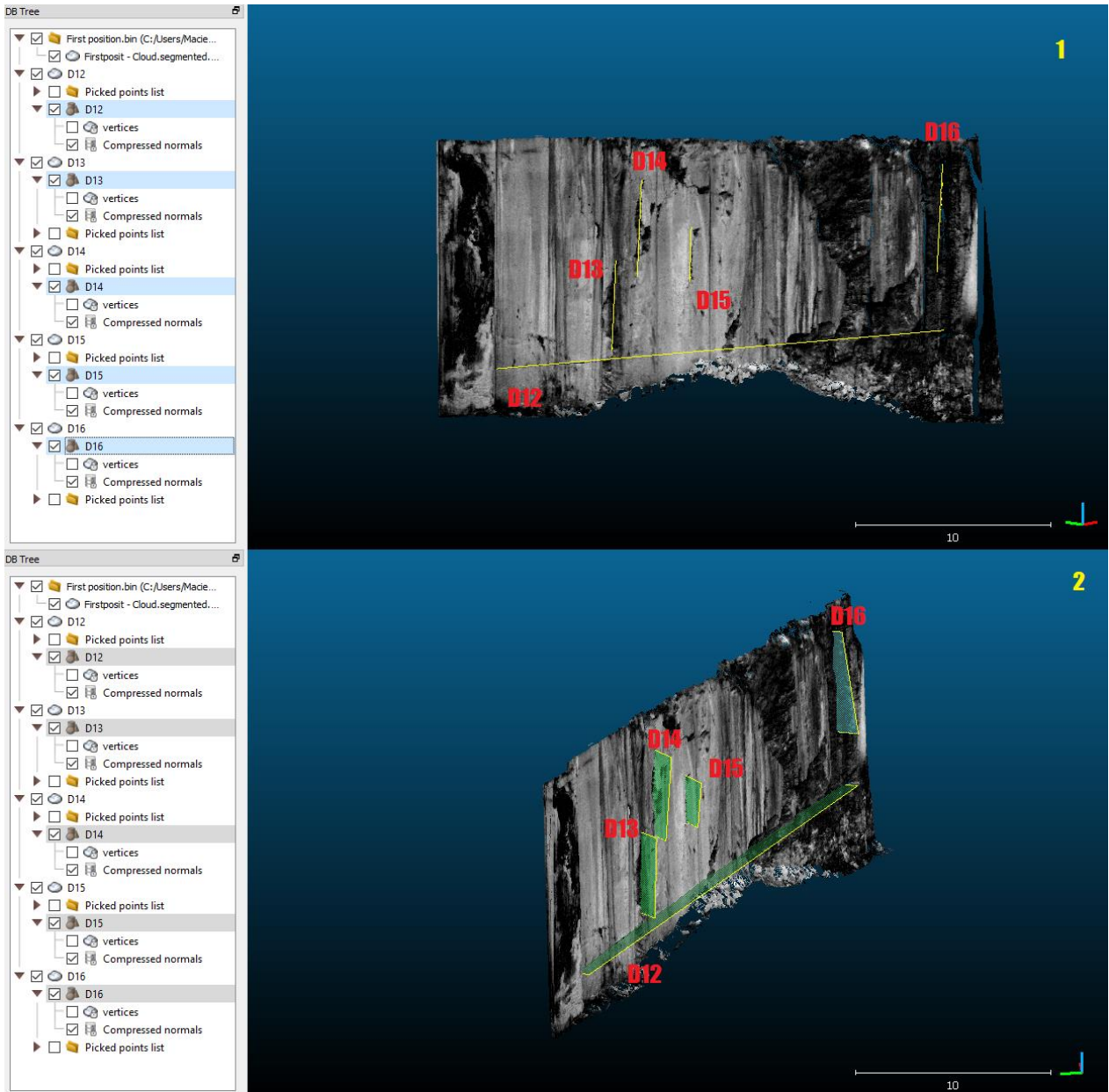


Figure 5.4 Wall NE in the lower resolution of scan, own source

5.1.3 Discontinuities in the model with higher accuracy

The principle of operation for the next model remained the same as for the scan showing the tested surfaces with lower accuracy and different location. Also here, the symbols of all the walls have remained unchanged. The only change visible in the record are discontinuities, observed and plotted on point clouds. This is, because in this situation a ending was added informing about the second stage of the research marked with a number 2. The SW wall was the first to be analyzed. Below is a drawing (Figure 5.5) showing the location of the gaps on the surface being tested.

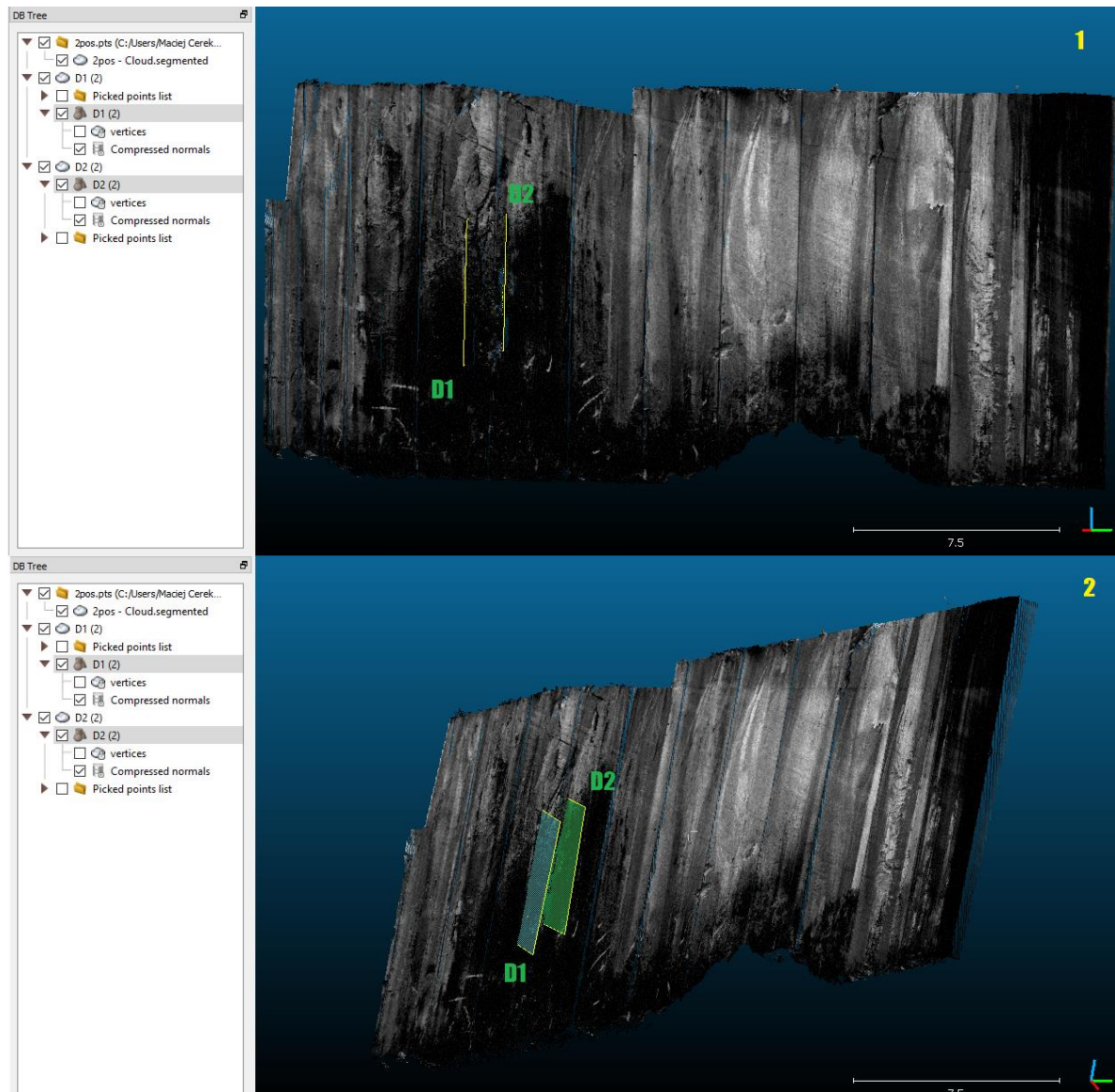


Figure 5.5 Wall SW in the higher resolution of scan, own source

The next surface, examined by searching for discontinuities and determining their dimensions and angles, was the NW wall. Scanning with a higher accuracy did not show a change in the number of observed gaps relative to the model in the first scanner configuration. Figure 5.6 shows the final result of this methodology.

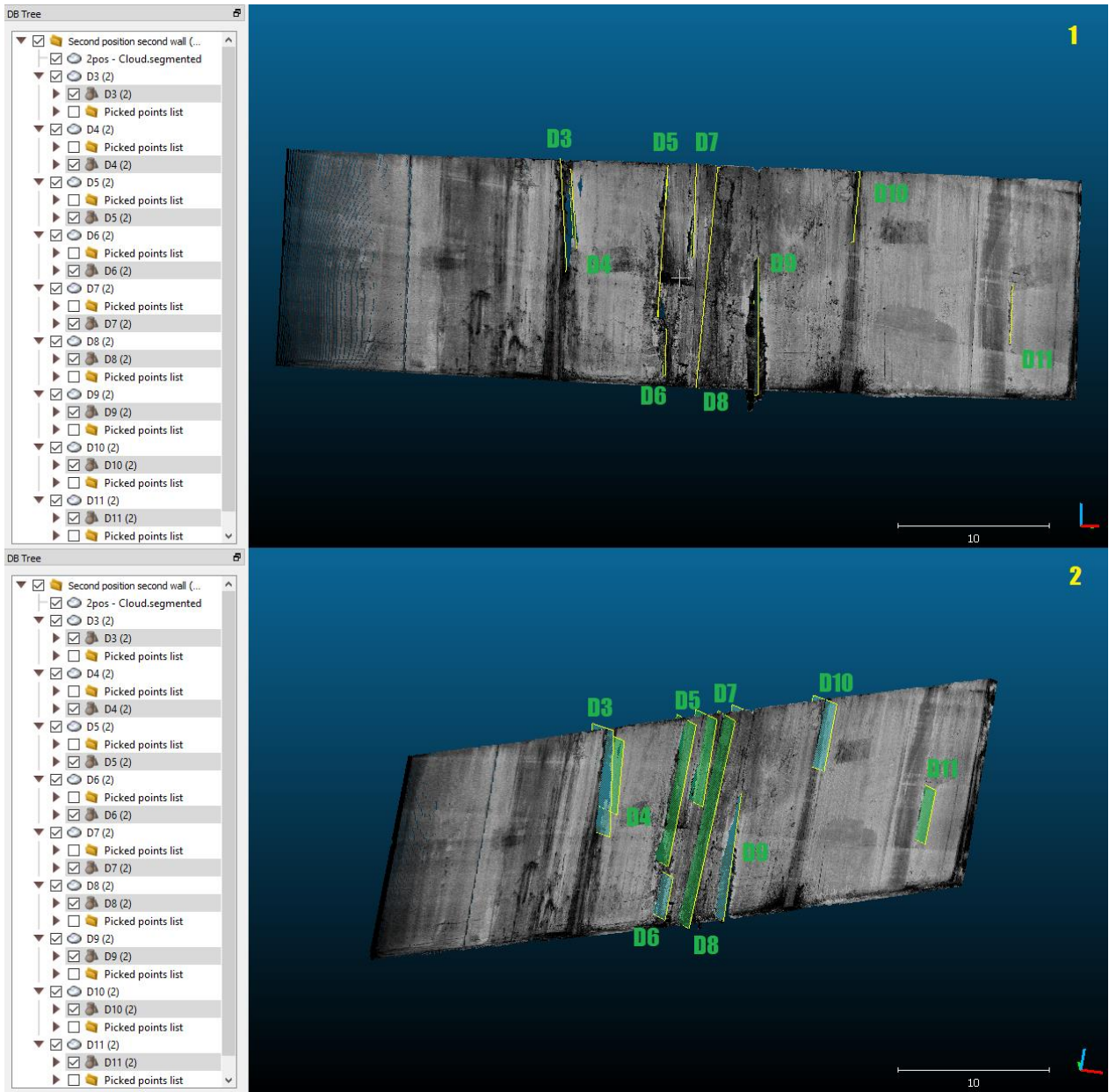


Figure 5.6 Wall NW in the higher resolution of scan, own source

The last analyzed wall in this scanner configuration was marked with the symbol NE. During the test, the number of discontinuities found on this surface did not change relative to the previous scan. The Figure 5.7 shows visible cracks and ticked surfaces corresponding to their angles and lengths.

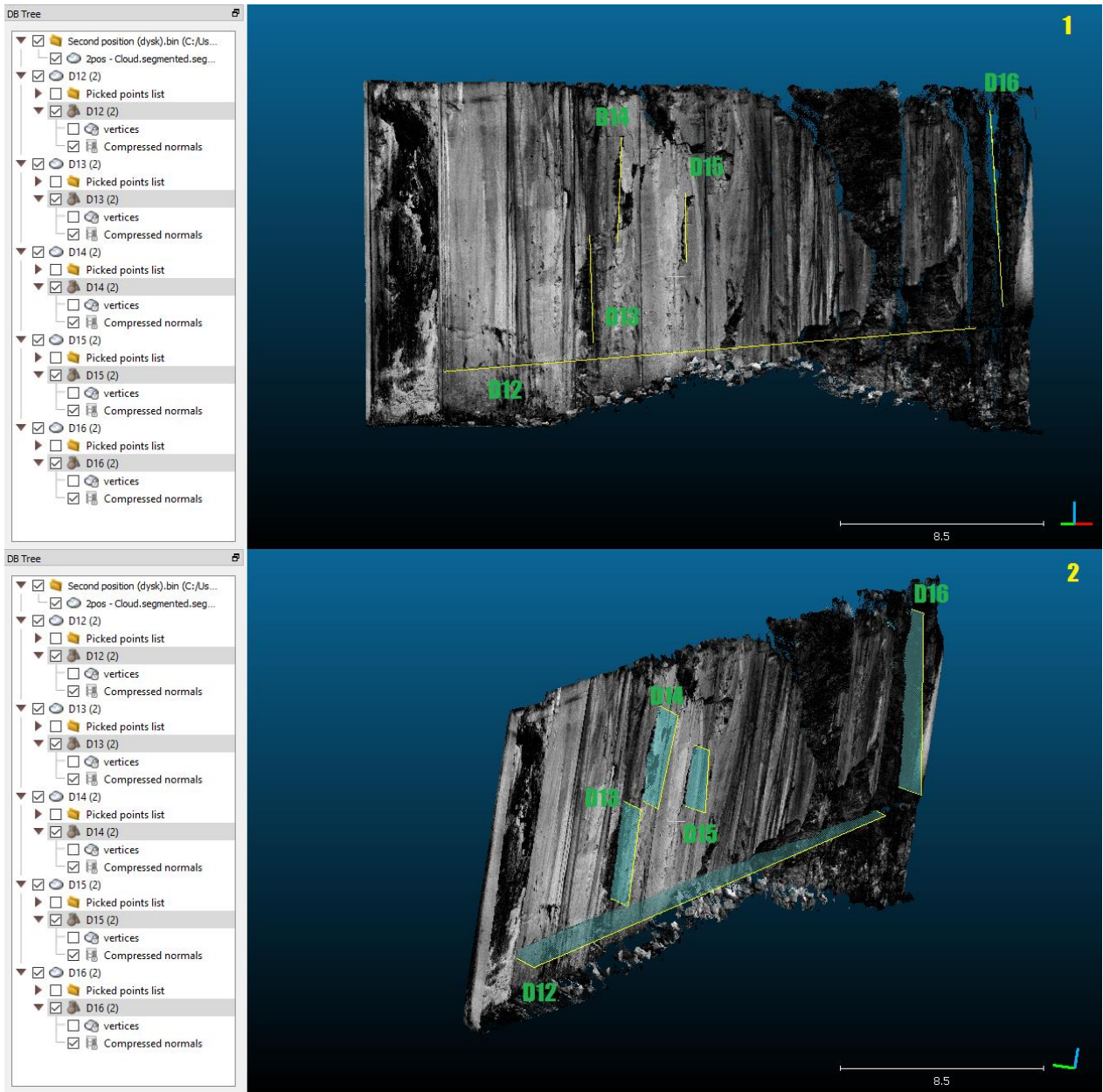


Figure 5.7 Wall NE in the higher resolution of scan, own source

5.1.4 Discontinuities in combined scans

When the previous two point clouds were analyzed the next phase had place – finding discontinuities in combined scans. The results of their visualization and information obtained during this process are presented below in the form of illustrations and descriptions used. The methodology is also repeated in this section, where the first wall discussed is the one with the designation SW (Figure 5.8).

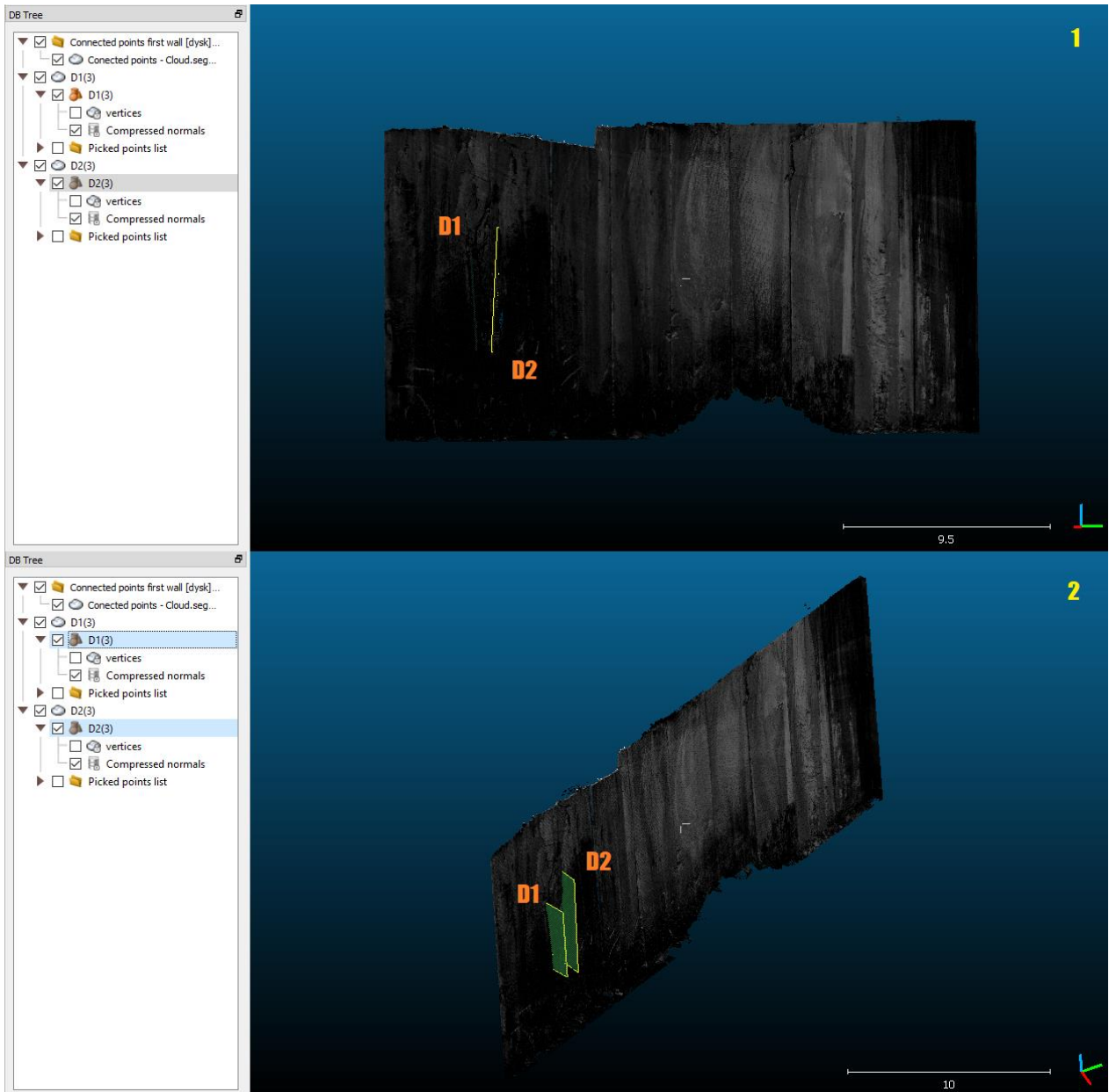


Figure 5.8 Wall SW in the connected scans, own source

The wall with the NW symbol directed towards the north-west was another object examined. Based on the generated model from a combination of two locations, it can be observed higher resolution and quality of points. This effects on the more accurate application of rectangular planes to emerging discontinuities. In this case, nine slots were observed, which are shown in Figure 5.9.

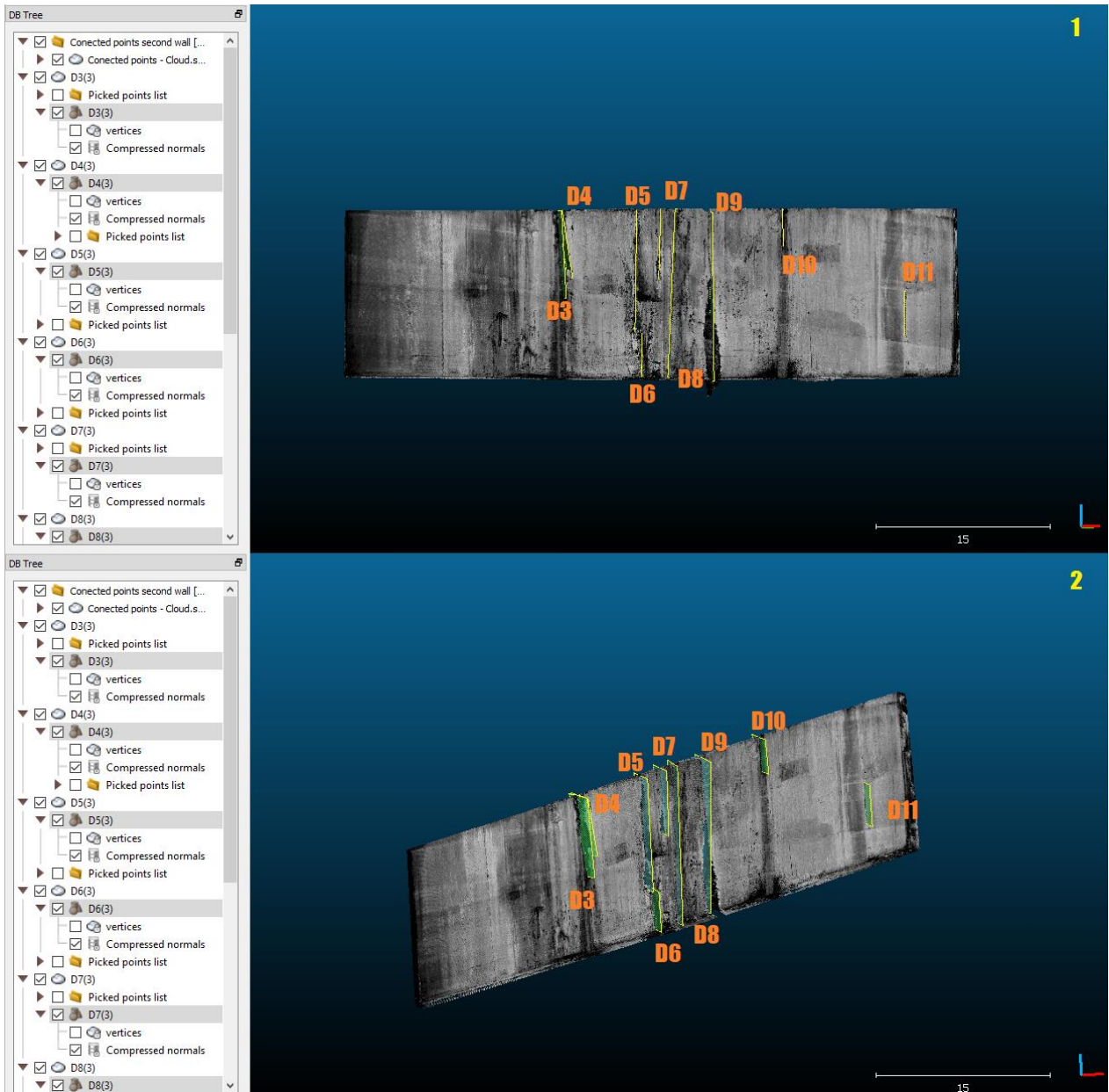


Figure 5.9 Wall NW in the connected scans, own source

The last tested object in terms of quantity and dimensions of discontinuities is the NE wall. Also here, there are no more visible cracks that could be found in compare to the previous two scans which are corresponding to the selected area. This number of them is five and is shown in Figure 5.10, which is located under the text, with symbols from D12(3) to D16(3).

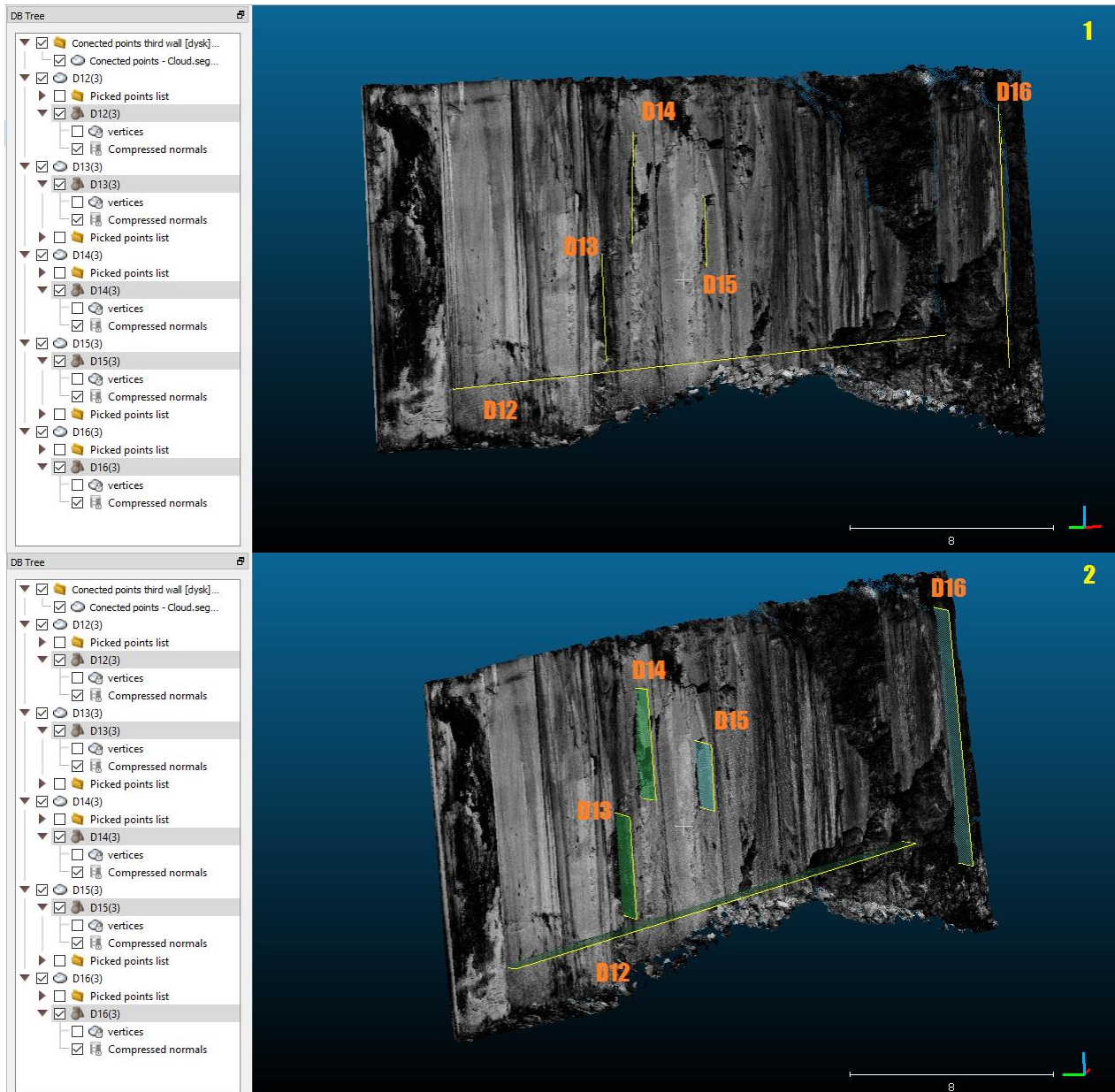


Figure 5.10 Wall NE in the connected scans, own source

5.2 Data obtained from the discontinuities planes

By using the point cloud processing program and applying planes, which inform about the location of discontinuities, in the previous chapter, it was possible to obtain the data presented in the subchapters. In the theoretical part there were presented several indicators that describing the discontinuities. In the work not all of them were used due to the lack of all available information and data. The final joints assessment consists: strike and dip direction, aperture, spacing, persistence, harshness and filling.

5.2.1 Strike and dip direction

At first, the joints found in scans with lower accuracy were presented, then with higher resolution and at the end of the chapter the combined of two models. The information in the Table 3 are represented by the angle indicating the inclination of discontinuity relative to the vertical marked as (0°) and the direction, also given in degrees, but measured on the basis of world directions, starting from the north, described as (0°). To check this parameter it was necessary to see the strike and dip direction which were attached to plane properties in every of the discontinuities. The Figure 5.11 shows the main panel from which were taken the results.

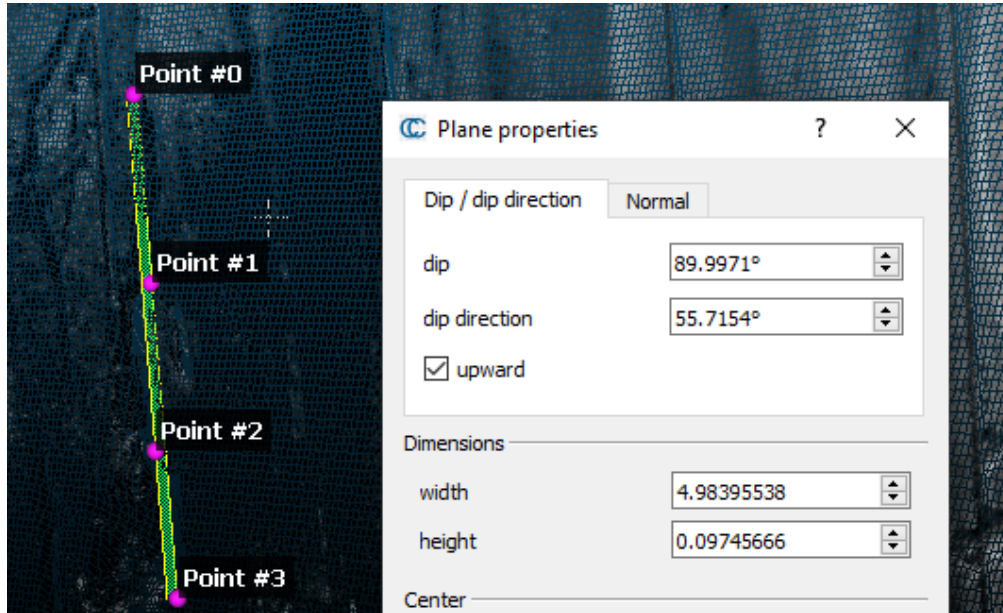


Figure 5.11 Analyzing strike and dip direction in the dedicated program, own source

The information generated in CloudCompare has been divided in relation to the walls occurring in the point clouds, starting with the symbol SW, then NW and at the final NE. The names of individual discontinuities were marked from D1 to D16. Thanks to given factors there can be seen that in the walls are several sets of discontinuities. The first one is a connection of D1 and D2 in the first wall. The second joints family include symbols from D3 to D11. The last set combine discontinuities with symbols from D13 until D16. The crack with the D12 symbol doesn't mix with any others because the location of it is in the perpendicular to the rest of discontinuities.

Table no 3 Strike and dip direction

Symbol	Dip direction – first configuratio n [°]	Dip direction – second configuratio n [°]	Dip direction – combined scans [°]	Dip angle – first configuratio n [°]	Dip angle – second configuratio n [°]	Dip angle – combined scans [°]
D1	221	220	220	89	90	87
D2	228	226	226	86	90	87

D3	307	310	309	87	85	87
D4	308	308	308	87	84	81
D5	305	306	305	88	88	88
D6	311	311	311	89	89	90
D7	313	312	313	90	90	88
D8	303	305	306	85	86	87
D9	315	315	315	88	88	89
D10	304	306	305	88	86	90
D11	310	310	310	90	90	90
D12	45	45	45	12	5	5
D13	40	42	42	88	88	89
D14	41	43	41	88	87	87
D15	37	39	37	89	90	90
D16	43	45	43	87	86	89

Key for discontinuities set:

The first group Table 3 has been marked on the light grey colour:

The second group in Table 3 has been marked on the grey colour:

The third group in Table 3 has been marked on the blue colour:



Discontinuities which were discovered in all of the scans are in joints shape. There are two different cracks with the symbols D5 and D9 which characterization is distinct than others. It's that because there was falling all of the water flow. It was accumulate in the top of the excavation wall when it was raining. This discharge of the water created different structure than others but it has no influence in the further rock deep because it has got a pipe shape and in the interior the joints are closed.

5.2.2 Spacing

In this geometrical factor the main aim was to check distances between discontinuities. To do this task it was necessary to use tool named "Point picking" in CloudCompare program and after that pick two point from two joints in the same horizontal height and measure the length between them. The results of this work is shown in the Figure 5.12.

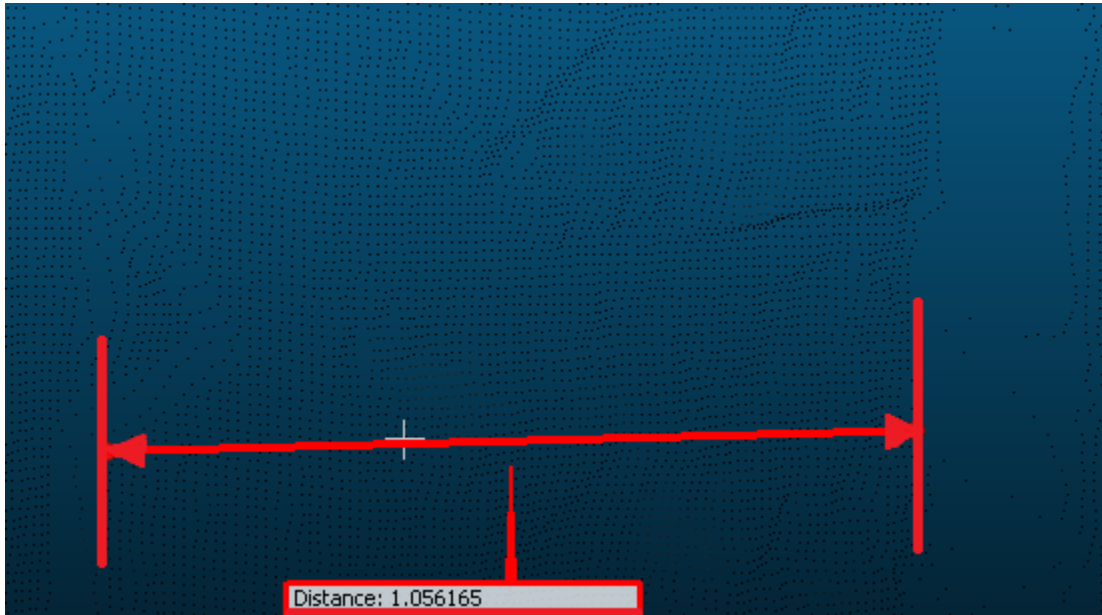


Figure 5.12 Spacing in progress, own source

It correspond with the first discontinuities placed in the wall SW in the first configuration of the scan. The chosen planes mapping the interior line of the joints. This task was done for all of the breaks in the rest of scans and for the rest of walls.

Table no 4 Spacing

Name of the spacing	Spacing - First Configuration [m]	Spacing - Second Configuration [m]	Spacing - Connected scans [m]
D1 – D2	1,06	1,05	1,06
D3 – D4	0,23	0,24	0,26
D4 – D5	5,24	5,26	5,24
D5 – D6	0,58	0,59	0,55
D6 – D7	4,87	4,87	4,85
D7 – D8	1,20	1,23	1,19
D8 – D9	3,12	3,14	3,12
D9 – D10	6,05	6,05	6,02
D10 – D11	10,49	10,55	10,56
D13 – D14	1,17	1,19	1,17
D14 – D15	2,38	2,39	2,37
D15 – D16	12,76	12,69	12,79

Key for discontinuities set:

The first group Table 4 has been marked on the light grey colour:

The second group in Table 4 has been marked on the grey colour:

The third group in Table 4 has been marked on the blue colour:



All of the distances visible in the Table 4 were done by prescribing between all of the point clouds. It was done by that to avoid picking wrong points and measure different distances from the same place of researches. In the calculations which have been done to describe this parameter, there was no possible to measure the joint with the symbol D12 because of the different rotation factor that all others.

5.2.3 Persistence

Next characterization factor focuses on the length of the discontinuities (Table 5). The measurement of these values has begun with the help of mapped planes on the joints from the previous researches. It was check in properties of the rectangles based on the shape of the fractures.



Figure 5.13 The persistence measuring, own source

The Figure 5.13 shows how the whole process of measure the persistence looked like. There is an example where both of the ends were connected with the help of point picking tool. By this work, it can be read the length of the discontinuity.

Table no 5 Persistence

Symbol	Length – first configuration [m]	Length – second configuration [m]	Length – combined scans [m]
D1	4,45	5,31	4,52
D2	5,22	4,98	5,51
D3	7,06	7,38	7,58

D4	5,34	5,28	5,83
D5	10,49	9,98	10,44
D6	3,28	3,07	3,77
D7	6,02	6,14	5,99
D8	14,51	14,60	14,50
D9	14,49	14,68	14,63
D10	2,61	4,67	3,17
D11	6,14	3,83	3,86
D12	22,92	22,30	19,38
D13	4,49	4,48	4,14
D14	4,76	4,31	4,39
D15	2,59	2,78	2,68
D16	5,45	8,14	10,26

Key for discontinuities set:

The first group Table 5 has been marked on the light grey colour:

The second group in Table 5 has been marked on the grey colour:

The third group in Table 5 has been marked on the blue colour:



As a result of these work was information about the persistence which have an influence on rock masses and can change between particular benches of excavation. The lengths of the joints here is different because level of the detail is different.

5.2.4 Aperture

The term of this factor focuses on the distance between exterior lines of the same discontinuity. In the work, some of them has got different shape and consequently different width. Every of the joint, which had been measured in the project, were calculated for this factor in several places – 1/3, 1/2 and in 2/3 of the whole length (Table 6).

Table no 6 Aperture

Symbol	Aperture – first configuration [cm]			Aperture – second configuration [cm]			Aperture – connected scans [cm]		
	1/3	1/2	2/3	1/3	1/2	2/3	1/3	1/2	2/3
-	1/3	1/2	2/3	1/3	1/2	2/3	1/3	1/2	2/3
D1	3	2	2	4	2	3	3	3	2
D2	4	11	9	5	11	8	3	12	8
D3	7	7	11	8	7	10	9	6	11
D4	12	19	36	13	16	35	11	17	40
D5	18	18	32	19	17	33	21	18	35
D6	4	12	30	5	14	30	5	14	31
D7	6	11	34	7	9	32	8	10	36
D8	2	2	2	1	2	3	2	3	2
D9	5	61	119	6	72	122	5	69	124
D10	11	33	4	12	32	6	12	32	6
D11	5	4	4	4	2	1	6	3	2
D12	9	7	21	9	6	24	9	6	19
D13	13	37	26	15	36	26	13	36	24
D14	6	29	14	8	25	15	8	26	15
D15	9	11	8	6	13	7	9	11	6
D16	22	24	20	23	22	25	21	23	19

Key for discontinuities set:

The first group Table 6 has been marked on the light grey colour:

The second group in Table 6 has been marked on the grey colour:

The third group in Table 6 has been marked on the blue colour:



The aperture factor has been measured using the same method as before - by selecting two points with the help of the tools provided by CloudCompare called "Point picking". The Figure 5.14 shows the D9 discontinuity under examination. There can be also seen the three picking stages on the different level of the joint length.

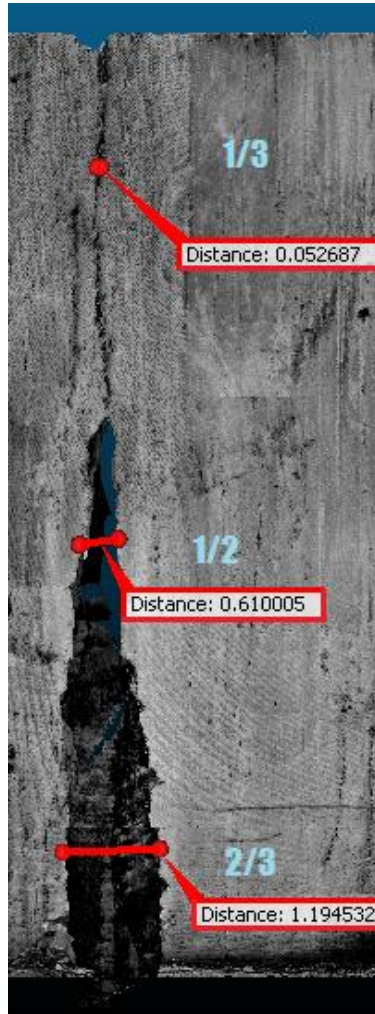


Figure 5.14 The aperture measuring, own source

There are several differences between the final data of each scans. It happened because the points in the extract position in one projection don't correspond specifically to the same location in other scans.

5.2.5 Roughness

This parameter was measured for each individual discontinuity by comparison with the test plane. Assuming that the mining wall is an almost ideal surface, which in the JRC table is treated as a determinant, it became possible to begin with description of the gaps using the roughness indicator.

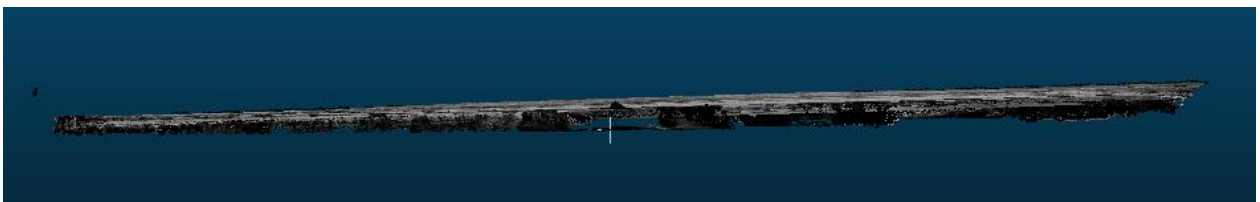


Figure 5.15 The roughness measuring, own source

To do this task it was necessary to cut the discontinuities on half in the middle along them and after rotate the camera in the position of profile view (Figure 5.15). Thanks that it was a possibility to zoom it and compare to the JRC table.

Table no 7 Roughness

Symbol	Harshness – First Configuration	Harshness – Second Configuration	Harshness – connected scans
D1	3	3	3
D2	3	3	3
D3	8	8	8
D4	7	7	7
D5	8	8	8
D6	6	6	6
D7	5	5	5
D8	2	2	2
D9	10	10	10
D10	4	4	4
D11	1	1	1
D12	1	1	1
D13	3	3	3
D14	5	5	5
D15	4	4	4
D16	8	8	8

Key for discontinuities set:

The first group Table 7 has been marked on the light grey colour:



The second group in Table 7 has been marked on the grey colour:



The third group in Table 7 has been marked on the blue colour:



Discontinuities visible during testing have a wide spectrum of roughness levels. In this case, there is no rule that would affect the same degree of calculated parameter. It is influenced by mining factors, rock properties and water flow inside the created cracks. After generating the results, it can be seen that there is no difference, in this type of measurement, between individual scans (Table 7).

5.2.6 Infilling

When checking scans and observations under measurement conditions, no discontinuity filling was found. This is due to the continuous operations of the whole walls and the flow of water in the interior of the gaps which effectively wash all materials from the interior of the cracks.

5.3 Summary of results

In the previous segment of work the final data from individual models was generated. This allowed to present the last part of the project so the comparison and analysis of results. During this phase, a number of connections between individual scans were taken into account.

In order to determine which configuration is the best solution for testing discontinuities with a laser scanner, the results of individual models and settings had to be profiled. The information specifying the gaps according to their direction and the average with the deviation between individual projections is a maximum of 1.12° . The biggest variation can be seen in discontinuities with the symbols D3 and D8. These are two of the sixteen cases where the discrepancies are higher than 1° . The rest of the planes determining the gaps oscillate within the limits of no bigger deviation of 1° . Due to this range and the average aberration of all cracks, which was calculated at the level of $\pm 0.56^\circ$, it can be observed that the strikes of discontinuities may be different between scans by the aforementioned value.

The Table 8 shows all used properties and their changes between two scans. In the line called resolution, the scanner focuses on a more accurate representation of the measured image. During the first scan, a smaller value of the described variable was used.

Table no 8 Comparison of settings parameters in both configurations

Parameter name	Scan number 1	Scan number 2
Resolution	$\frac{1}{4}$	$\frac{1}{2}$
Quality	4x	6x
Scanning time [min]	12:59	33:31
Distance between points $\left[\frac{mm}{10m}\right]$	6,1	3,1
HDR mode	2x	2x

Another parameter is quality, which focuses on the quantitative repetition of the same point, depending on the settings. When the instrument was used in the outdoor work, the efficiency of this was increased for the second model one and a half times higher. The time is constantly changed when the rest of the parameters are updated. As the distance between points increases, the final quality of the scan decreases, which translates into fewer points during measurements. At the second scan, this parameter was reduced twice to get more accurate picture. The last variable and at the same time the only common element was the quality of the high resolution photos imposed on the scan. The model from the combined two point clouds, because of connected two of them obtained higher quality and proportionally longer time of implementation.

6. Conclusions

The purpose of this work was to analyze the possibility of using a laser scanner survey for map discontinuities in limestone rock masses, and which configuration should be adopted for this task. The obtained results gives an answer that the use of laser scanning technology is enable the visualization and identification of discontinuities in limestone rock masses. These discontinuities that can be visible in the project may relate to later change of direction and slope of the gap. It is that, because the work didn't conclude more surveys - when the excavation process of the block will be on further way, however, the orientation and dimensions of the length will remain identical with the main tested surface.

After conducting measurements in various configurations of the laser scanner and subsequent processing of the results, it can be concluded that the differences, in obtained final data, between scans and settings are less than $\pm 0,56$. Laser scanner settings allow to create hybrids between quality and resolution, which in turn can divide accuracy groups between: low, medium and high. Two of these three types have been implemented in the given work - medium and high. The difference between them was $\frac{3mm}{10m}$ so with found discontinuities in the limestone rock mass it did not affect the final picture of the results. Also, the combination of two point clouds into one did not provide radically different data compared to previously ones. To conclude which of the scans is the best suited for this work, the answer is the surveys done by the lowest resolution. It is that, because for checking the whole characterization of the discontinuities there is no need to choose higher quality or any of the connections between scans.

With the possible introduction of this technology for widespread use in the mine areas in the future, attention should be paid to the time of measurements, financial aspects and the possibility of cooperation with other activities in the area of extracted raw material. By increasing the accuracy the data collection can take several hours of continuous operation, and thus, during this task it is not possible to stop without cutting data. Once again there can be seen that the best option for this aim the use of lower configuration, it's because, on the field work the time of surveys were 20 min and 32 s faster that with higher resolution. Also the time of post processing of data is longer with the higher quality of the scan. The problem with this task is connected with too much points that the machines, such as stationary computers and laptops, needs to upload. These activities are related to the fact that during the measurement all visible planes should remain motionless. Therefore, there is a probability of problems during cooperation between the research team and the mining group.

The purpose of this work has been achieved, and the individual stages and conclusions are described in a number of chapters. While constructing the overall picture, aids in the form of drawings and tables were used. All project phases helped to enable the final summary and answer to the question.

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