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Two geologists – three opinions

On the variability and consequences of geological roughness classifications conducted by different observers

Master's Thesis

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and

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Danksagung

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Kurzfassung

Die aktuellen Standards einer geologischen Untersuchung von Gesteinsoberflächen beinhalten manuelle und subjektive Wege zur Abschätzung der Rauigkeit. Ziel dieser vorliegenden Arbeit war es, zunächst zu untersuchen, wie groß die Variabilität der Klassifikation ist, wenn verschiedene Beobachter dieselbe Oberfläche mit zwei verschiedenen Klassifizierungsmethoden bestimmen. In diesem Zusammenhang wurde eine Umfrage an der Technischen Universität Graz durchgeführt. Insgesamt 30 Personen aus drei verschiedenen Berufsgruppen klassifizierten angefertigte Modelle von Gesteinsoberflächen mit zwei verschiedenen Rauigkeits-Klassifizierungsmethoden. Die erste verwendete Klassifizierungsmethode ist die Bestimmung des JRC (Joint Roughness Coefficient) mit dem Barton Kamm und die zweite Methode ist die Bestimmung der Rauigkeit unter Verwendung der ÖNORM EN ISO 14689-1. Die drei verschiedenen Berufsgruppen, die von Geologen, Bauingenieuren und Studenten vertreten wurden, wurden ausgewählt, um den Einfluss von Beruf und Berufserfahrung auf die Ergebnisse der Umfrage zu untersuchen.

Der erste Teil der Arbeit beschreibt die allgemeinen Aspekte von Trennflächen- und Rauigkeit-Klassifizierungsmethoden. Weiters wird die Modellierung künstlicher Trennflächen ausführlich beschrieben und die dazu notwendigen Arbeitsschritte im Einzelnen definiert.

Im zweiten Teil der Arbeit werden die Ergebnisse der Umfrage für beide Klassifizierungsmethoden vorgestellt und diskutiert. Zusammenfassend zeigt die Umfrage, dass beide Arten der Rauigkeitsbestimmung nicht zu präzisen Ergebnissen mit einer geringen Streubreite führen. Die Bestimmung hängt von der persönlichen Einschätzung des Beobachters ab, ob sich eine Oberfläche glatt oder rau, wellig, flach oder stufig anfühlt und welches Profil von dieser mit dem Bartonkamm abgenommen wird, um die Rauigkeit mit den JRC-Profilen visuell zu vergleichen. Die Rauigkeitsbestimmung unter Verwendung der ÖNORM EN ISO 14689-1 ergab eine höhere Übereinstimmung im Vergleich zur Barton-

Kamm-Methode. Nach Verwendung der Barton Kamm-Methode liegt die Übereinstimmung unter 50%. Mit der Methode nach ÖNORM EN ISO 14689-1wurden mindestens 50% Übereinstimmung erreicht. Darüber hinaus ergab die Umfrage, dass die Gruppe der Studenten mit der geringsten Erfahrung die höchste Übereinstimmung aufweist. 67% der Beobachter bevorzugten die ÖNORM-Klassifikation gegenüber der Methode mittels Barton-Kamm mit nur 10%. Die restlichen 23% konnten sich nicht auf eine bevorzugte Methode einigen.

Abstract

The current standards of a geological investigation of rock surfaces include a manual and subjective way for the estimation of the roughness of rock surfaces. The aim of the present work was to investigate how big the variability of the classification is when different observers classify the same surface by using two different classification methods. In this context a survey was performed at the Graz University of Technology. In total 30 persons, of three different professions classified special test specimens by using two different roughness classification methods. The first classification method which was used is based on the determination of the JRC (Joint Roughness Coefficient) using the Barton Comb and the second method was the estimation of roughness by means of the ÖNORM EN ISO 14689-1. The three different profession groups, which are represented by geologists, civil engineers and students, were chosen to investigate the influence of the profession and work experience on the results of the survey.

The first part of the thesis describes the general aspects of joint roughness and roughness classification systems. Further, the modelling of artificial joint surfaces is described in detail and the workflow steps are defined.

In the second part of the thesis the results of the survey for both classification methods are presented and discussed. To sum up the results, the survey shows that both ways of roughness classifications do not lead to precise results with a low scatter range. The classifications are dependent on the observer’s view of which surface feels smooth or rough, undulating, flat or wavy and the profile taken with the Barton Comb were classified by visually comparing the JRC profiles. The roughness classification using the ÖNORM EN ISO 14689-1 showed a higher match compared to the Barton Comb method. The results of the roughness estimation using the Barton Comb method show a match under 50% and the ÖNORM EN ISO 14689-1 reached at least 50%. Furthermore, the survey showed that the group of students, who have the least experience, has the highest agreement on a sample belonging to a certain roughness category. 67% of the

observers preferred the ÖNORM classification over the Barton Comb method, with only 10% of the observers preferencing this classification method. The remaining 23% do not prefer one method over the other.

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1 Introduction

1.1 Motivation

The roughness coefficient is one of the most important parameters when it comes to rock mass classification, especially to joint classification. Joints have a strong impact on the behaviour and strength of the rock mass; therefore, it is of high importance to characterize them. One of the joint characteristics, next to the joint set spacing, the aperture or the joint orientation is described by the joint roughness. The roughness coefficient is a highly important value to be determined during the geological and geotechnical investigation phases and influences the taken measures in supporting of a tunnel excavation. Therefore, it is of great interest to ensure an objective way of roughness estimation. The current standards of a geological investigation of rock surfaces only include a "manual" estimation of the roughness. The ÖNORM EN ISO 14689-1 states that the goal of the estimation is to classify a surface into either smooth or rough on a millimetre scale and into planar, stepped or undulating on a centimetre and meter scale. The Barton Comb is also typically used for roughness estimation in engineering geology by visual comparison of the roughness profiles of natural rock surfaces and standard roughness profile lines associated with the JRC ranges. The profiles are given on a scale from zero to ten centimetres.

1.2 Problem statement

When it comes to roughness classification there are several methods available. In this present work two classification methods, on the one hand the classification with the Barton Comb and on the other hand the method suggested by ÖNORM EN ISO 14689-1, are discussed and compared. Both classification methods are dependent on the observers own perception and therefore represent subjective ways of classifying the rock surface. The greater the influence of the observer is, the more impact is given for the construction work, for example in tunnelling, hence the costs of the project depend on one person's opinion. Therefore, it is essential to investigate this influence on the outcome of the classification methods to get a proper basis for optimizing the classification in future.

1.3 Aim of the work

This study investigates how big the variability of the classifications is when different observers classify the same surface by using two different classification methods. Within a survey, artificial test specimens are classified by 30 persons, of three different professions. To acquire reproducible results, the test specimens are prepared by digitizing of natural rock surfaces and subsequent milling of the models from hard foam plates. In total 12 artificial samples are produced to ensure the same conditions for every survey participant. It is investigated how objective the classification methods are, which method is the more accurate one, showing the least scattering and how big the work experience influences the results.

1.4 Methodology

The rock samples used for this study were provided by the Institute of Applied Geoscience from Graz University of Technology. The rock samples originate from the excavation site of the Semmering Basetunnel. The samples are mainly composed from mica schist, quartz rich mica schist, albite schist and albite gneiss. 12 modelling surfaces were picked from 7 different rock samples for the generation of the artificial surface models. The seven rock samples presented in Figure 1 show the modelling surfaces which were chosen due to their character and quality of surface and to ensure a high diversity in the appearance of the surface models. The survey was executed with 30 participants of three different professions which will be specified in chapter ,,Survey and evaluation of results''.

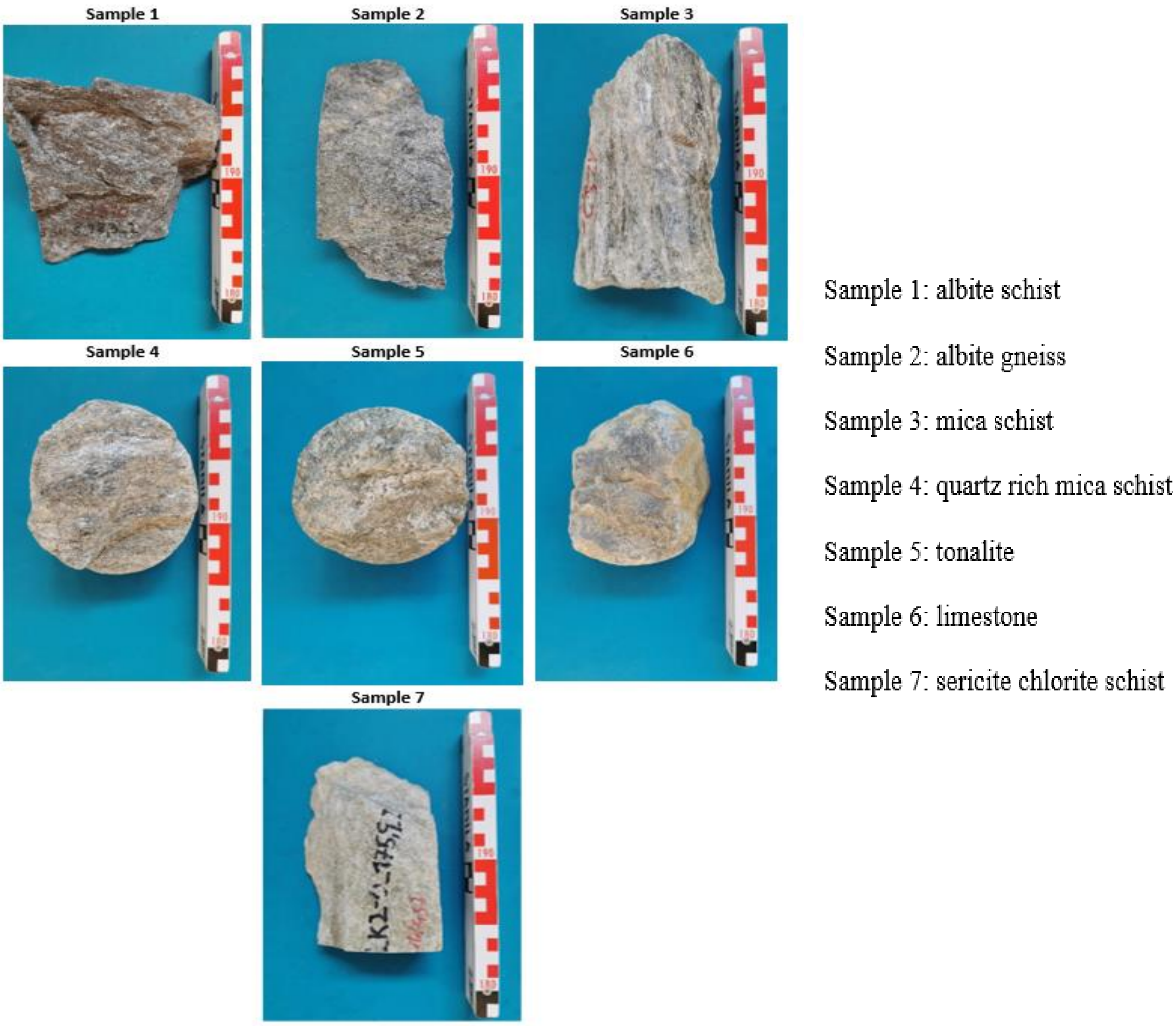

Figure 1: Rock samples as a basis for the generation of the digital surface models.

1.5 Thesis structure

The following chapter of this thesis provides information for understanding the basics of the joint roughness and further the classifications with the Barton comb and JRC the ÖNORM and other common classifications for the roughness classification. In chapter 3 the modelling of joint surfaces and the workflow within the modelling and editing are described. In chapter 4 the survey evaluation and the results are presented and discussed and finally in chapter 5 the conclusion and outlook of this master’s thesis are given.

2 Joint Roughness – General Aspects, Implications and Classification

2.1 General Aspects of Joint Roughness

A rock mass is ideally composed of a system of blocks and fragments which are separated by discontinuities and these elements behave in multiple dependencies as a unit. (Palmström, 2001) The main features constituting a rock mass next to the rock material are the joints which are described as discontinuity planes of natural origin which there has been no visible displacement. (ISRM, 1978) Joints are characterized by the joint roughness, joint condition or alteration and their length. The joint roughness describes the condition of the joint wall surface and can be characterized by the large-scale undulations of the joint wall, joint waviness or planarity and the small-scale smoothness of the surface (Palmström, 2001). Figure 2 shows the main joint characteristics.

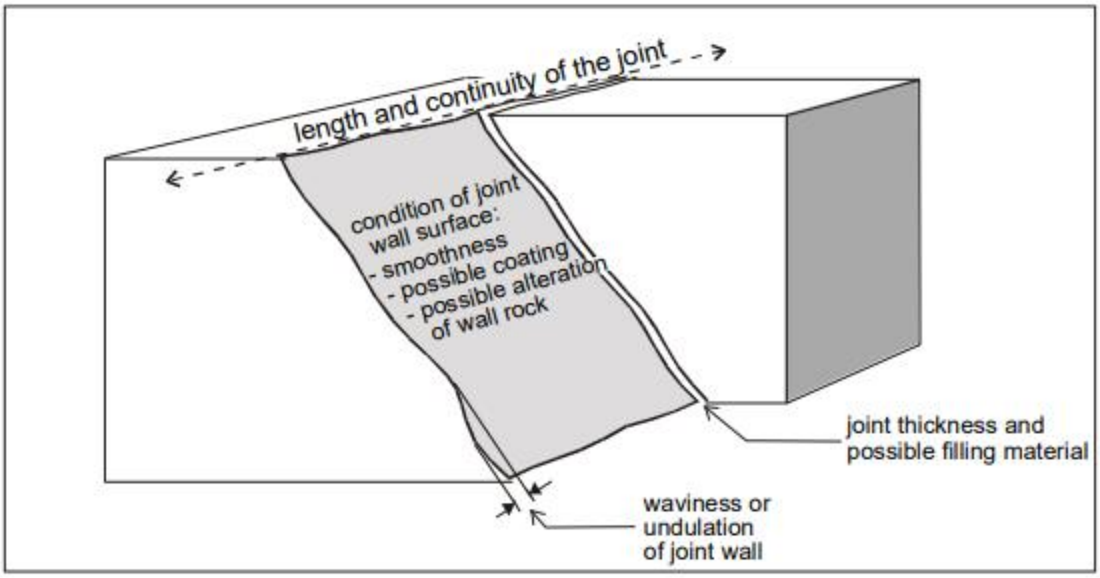

Figure 2: The main joint roughness characteristics which are: length and continuity of the joint, condition of the joint, joint thickness and joint waviness or undulation.

2.2 Implications of Joint Roughness on engineering works

The joint roughness can be estimated using the Joint Roughness Coefficient (JRC). The JRC is used for example in tunnelling during the excavation period. The continuous determination of the Joint Roughness Coefficient during the tunnel excavation at the exposed tunnel cross sections and the exposed joints, enables the investigation of the structural stability of the tunnel. The JRC is also used to analyse the deformational behaviour of rock slopes and is one of the most important parameters when it comes to determining the shear strength of joints. The shear strength increases with an increasing joint surface roughness and this strength increase is important when it comes to the stability assessment of construction works carried out in the rock mass. (Palmström, 2001)

With the help of different equations, such as the one suggested by (Barton and Choubey, 1977), see Equation 1, it is possible to estimate the shear strength. Barton's non-linear strength criterion for rock joints uses the JRC (Joint Roughness Coefficient), the JCS (Joint Wall Compressive Strength) and the residual friction angle. (Barton and Choubey, 1977)

Equation 1 Empirical equation of shear strength where **τ**=peak shear strength, **σ_n**=effective normal stress, **Φ**r= basic friction angle, JRC =joint roughness coefficient and JCS= joint wall compressive strength. (Barton and Choubey, 1977)

$$\tau = \sigma_n \tan\left(\phi_r + JRC \log_{10}\left(\frac{JCS}{\sigma_n}\right)\right)$$

The practical application of this method is shown in Figure 3. Curve A is showing the progression for a JRC of 20, curve B is showing the progression using a JRC of 10 and curve C uses a JRC of 5. Each curve is numbered with the corresponding JCS value. (Barton and Choubey, 1977)

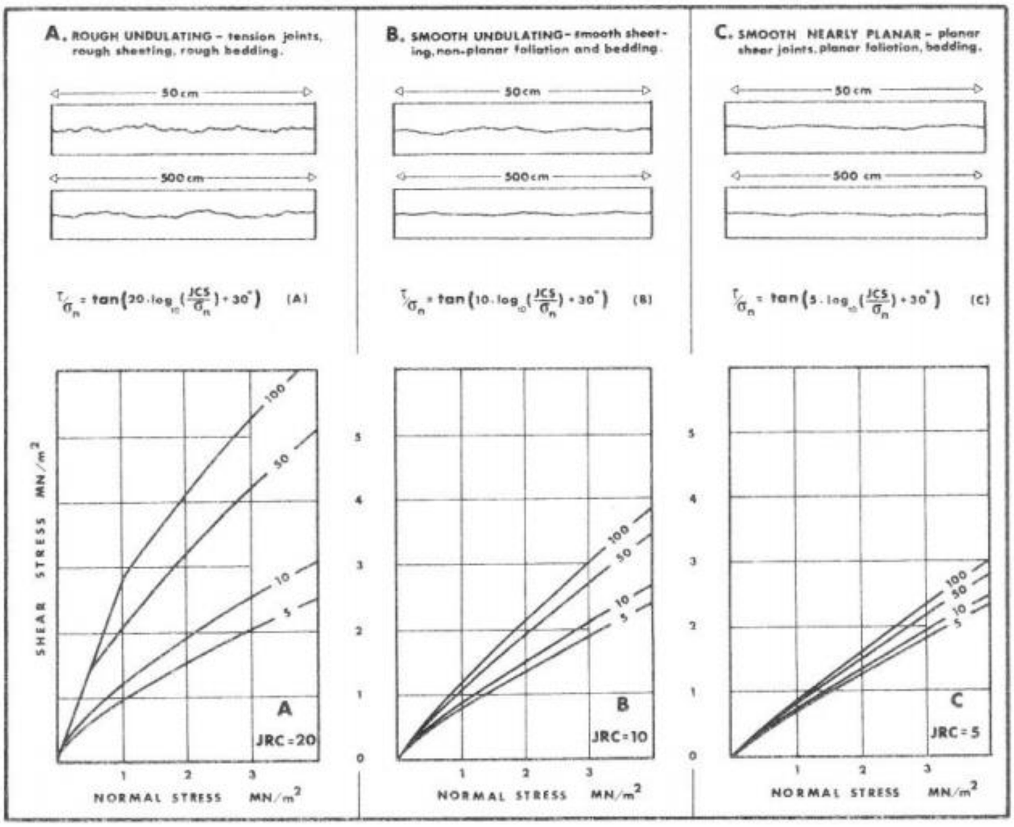

Figure 3: Practical application of the empirical equation of shear strength, using different JRC values. (Barton and Choubey, 1977)

2.3 Roughness Classification Systems

Barton JRC

The JRC is the most frequently used measure of the roughness of rock joint surfaces. It is part of the Barton-Bandis (Barton-Bandis, 2017) rock joint shear strength criterion. The joint roughness coefficient JRC is estimated by comparing of surface profiles with standard profile lines (Barton and Choubey, 1977). With the help of the Barton comb the surface is reproduced and can visually be compared with the profiles and the JRC value, corresponding to the profile which most likely matches can be determined. A Barton Comb is a small instrument that contains 100-150 metal pins with a diameter of 1 mm that conforms to the surface on which it is applied. The measured profiles using the Barton Comb are compared to the JRC profiles, which are shown in Figure 4, and the surface is classified into one of the ten profiles. (Barton and Choubey, 1977)

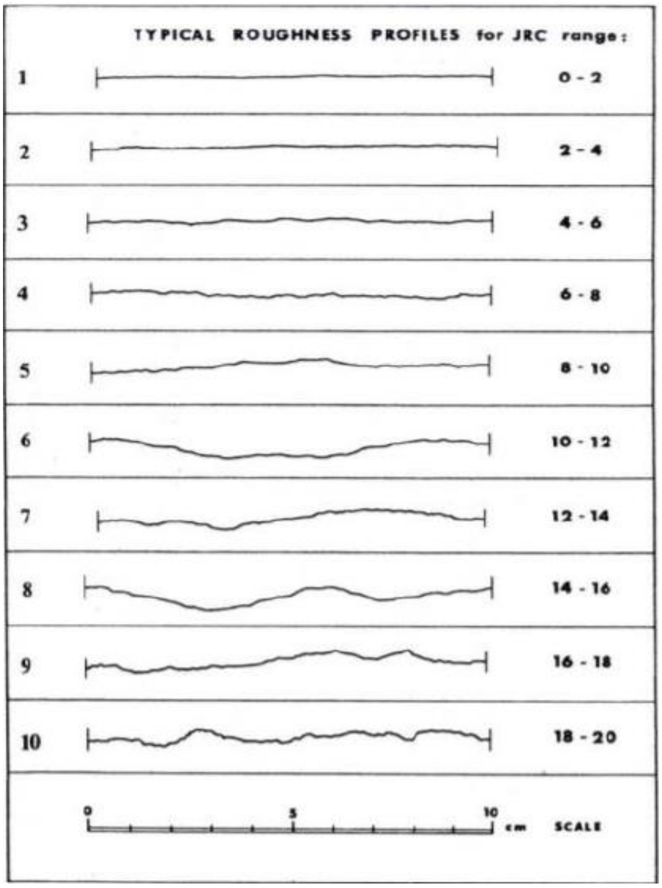

Figure 4: Typical roughness profiles for JRC range. (Barton and Choubey, 1977)

ÖNORM EN ISO 14689-1

Another method is the classification of the roughness with the ÖNORM EN ISO 14689-1. The surface of the joint faces is classified using three different scales:

- Small scale (a few millimetres) – rough or smooth surface
- Middle scale (a few centimetres) - planar, stepped or undulating
- Big scale (a few metres)- planar, stepped or undulating

The surface of the joint faces can be classified by dividing the sample into either rough or smooth on a small scale and in a second step into planar, stepped or undulating on a middle scale or big scale. There are six possible classes describing the roughness of the surface. For example one sample could be described as,, stepped smooth'' or ,,undulating rough''. If required, the height and wavelength of the largest estimated joints can be measured. (ÖNORM EN ISO 14689-1, 2004).

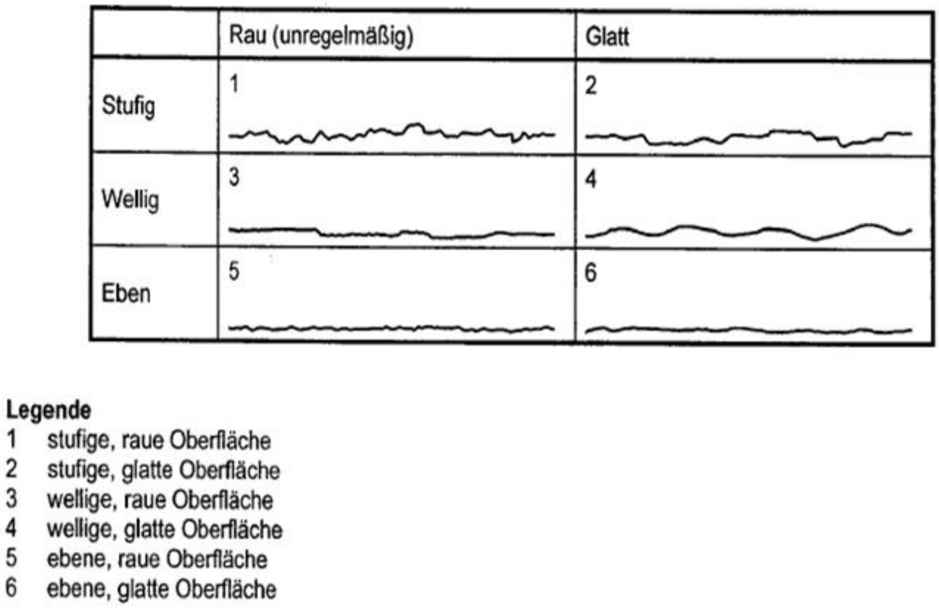

Figure 5: Large- and small-scale nomenclature acc. to ÖNORM EN ISO 14689-1

IRSM-1978

According to the (ISRM, 1978), discontinuity roughness includes large-scale (waviness) and small-scale (unevenness) components. The (ÖNORM EN ISO 14689-1, 2004)and the ISRM use the same descriptive approach for classifying the roughness into either stepped, undulating or planar and rough, smooth or stepped by visual comparison of the surface with roughness profiles. The scale of the components is shown in the Figure 6 below (ISRM, 1978) In Austria, the method by (ISRM, 1978) and the ÖNORM EN ISO 14689-1 (ÖNORM EN ISO 14689-1, 2004) are most commonly used for roughness estimation.

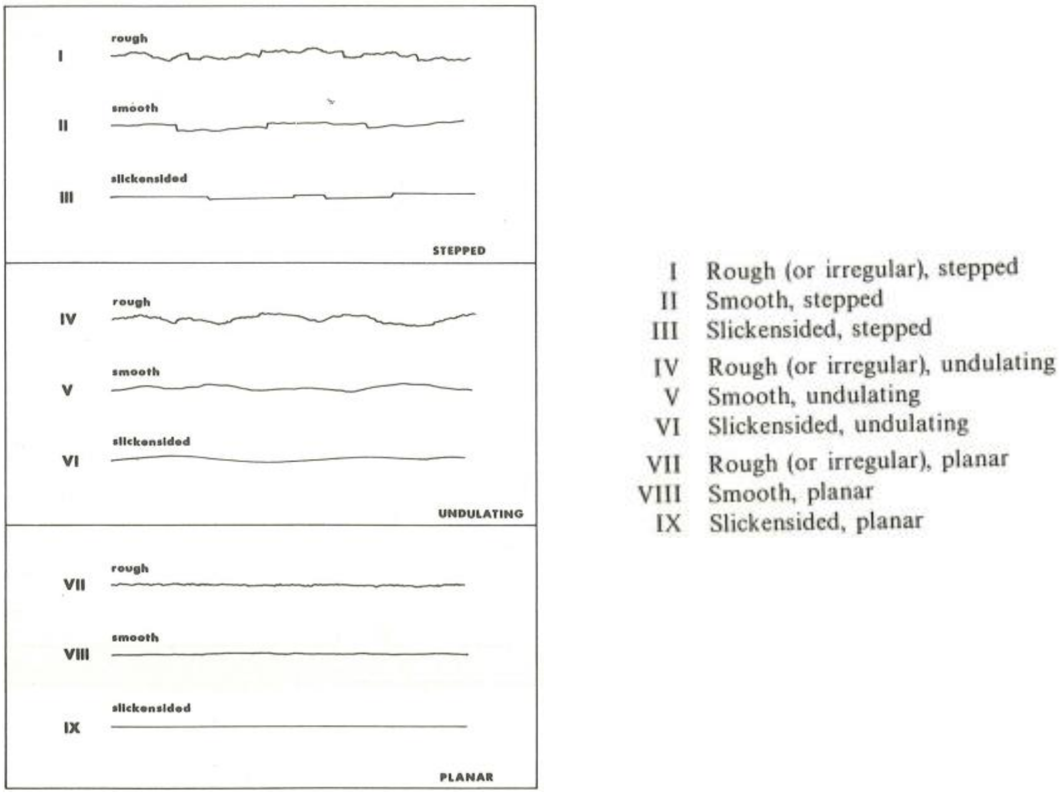

Figure 6: Roughness profiles and nomenclature. The length of each profile is in the range from 1 to 10 meters using (ISRM, 1978).

Roughness estimation by using three-dimensional photogrammetry or laser scanner point clouds

Another method to estimate the roughness of a surface is the use of 3D photogrammetry or laser scanner point clouds. In contrast to the methods which were discussed before, the use of photogrammetry or laser scanning is representing a more objective way of roughness estimation. Due to technological advances, digital photogrammetry and laser scanning have become reliable and affordable tools for rock mass characterization. Recently, terrestrial laser scanning (TLS) and close-range photogrammetry (CRP) have been used to generate 3D surface models and the data of discontinuities with high resolution and accuracy (Haneberg, 2007). It is possible to obtain surface features such as roughness from the generated 3D models by depiction of the roughness profiles (Eberhardt, 2007) or by using a regression equation such as the one suggested by (Maerz, 1990). The equation describes the relationship between the JRC and the roughness profile index Rp.

The Rp is defined as the ratio of the true length of a fracture surface trace to its projected length in the fracture plane (Maerz, 1990). Haneberg (2007) and Propat (2009) demonstrated that roughness profiles can be produced using photogrammetric point clouds and extracting the area of interest. The most important step is the referencing of the points to a local coordinate system. After the model is referenced and the surface is depicted the JRC can be estimated using empirical relationships such es the one suggested by (Maerz, 1990) or by comparing the model with the roughness profiles suggested as shown in Figure 7 by (Barton and Choubey, 1977).

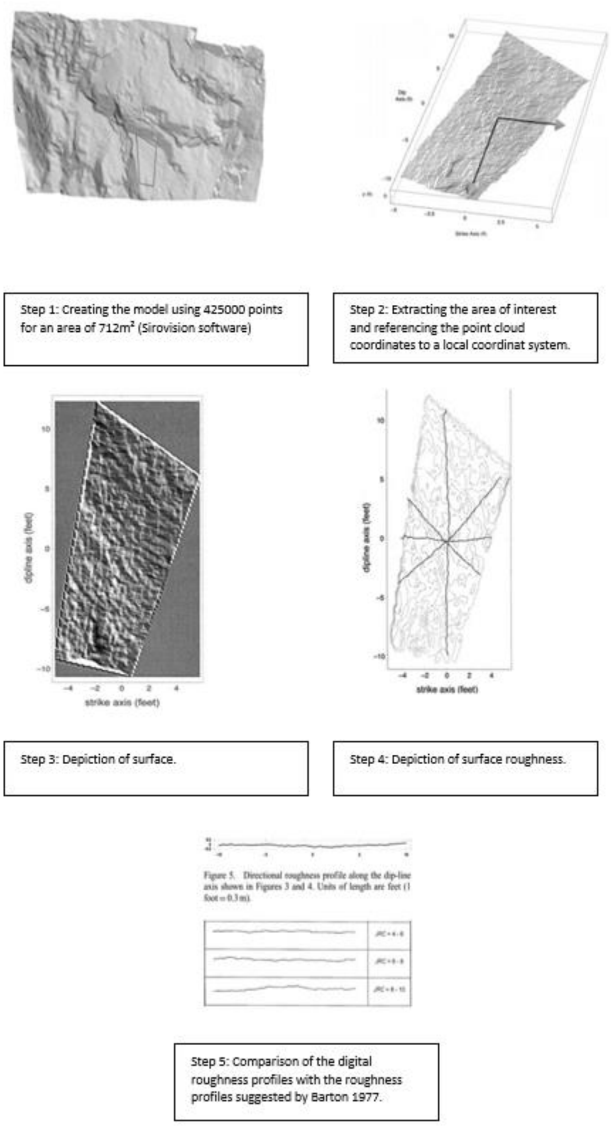

Figure 7: Steps for the roughness classification with 3D photogrammetry and comparison with the JRC profiles by Barton and Choubey. (Eberhardt, 2007)

3 Modelling of Artificial Joint Surfaces

3.1 Natural rock specimen

The natural rock specimens used for this study were provided by the Institute of Applied Geoscience and due to cooperation's with tunnelling projects in Austria the Institute had a big variation of different rock samples. These rock samples originate from the excavation sites of different tunnelling sections from the Semmering Basetunnel. The samples are mainly composed out of mica schist, quartz rich mica schist, albite schist or albite gneiss. For the modelling, 12 models were picked which originated from 7 rock samples. The seven rock samples and the 12 models are pictured in Figure 8 below.

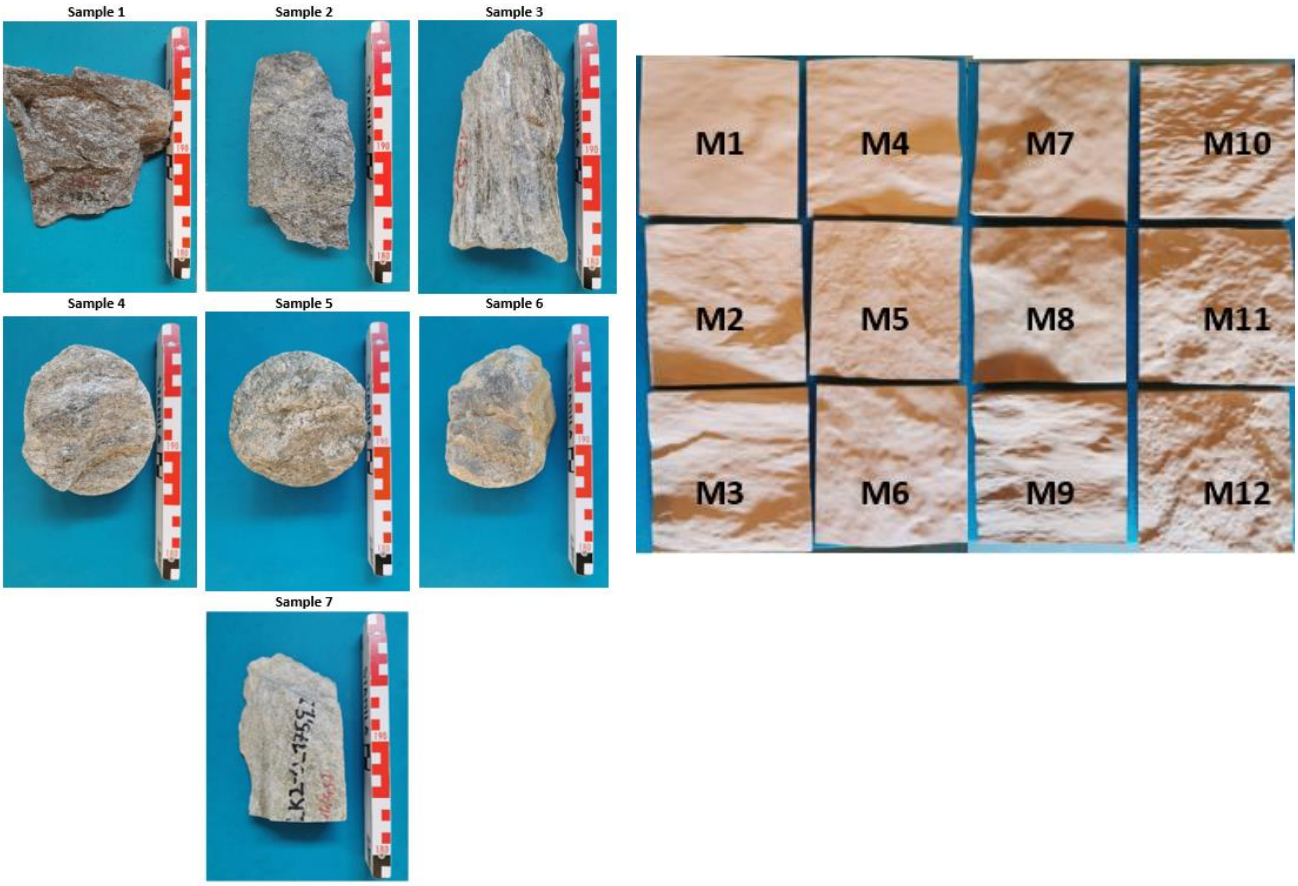

Figure 8: 12 models which were generated from natural rock specimen. Model M1and M2 originated from sample 3, model M3 and M4 originated from sample 4, model M5 from sample 7, model M6 from sample 5, models M7 and M8 originated from sample 6, model M9 from sample 5, model M10 from sample 1 and models M11 and M12 from sample 2.

3.2 Modelling Workflow

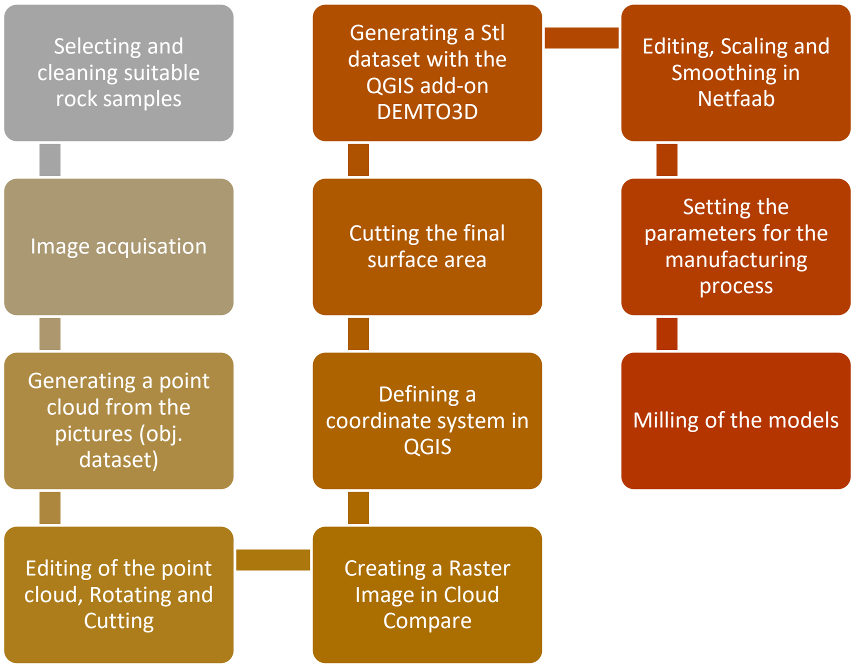

Figure 9: Modelling workflow

Figure 9 shows a workflow overview of the modelling process and the manufacturing of artificial models. The first step of the workflow is to choose a suitable natural rock specimen for the generation of the digital surface models. One of the most challenging and important steps is the image acquisition because the characteristics of the taken pictures (illumination of the natural rock, angle, camera settings) define the quality of the digital surface models. Further, it is important to take a minimum of 30 pictures per sample from different angles to guarantee a high resolution of the models. The pictures from the image acquisition are used to generate a point cloud in Meshroom. Furthermore, the first editing, rotating, cutting and a raster image generation was executed with Cloud Compare. The next important step was to generate a stl-file with the 3D model in QGIS for the further workflow. The last steps were to edit, scale and smooth the final 3D models and to prepare and set the parameters for the manufacturing process.

3.2.1 Workflow Step 1 – Photogrammetrical Surface Imaging

3.2.1.1 Basics of Photogrammetry

„Photogrammetry is a procedure for mapping of objects by position and shape, thereby the measuring isn't directly conducted on the object, but rather on pictures of the object indirectly. Photogrammetry is a procedure of remote sensing." (Konecky & Lehmann, 1984)

Photogrammetry includes every procedure and devices for obtaining processing and storage of primary geometric information's (shape, size, position) of objects and processes from pictures. The major objective is to relate the pixel coordinates to the geographic coordinates of the terrain points. Photogrammetry can be categorized in satellite photogrammetry, aero photogrammetry, and terrestrial photogrammetry. (Knödel, et al., 2007)

In the terrestrial and areal photogrammetry, it is differentiated between the "two pictures evaluation" and the "poly picture evaluation". The poly picture evaluation is directly used in the terrestrial photogrammetry for the determination of three-dimensional object coordinates. The poly picture evaluation has a major quantity of observations for every object point. Therefore, the accuracy of the point determination is much higher.

The taken pictures from the camera are loaded in the photogrammetry software. Subsequently the pictures are automatically balanced because of feature matching and a point cloud is generated. This point cloud can subsequently be refined and edited. Thereby a 3D surface model and an image texture can be created from this point cloud. A few parameters from the software can be changed and controlled but mainly the quality of the model depends on the quality of the initial pictures.

3.2.1.2 Image Acquisition

One of the most important parts in the process of photogrammetry is the acquisition of high-quality images as it directly impacts the quality of the mesh.

The main goal of the image acquisition is to generate sharp images without depth or motion blur. To minimize the noise the ISO should be reduced. The aperture is reduced (high f – number) to allow for large depth of field. To avoid the motion blur, it is important to have a fast shutter speed.

In this thesis, a Huawei P30 Pro quad camera from Leica with a 40-megapixel main camera (f/1.6, ISO,27mm), a 20-megapixel ultra-wide-angle lens (f/2.2,16mm) a 8 megapixel tele lens (5x, f/3.4, ISO,125mm) and also an AI image stabilization was used. The camera settings for the taken pictures, which were used to create the 3D models, were with a depth of field from f/2.2 to f/2.8 and an ISO 160 – 180 and a shutter speed between 1/150s and 1/220s. The shooting took place during daylight conditions. Each 3D model was created with about 40 pictures taken from various directions around each sample.

Figure 10 shows the difference in the quality of two pictures. On the left side a picture with a good quality and a more detailed surface and on the right side a picture with a blurry background can be seen.

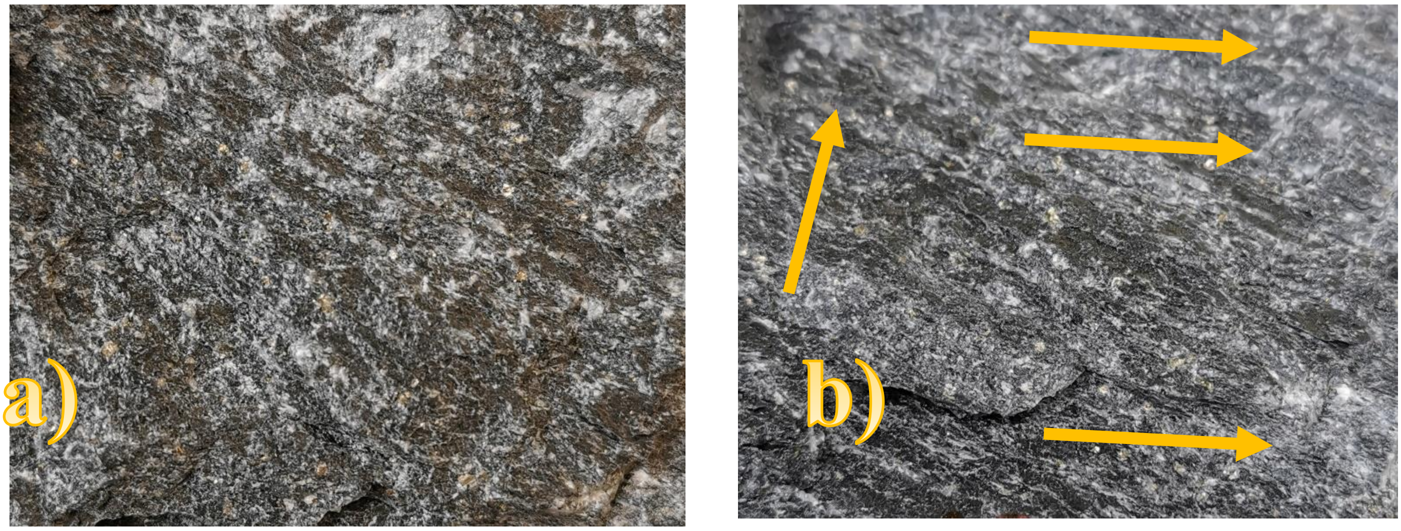

Figure 10: Difference in image acquisition, blurry segments are shown with orange arrows

a) Good quality b) Bad quality

3.2.1.3 Softwaretool “Meshroom”

The software Meshroom can be used within the photogrammetric modelling process to easily obtain a 3D surface model from multiple images with minimal user action or skills in photogrammetry. The software is totally open source, and it is a result of a European collaboration between industries and academies. Furthermore, it is necessary and recommended from the software developer to have a high random-access memory (minimum 32 GB) for a faster operating within the meshing process and to get a better- and high-quality resolution of the surface (Lanthony, 2019).

3D Surface model

The 3D model in Meshroom is generated via a set of photographs. The photographs or images are imported with drag and drop into the image area, as shown in Figure 12. The program analyses the metadata from the images and sets up the scene. It relies on the camera sensor database to determine the camera internal parameters and groups them all together. Before running the computation, the project must be saved locally. After these steps, the start button can be activated, and the computation will run until the model is finished. All data from Meshroom will be saved in the “Meshroom Cache” folder. The generic photogrammetry pipeline from Meshroom can be described in two important steps. The sparse reconstruction concludes the 3D points with the position and orientation and all internal calibration of all cameras. The results are calibrated cameras in a sparse point cloud. The second important step is the dense reconstruction (Multiview stereo), which uses the calibrated cameras from the sparse reconstruction to generate a dense geometric surface. The successfully reconstructed images are shown with the camera symbol with a green icon on it. Finally, the textured mesh is shown as the result of the photogrammetry in Meshroom (Meshroom Manual, 2015).

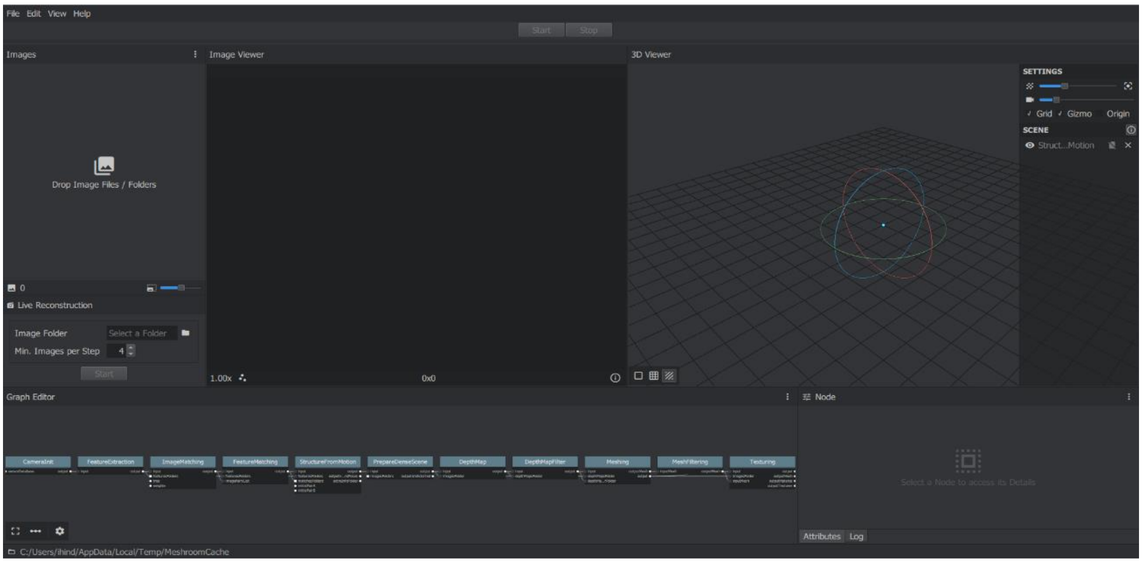

Figure 11: Meshroom interface

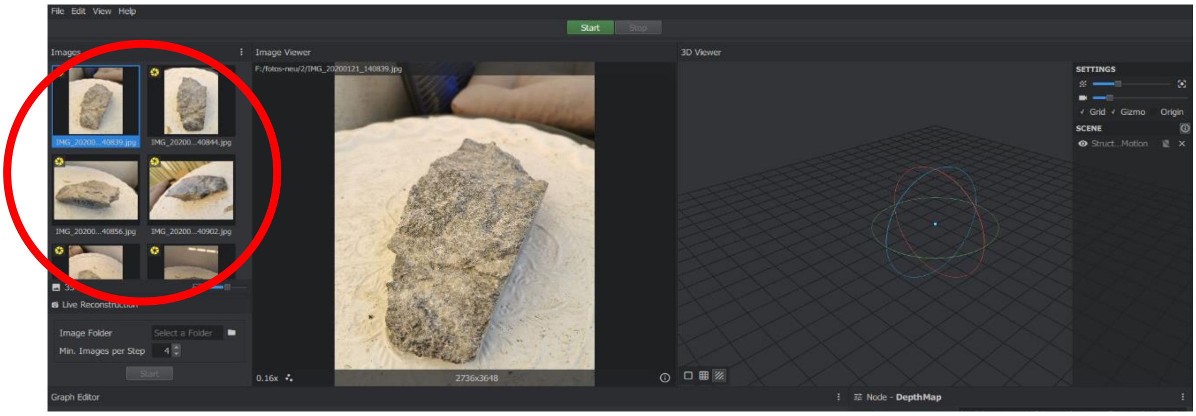

Figure 12: Drag and Drop interface marked in the red area

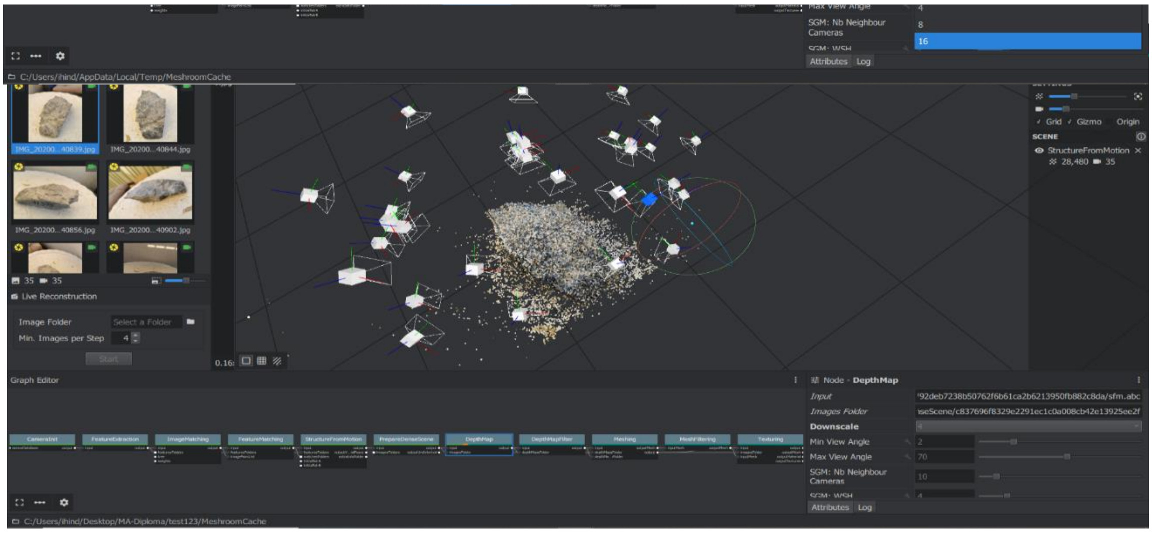

Figure 13: Textured mesh is shown as the result of the photogrammetry in Meshroom

3.2.2 Workflow Step 2

3.2.2.1 Basics of Raster Images

The generating of the raster images in this study was executed with Cloud Compare. The raster image is required to generate a STL file format, which is necessary to produce the physical models via milling or 3D printing.

A geotiff data is primaly used to provide an image file with coordinates for geo-referencing and information of the used map projection. The geotiff data also includes the reference information in the additional meta tags of the file. GIS based software can read these geo reference tags, and the raster images can be set in relation to the existing vector- and metadatas. The elevation information is saved in Cloud Compare in the tiff file. (Ritter, 2020)

3.2.2.2 Softwaretool „Cloud Compare“

The open-source software Cloud Compare is a 3D point cloud and triangular mesh editing and processing program. The software allows large point clouds to be stored in memory and displayed and to calculate differences between two large data sets rapidly. The software considers almost every 3D model as point clouds, so every triangular mesh is also considered as point clouds with an associated topology. Cloud Compare lets the user apply some tools directly on the mesh structure for example – triangles, but some tools can only be used to the mesh vertices (point clouds). So, it is mainly used as a point cloud processing software (Cloud Compare Manuel, 2015).

3.2.2.3 Softwaretool “Meshroom”

The generated point cloud from Meshroom is loaded into Cloud Compare. Further, the normal is calculated per-vertex, which means that the mean normal of all the triangles is connected to a vertex that is assigned to a vertex - smooth look. This step leads to no preservation of sharp edges. (Cloud Compare Manuel, 2015) After this step, the model should look like shown in Figure 15. The point cloud was generated with a minimum amount of one million points. In this step the total number of points can be specified. Also, the colour information from the original mesh can be exported at this point. The next step after creating the point cloud is the generation of the raster grid and further the TIFF dataset. Ultimately, the step „rasterize'' is used to edit the point cloud in Cloud Compare. The grid step size is defined by the user, in this present master's thesis, the grid size has a minimum of 5000x5000 points. Cloud Compare automatically updates the resulting grid size with the result that the grid is neither too small nor too big before generating the actual grid with the best fitting parameters. (Cloud Compare Manuel, 2015)

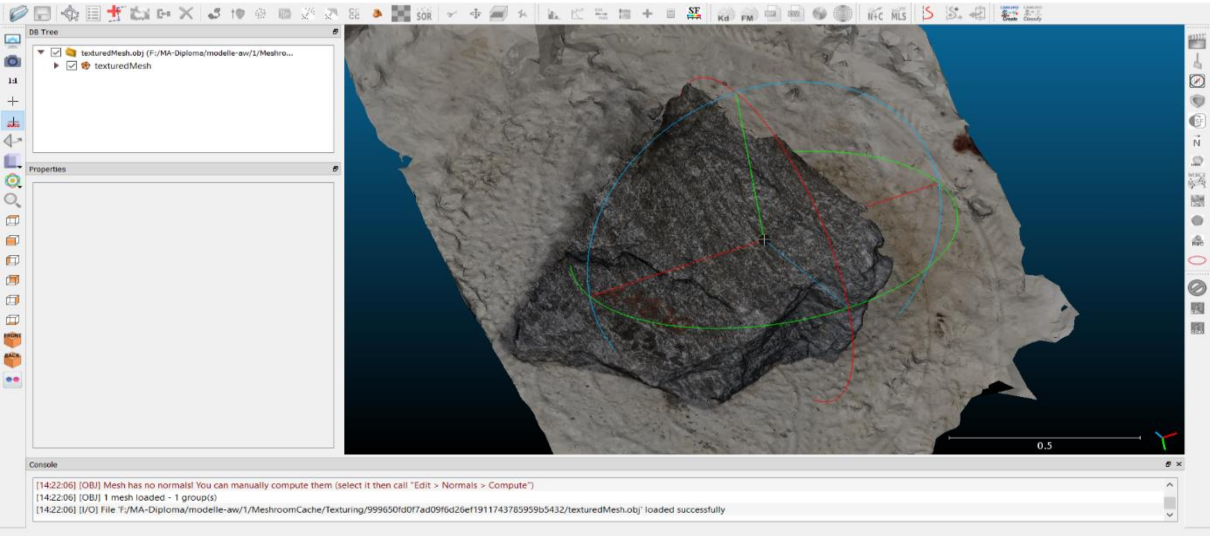

Figure 14: Point cloud edited in Cloud Compare

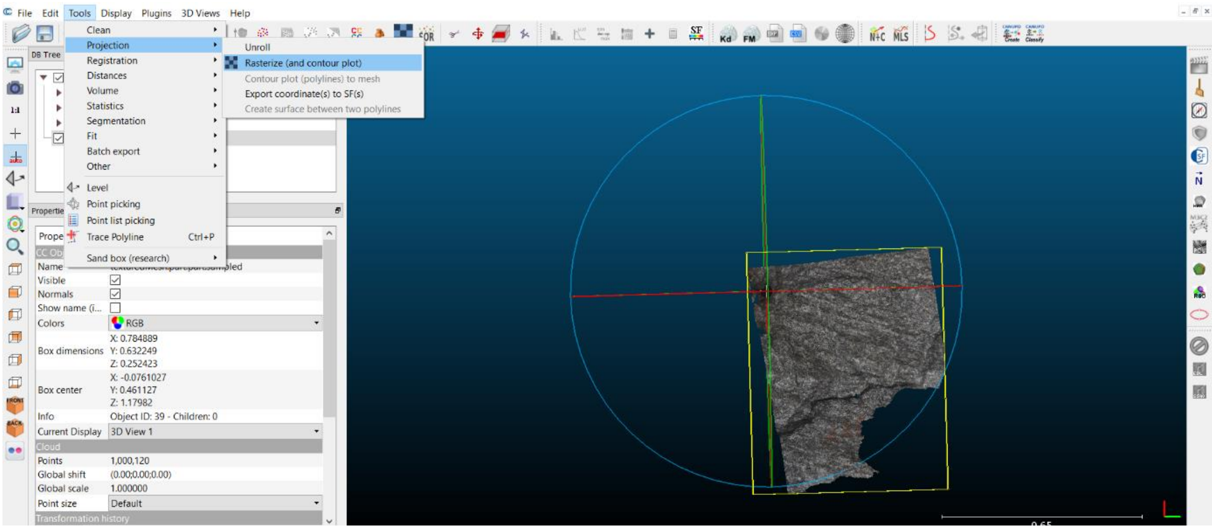

Figure 15: Rasterizing a point cloud and export it as a new raster image

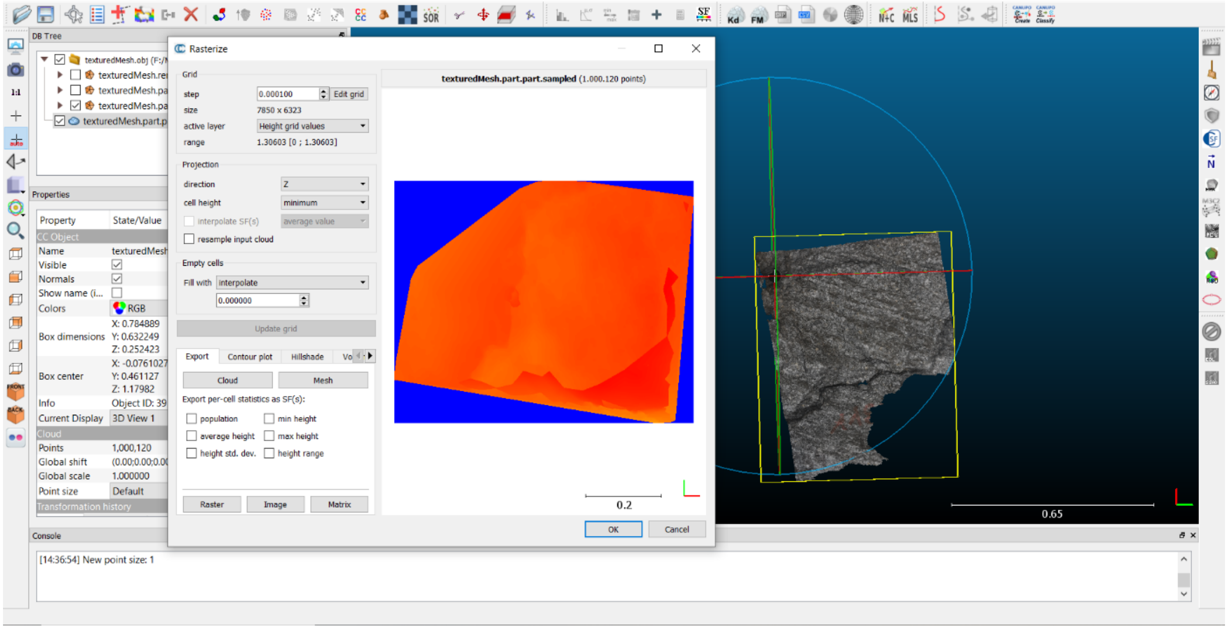

Figure 16: Raster Image Generation with a minimum size of 5000x5000 points

3.2.3 Workflow Step 3 – STL-File Generation for Sample Manufacturing

3.2.3.1 Basics of STL-File Format

A stl-file format is an exchangeable format that illustrate three-dimensional surface geometry. This file format type is very common in prototyping, 3D printing or computer aided manufacturing. The file format illustrates surfaces as a combination of small triangles or facets. The facets are described by a vertical direction and three points illustrating the vertices of the triangle. Further there are no colour information or other texture attributes in STL file format files (Aspose Pty Ltd, 2001-2020) .

3.2.3.2 Softwaretool „QGIS“

QGIS is an open-source geographic information system, which can be used on Windows and MacOSX. Nowadays it is commonly used for raster and vector formats. With QGIS 3 it is possible to show vector and raster data’s (2D and 3D) in different formats and with various projections without converting them into an intern format or into the same format (Athan, 2020). Tables and views from spatial data bases like PostGIS, SpatiaLite and MS SQL Spatial, Oracle Spatial, ESRI shape data, MapInfo, SDTS and GML are supported. Raster and picture data formats like GeoTiff, Tiff, ERDAS IMG, ArcInfo ASCII GRID, JPEG, PNG are mainly supported (Athan, 2020).

3.2.3.3 STL-File Generation

The stl-file was generated in QGIS from the raster image file from Cloud Compare to create in a further step the physical models by milling. The raster image file from Cloud Compare was loaded with drag and drop into QGIS and edited. After reproducing the layer, the raster image file is ready to be extracted. To extract/cut the image, it is necessary to know how your original model look like and how the parts from the model looked in Cloud Compare, to know which parts had the best resolution. As shown in Figure 19, the extraction area must be marked on the raster image file format to give the STL file the final shape. With the QGIS add on "DEMTO3D", as shown in Figure 21, the raster image file format is transformed into a stl-file. Before generating the final stl-file in QGIS, the parameters (width, length, height, spacing) must be defined. The length and width were standardized to 95x95 mm, because of the milling requirements. The height is dependent on the lowest point of the model, because the basis of the model should be less than 1 cm. The spacing is recommended to be set below 0.2 mm. The setting for this thesis were 0.1 mm to get a better resolution of the surface.

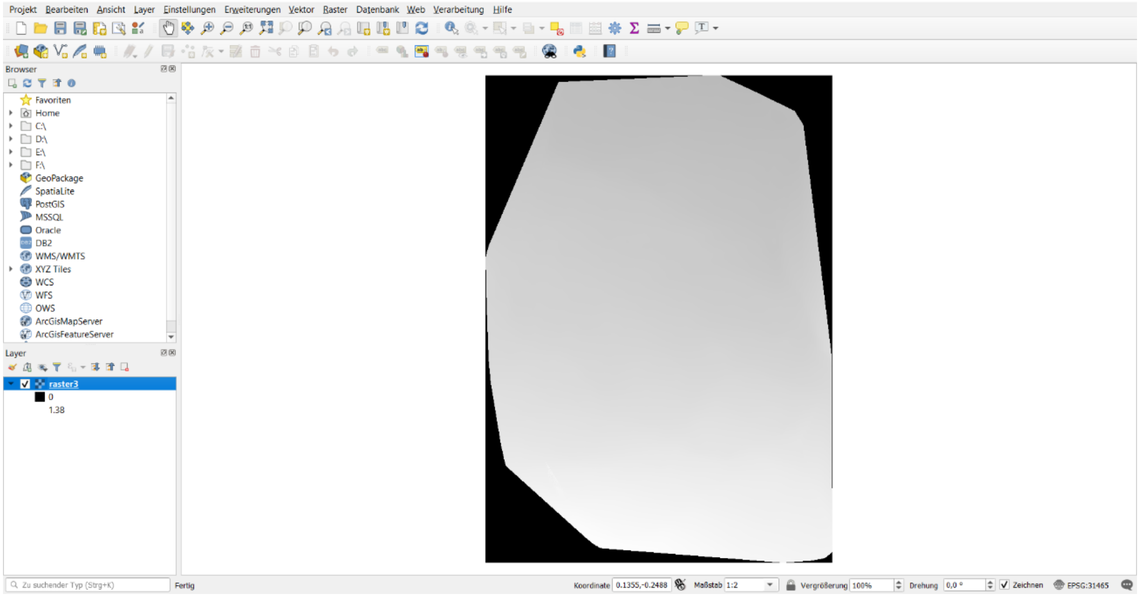

Figure 17: Loaded raster image from Cloud Compare in QGIS

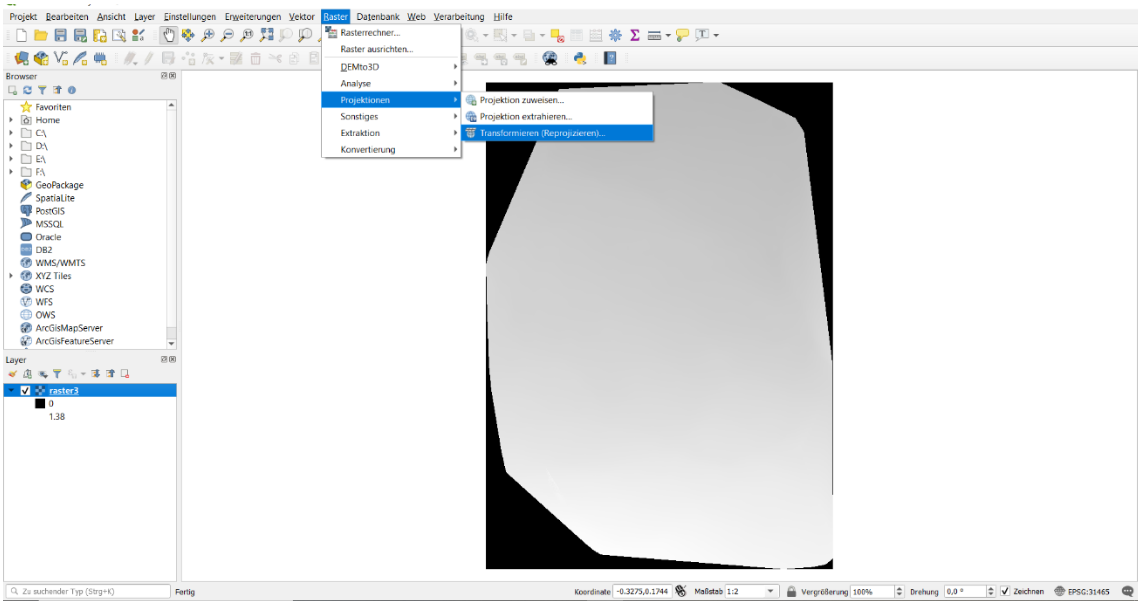

Figure 18: Reproducing a new layer for the extraction

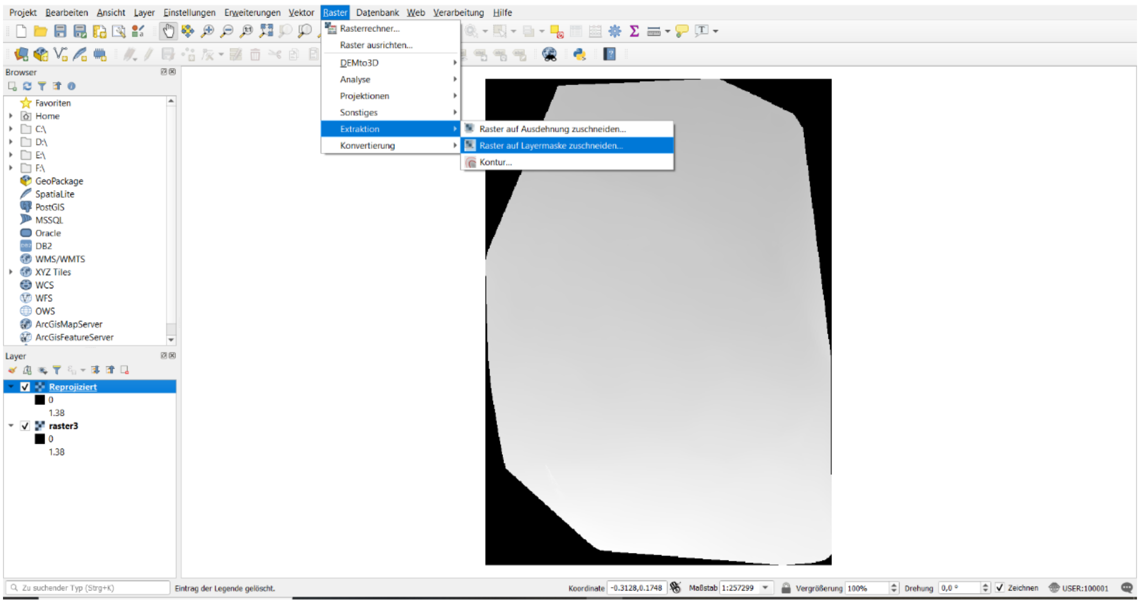

Figure 19: Selecting the extraction area on the layer

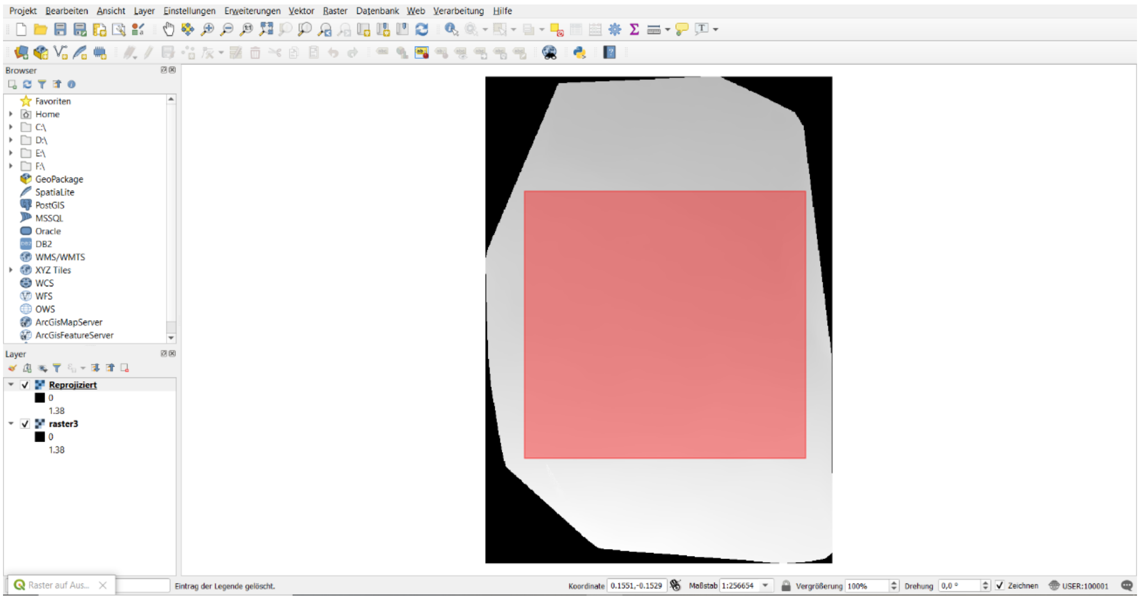

Figure 20: Extraction area marked on the raster image file format

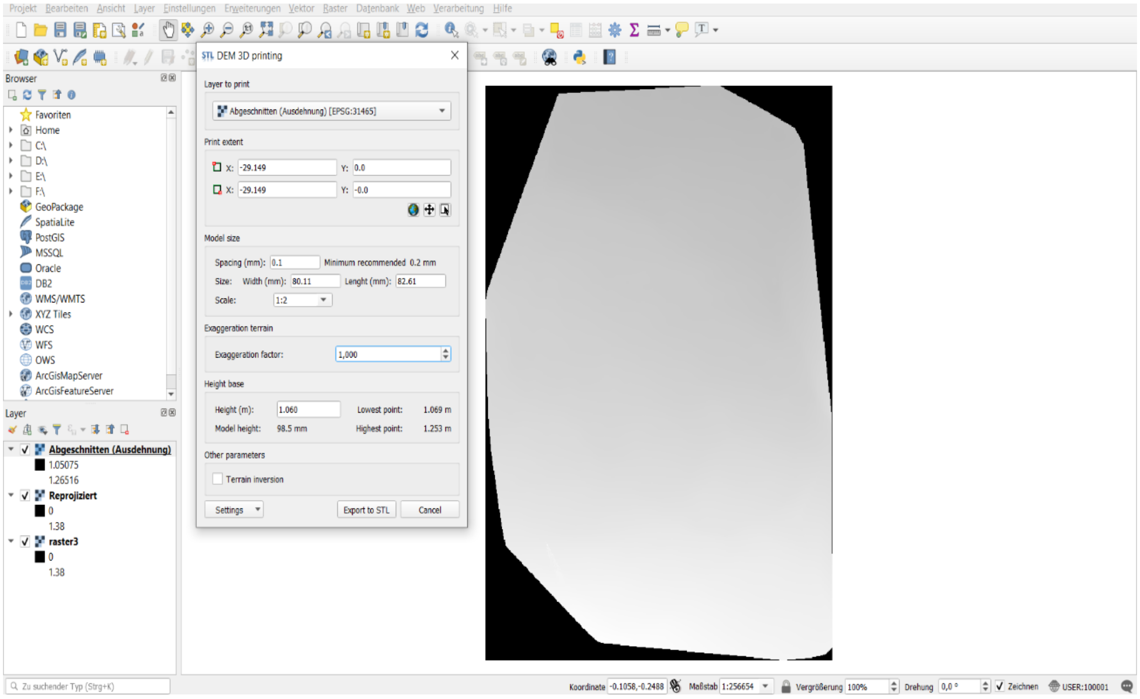

Figure 21: Transforming the raster image file into a stl-model setting the parameters - width, length, height, spacing

3.2.4 Workflow Step 4 – Model Post Processing

3.2.4.1 Model geometry and quality requirements

The requirements for the post processing of the edited models were to ensure that the appearance and quality fit the original rock surface. Further it was important to make sure that the height of the roughness was not excessively scaled and fit the original rock sample.

3.2.4.2 Softwaretool "Autodesk Netfabb"

The last tasks before the physical models can be created are the cutting, scaling, and smoothing. The cutting was necessary to remove the redundant parts of the model. The working steps are shown in Figure 22 and Figure 23. After the cutting part is done, it is required to scale the model because as a result of the the cutting process the standardized length and width of 95x95 mm is not given anymore. It is important not to select "fix scale ratio" because otherwise it is not possible to get a square base. The smoothing part is for the gentler transition of the roughness peaks.

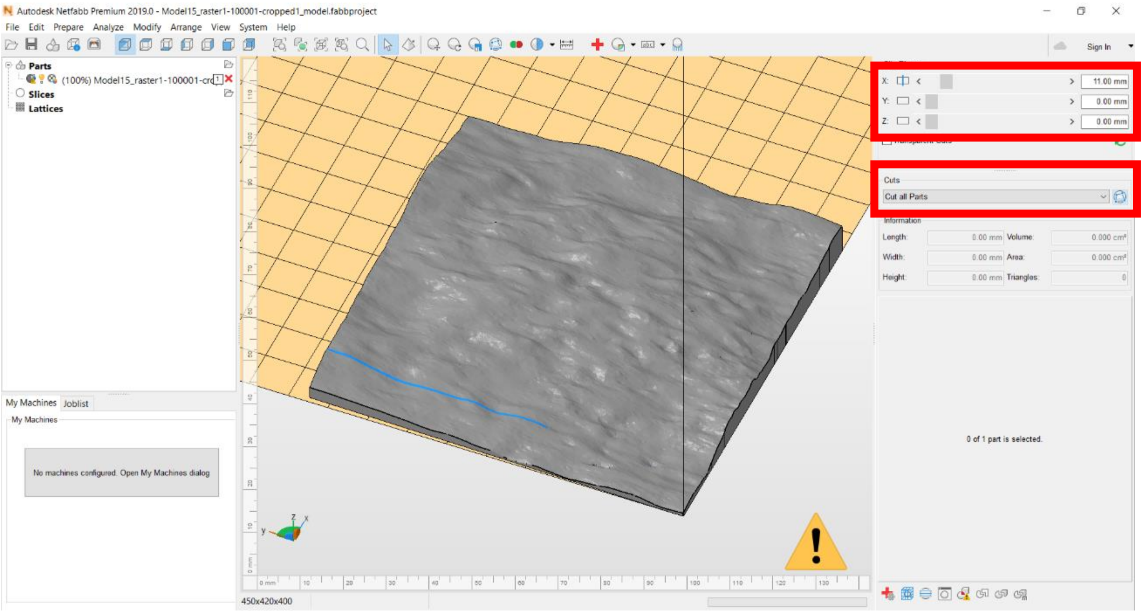

Figure 22: 1 Cutting plane (x,y,z) settings ; 2: Preparing the cutting plane within this step

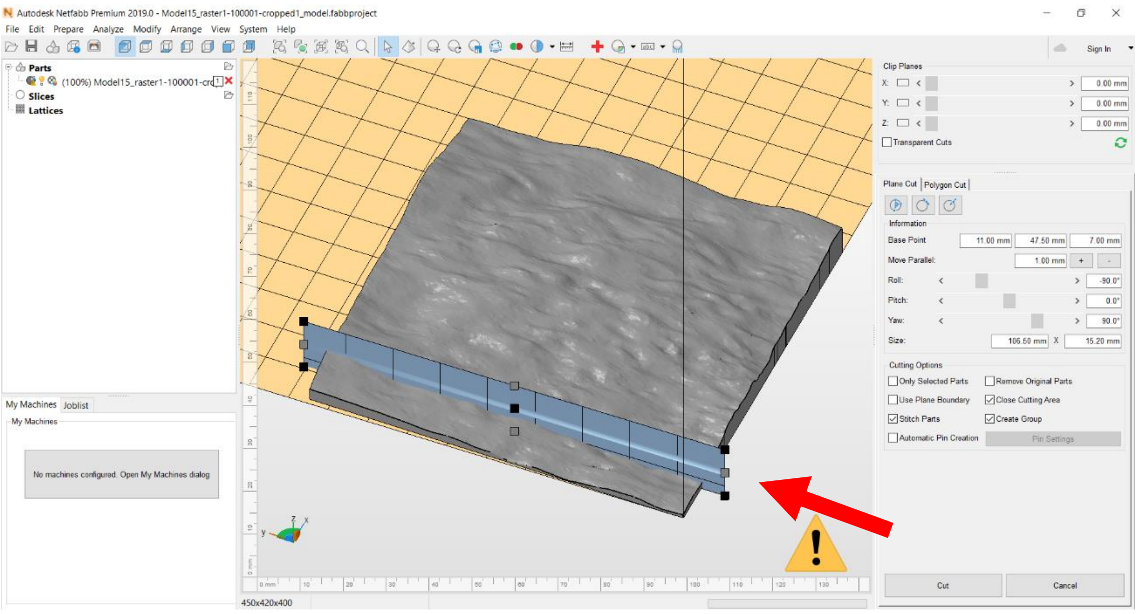

Figure 23: Generated Cutting Plane

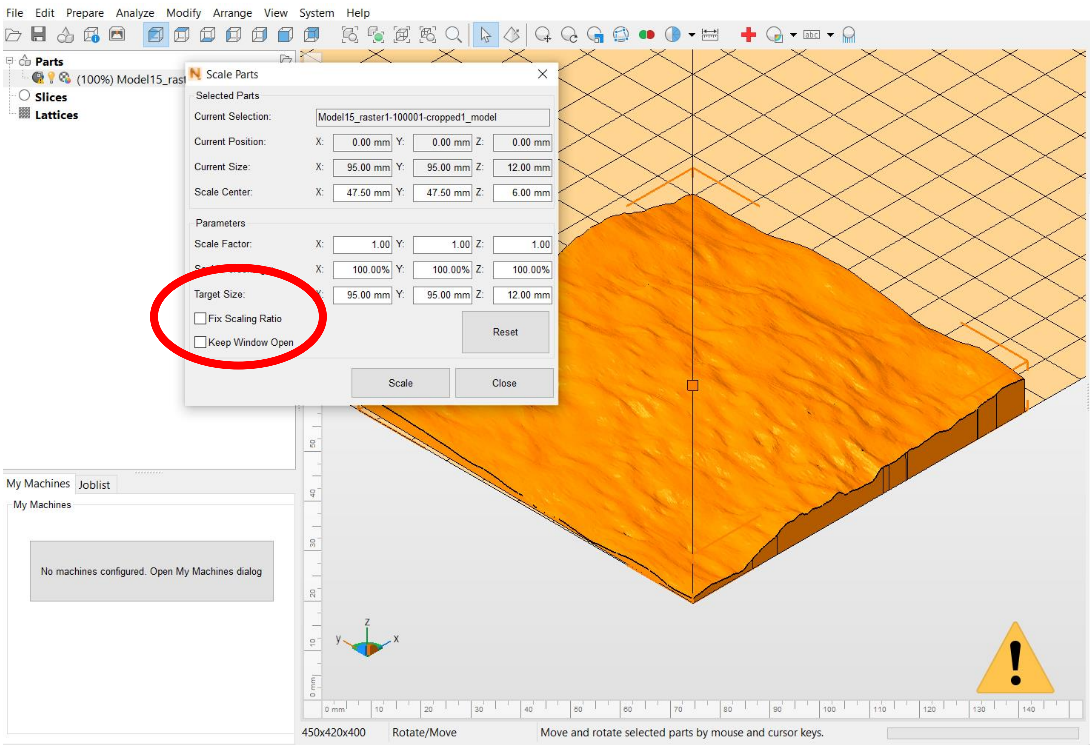

Figure 24: Scaling the models - Fix scaling ratio must be removed

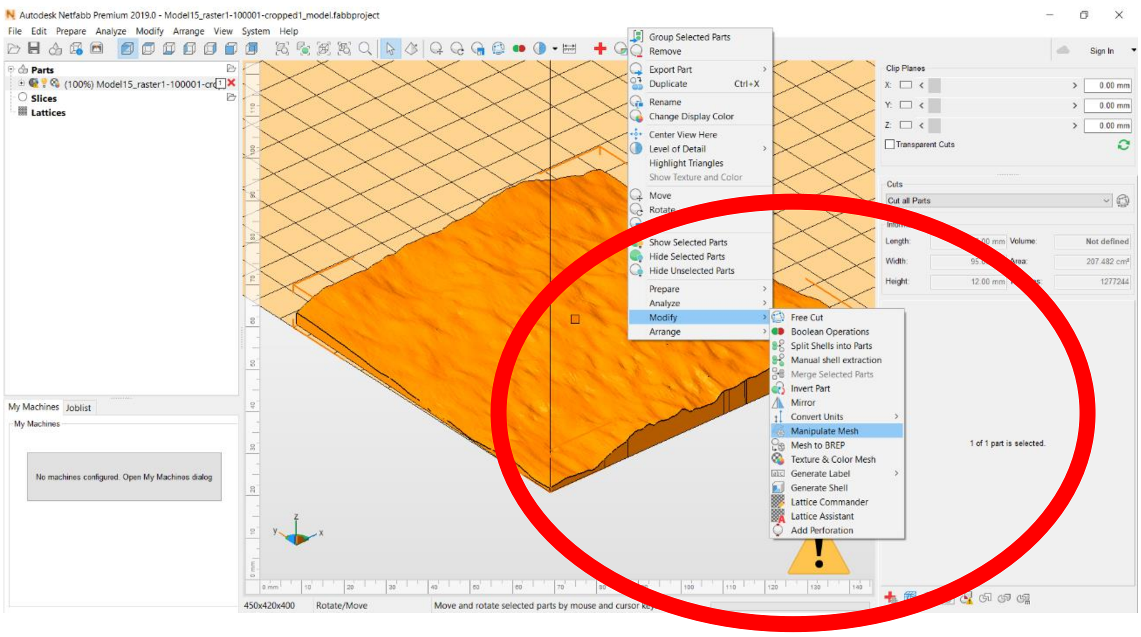

Figure 25: Manipulating the mesh for the smoothing

3.2.5 Workflow Step 5 – Physical Model

3.2.5.1 Requirements on Physical Model

The main requirement for this study, was to reproduce the rock surface into 3D printed or milled models to ensure that every participant of the survey has the same conditions within the roughness classification since natural rocks are brittle and could break when the survey is executed. One of the requirements was that the generated models show a rock like surface and that the surface feels rock-like. The feeling of the model surface plays a prominent role for the classification with ÖNORM EN ISO 14689-1.

3.2.5.2 Model Production by Milling

A three-axis milling machine was used to generate the physical models from SIKA-450 material. Rotary cutters are used to remove material from a model or workpiece, by feeding the model to an angle to the axis of the tool. The three-axis milling is one of the most used milling techniques. It can be used for automatic operation, drilling holes, cutting sharp edges, and milling slots. The model is generated when the cutter rotates at high speeds and feeds step by step the workpiece or model into the rotating cutter. The material from the model is cut away, and the desired shape is created at the end of the cutting steps. The three-dimensional surface contours are typically used for also milling parts which are not axially symmetric. There are very important parameters for the correct milling, for example: cutting feed, cutting speed, spindle speed, feed rate, axial depth of cut and radial depth of cut (Custompartnet, 2020).

3.2.5.3 Model Production by 3D Printing

Although there are different types of 3D printing, for this thesis Fused Deposition Modelling (FDM) was the one the focus was put on. The printing with FDM printers uses a thermoplastic filament, which gets heated up until to its melting point. After that it get extruded, layer by layer, to create a three-dimensional object. For 3D printing there are a few parameters which have a huge impact on the costs and stability for example the infilling and layer thickness. As shown in Figure 26, there are a few options of infilling, dependent on the designated use of the printed models. (Melnikova, et al., 2014)

To create a model with a FDM printer a stl- or cad- (computer-aided design) data format and a 3D printer is needed. The models manufactured for this master thesis were generated based on stl-files. A reason why 3D printing was considered was the rock filament, which seemed promising for physically replicating natural rock surfaces.

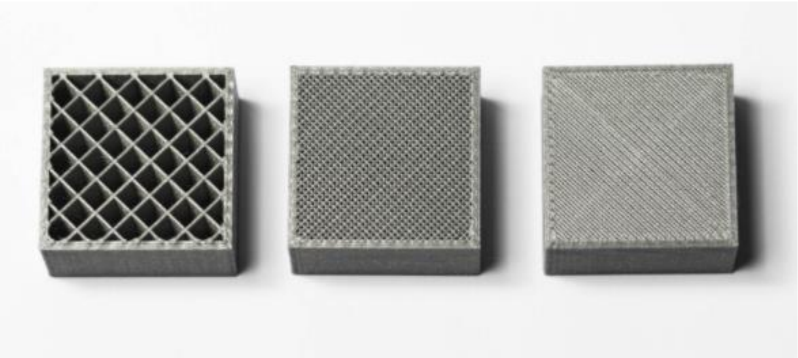

Figure 26: Infilling options with 3D printing (O'Connell, 2020)

3.2.5.4 Milling vs. 3D Printing

In a first step the two methods were compared by producing a test sample for both methods. After comparing the printing time, cost factor and the surface quality, the milling method was chosen. The cost factor and printing or milling time are almost the same, therefore the decision was made by the surface quality only. The milling samples are looking more natural and the model surfaces look closer to a real rock surface. It needs to be mentioned that both methods did not show a perfect resolution compared to the original samples. The general information of the two manufacturing processes is mentioned in Table 1.

Table 1: General Information for Milling and 3D printing

Milling	**3D Printing**
Printing time: 8 hours for 12 models	**Printing time: 9 hours for 12 models**
18 € -25 € per model with machine time, material and personnel costs	**12 € - 30 € per model with machine time, material**
SIKA-M450	**PLA print**
More natural looking surface	**Surface with contour lines**

Figure 27:Model generated by 3D printing

Figure 28:Model generated by milling

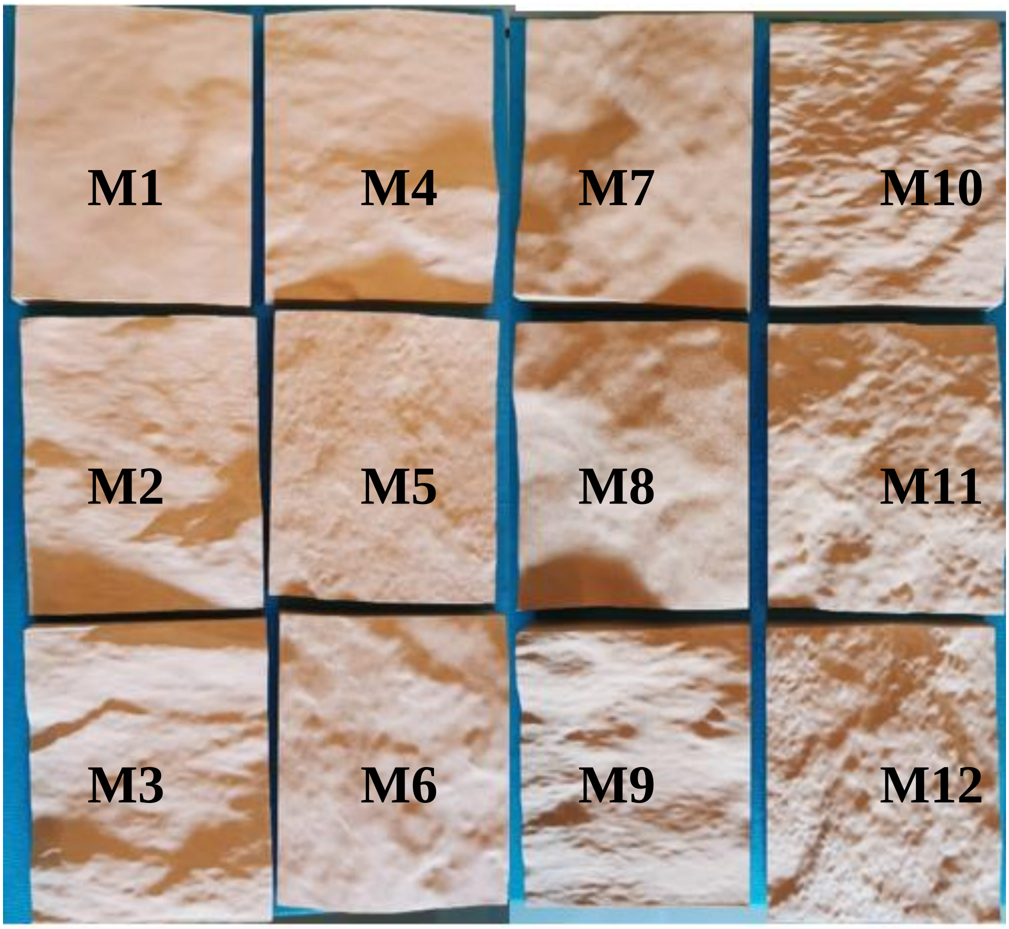

Figure 29: 12 final milled models, which were used for the present survey.

4 Survey and Evaluation of Results

4.1 Survey Goals

As previously mentioned, a major part of the present work is the comparison of two roughness classification systems by letting the survey participants classify the manufactured artificial models. Therefore, a survey was started at the Graz University of Technology and Karl Franzens University Graz, where two types of classifications, on the one hand the ÖNORM EN ISO 14689-1 and on the other hand the roughness estimation with the Barton comb, were compared. Both classification types are depending on the observers own perception, hence this study investigates how big the variability of classification is, if different observers classify the same samples.

4.2 Definition of Target Groups

In total thirty participants of three different professions attended the survey. The first group is represented by geologists, the second by civil engineers and the third one by students who study geology or civil engineering. The three different groups were chosen to estimate if the profession has an impact on the variability of roughness estimation and secondly if the working experience led to a lower scatter range in the classification.

4.3 Design of the Questionnaire

The survey for the roughness classification with the Barton comb plus the JRC and the (ÖNORM EN ISO 14689-1, 2004)included a short introduction for the participants about the aim of the survey and an explanation about roughness classification. The survey was executed in German, also the questionnaire was written in German. Before the observers classified the 12 different models, three questions needed to be answered to retrieve information on the participant's profession and working experience in years and to find out if they work with roughness estimation on a daily basis. The participant executed the classification of the models with the Barton Comb method and the ÖNORM EN ISO-14689-1.

For the estimation of the roughness, two attachments, typical roughness profiles and JRC ranges and explanation and the extract 4.3.3.5 from ÖNORM EN ISO-14689-1, were handed to the participants. The attachments can be found in the appendix. The remaining questions included the selection of a method for, in their opinion, easier, or more effective way to classify the roughness and their own way of estimating the roughness of a surface. The last questions intended to give a new perspective of roughness estimation.

4.4 Survey Procedure and Survey Period

The survey was executed at the Graz University of Technology. Due to the circumstances caused by the Coronavirus the survey could not be realized at other places like private offices or at construction zones. The survey started in June after the models were cut and was finished in July 2020. Every participant conducted the questionnaire on his or her own. The duration of every questionnaire was dependent on the participants and took about 30-70 min per participant.

4.5 Result Evaluation

4.5.1 Work Experience and Method Preferences

As already mentioned before, the question if the work experience has an impact on the results was of great interest, therefore the participants confirmed their profession and work experience in years and if they work with roughness estimation on a daily basis. Six out of ten geologists confirmed a work experience of over 15 years, whereas three out of those six have more than 20 years of experience. Only one out of ten civil engineers has an experience over 20 years, the remaining 9 have an experience of two to four years. Seven out of ten students are in their master’s programme, the remaining three are in their bachelor’s programme. It needs to be mentioned that only one out of 30 participants work with roughness estimation daily. The question after the, in their opinion, easier to handle estimation system was answered with 67% for the (ÖNORM EN ISO 14689-1, 2004), only 10% of the participants chose the Barton Comb method and the remaining 23% decided that none of the methods were suitable for the roughness classification. (see Figure 30)

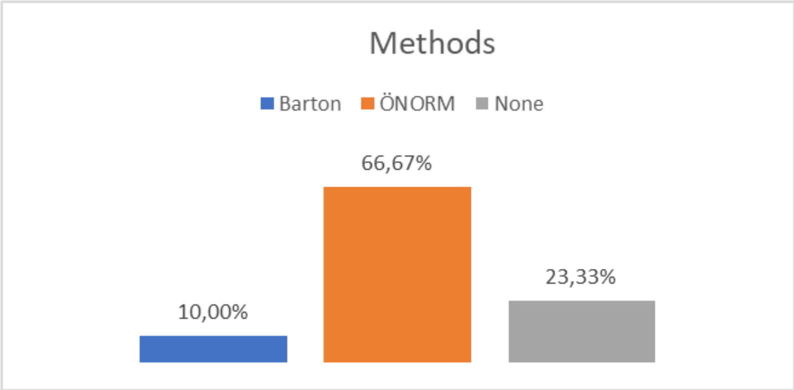

Figure 30: Selection of preferred method for roughness estimation

4.5.2 Evaluation of the Results from the Classification using Barton's Comb

In the following chapter the results of the survey are presented. In the first step the results of the Barton Comb are discussed and in a second step the ÖNORM results are presented and described. Both roughness classification methods are evaluated as column diagrams. Some examples for the corresponding models are shown in the appendix (Model M3 and Model M9). The results are shown in percentage.

For the evaluation of the Barton Comb method, the results of the survey were analysed and transformed into the corresponding JRC ranges. The JRC was not identified by the survey attendants directly but was derived from the roughness profile (1-10) which was selected by each attendee. If, for example, a participant selected the roughness profile 3 for the model M1 it results in JRC ranging from 4-6. Further, the results are presented for each profession.

The results of the model M1 are shown in Figure 31. The JRC varies for all tested groups. 10% of geologists determined the JRC 6-8, 8-10 and 12-14, whereas 20% determined a JRC of 2-4 and 50% identified model M1 with a JRC of 4-6. 40% of civil engineers selected JRC 4-6 for model M1, whereas only 10-20% choose JRC 2-4, 6-8, 8-10 and 10-12. The groups of students show the highest number of agreements for the model M1. 70% of students determined a JRC of 4-6. 10% selected a JRC of 2-4, 6-8 and 8-10.

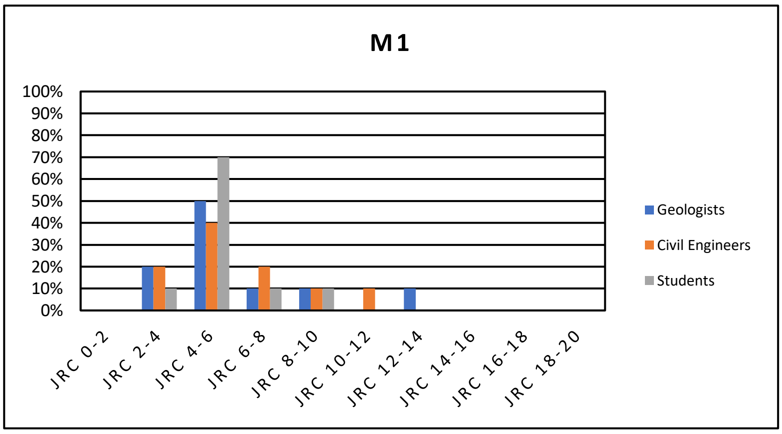

Figure 31: Results of M1, shown as column diagram.

The results of model M2 are presented in Figure 32. The results are showing a higher variety compared to model M1. Eight out of ten possible joint roughness coefficient ranges were determined. The highest correlation is reached by the group of students. 60% agreed on a JRC of 8-10 whereas only 40% of geologists and 30% of civil engineers complied on the same JRC of 8-10. Only 10-20% determined a JRC of 2-4, 4-6, 6-8, 10-12, 12-14, 16-18 and 18-20.

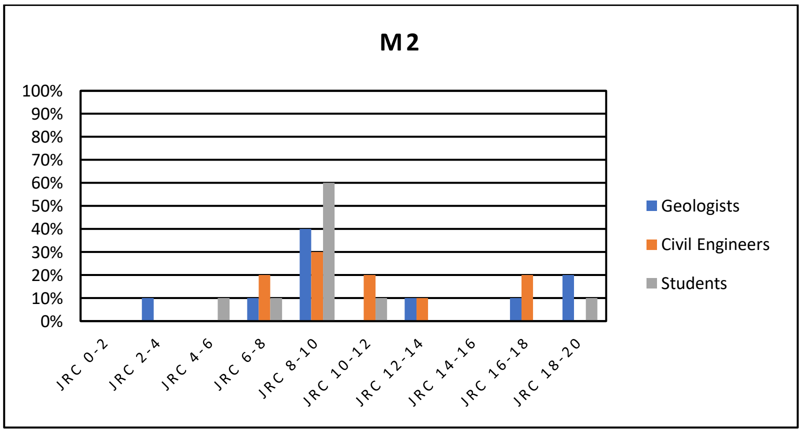

Figure 32:Results of M2, shown as column diagram in percent.

Figure 33 is showing the JRC values for model M3. As previously described the highest correlation is shown by the group of students. 70% identified the JRC with 10-12. 10% of students classified JRC 4-6, 8-10 and 12-14. The highest correlation for the profession of geologists is presented by 40% for a JRC of 10-12. 30% of geologists agreed on a JRC of 12-14 and 10% selected a JRC of 4-6, 8-10 and 14-16. 40% of civil engineers determined a JRC value of 12-14 for model M4, 20% classified a JRC of 2-4 and 10% a value of 14-16, 16-18 and 18-20.

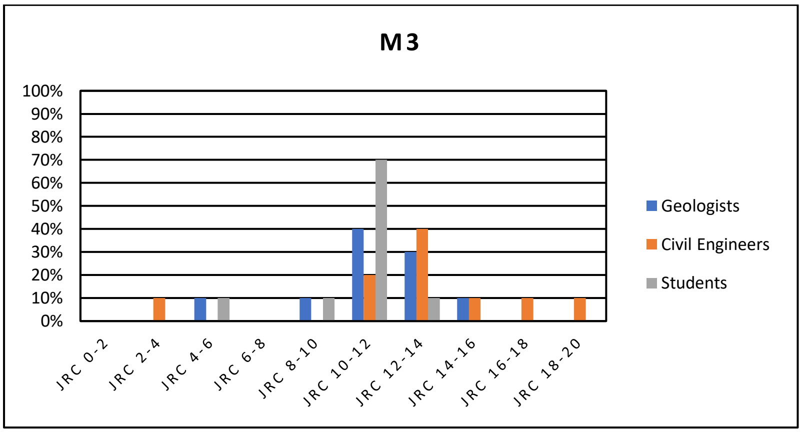

Figure 33:Results of M3, shown as column diagram in percent.

The JRC values for model M4 are presented in Figure 34 below. The highest correlation is represented by the group of civil engineers. 40% selected profile lines corresponding to a JRC range of 14-16. 30% of geologists and students agreed on a JRC value of 10-12 and 14-16 for model M1. 10- 20% of geologists selected a JRC value of 0-2, 4-6 and 12-14. 10-20% of civil engineers classified model M5 with a JRC of 4-6, 6-8, 8-10, 10-12 and 12-14. 20% of students selected a JRC of 8-10 and 12-14. Again, the high variety of JRC values is showing the subjective way of roughness estimation by using the Barton Comb.

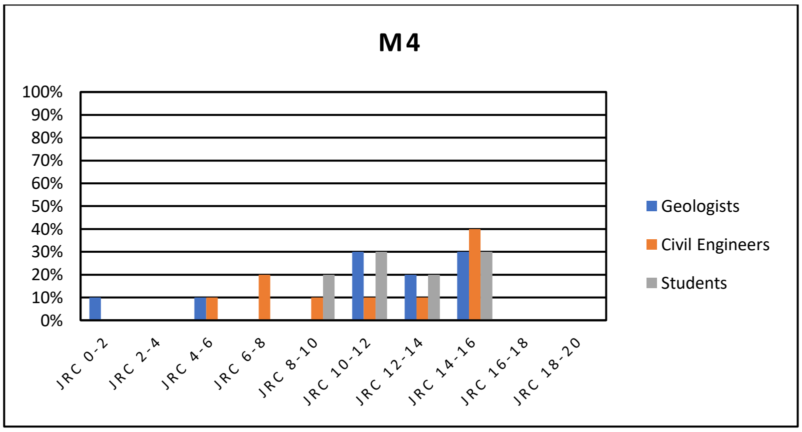

Figure 34: Results of M4, shown as column diagram in percent.

Figure 35 is showing the results in terms of JRC values for model M5. The JRC values determined by the geologists show wide variations. Again, under 50% of geologists agreed on a JRC value for the model M5. 10% or 20% selected the values 2-4, 4-6, 6-8, 10-12 and 12-14. The highest agreement was represented by the JRC of 8-10, 30% of the asked geologists determined this range. The group of civil engineers show a similar variation as the Geologists. Only 40% agreed on the JRC value of 14-16. The remaining 60% is divides on the values of 4-6, 6-8, 8-10, 10-12 and 12-14. The highest similarity in the evaluation of the JRC value is represented by the group of students. 50% agreed on the value between 8-10. The remaining 50% are split into the JRC of 4-6, 6,8 and 12-14.

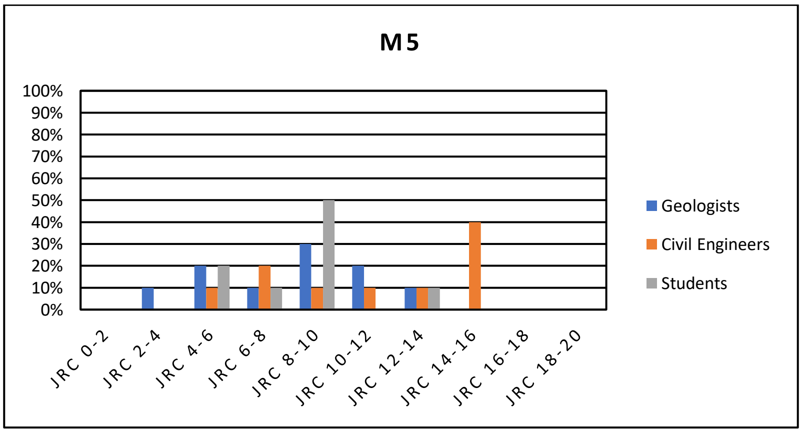

Figure 35:Results of M5, shown as column diagram in percent.

The JRC values for model M6 are presented in Figure 36 below. 40% of geologists and civil engineers agreed on the JRC value of 8-10, whereas only 20% of students picked this range. 30% of geologists determined the JRC value of 4-6, the rest of 30% are split into the value of 10-12 and 12-14. 40% of civil engineers agreed on the values 8-10 and 10-12, the remaining 20% are split into the values of JRC 12-14 and 16-18. Again, the highest similarity is represented by the group of students. 80% picked the JRC value of 14-16 and 20% the value of 8-10.

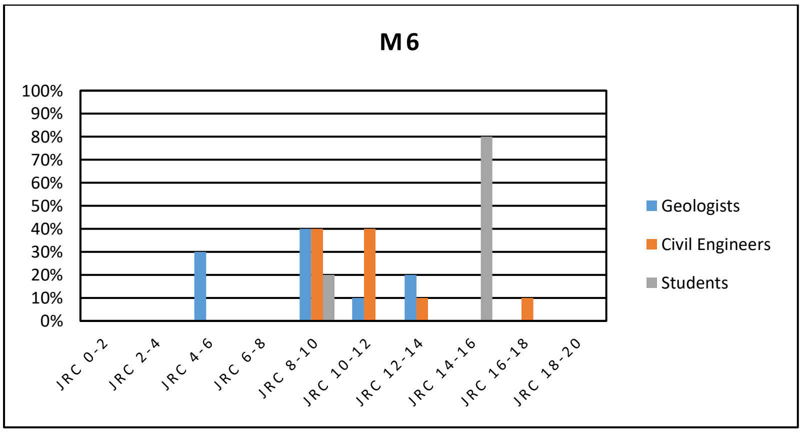

Figure 36:Results of M6, shown as column diagram in percent.

In Figure 37 the results of the JRC ranges for the model M7 are shown. 50% of geologists classified a JRC value between 10-12, 20% the values 4-6 and 16-18 and 10% a value of 8-10. The estimation of the JRC values from the civil engineers is split into each 20% for a JRC of 4-6, 8-10, 10-12 and 14-16. Each 30% of geologists picked the JRC value between 8-10 and 14-16. The rest amount of 40% is split up into the values of 10-12 and 12-14.

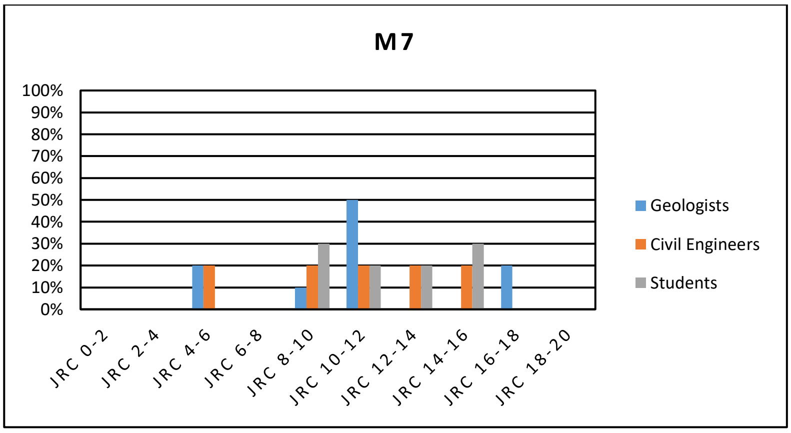

Figure 37:Results of M7, shown as column diagram in percent.

In Figure 38 the JRC values for model M8 are pictured. Once again, the opinion of the geologists is very split. 10% classified the values 4-6, 8-10 and 10-12, 40% divided the model into a JRC value of 12-14 and 30% a value of 14-16. 60% of civil engineers and Students agreed on the value of 14-16 and 20% on 12-14 for model M8. 20% of students classified M8 with the JRC of 10-12. 10% of civil engineers graded the model into the JRC values 10-12 and 16-18.

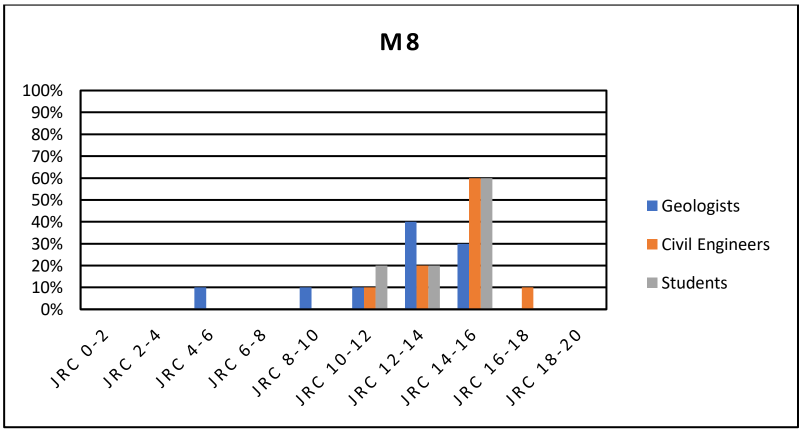

Figure 38:Results of M8, shown as column diagram in percent.

The JRC values for model M9 are presented in Figure 39 below. 40% of geologists classified M9 with a JRC value of 14-16, 20% with a value of 10-12 and 14-16 and 10% determined the values 4-6 and 18-20. 60% of civil engineers classified a value of 16-18, 20% a value of 10-12 and 10% for the values of 12-14 and 14-16.

40% of students agreed on a JRC of 14-16, 30% on a JRC of 16-18 and each 10% for a value of 8-10, 12-14 and 18-20.

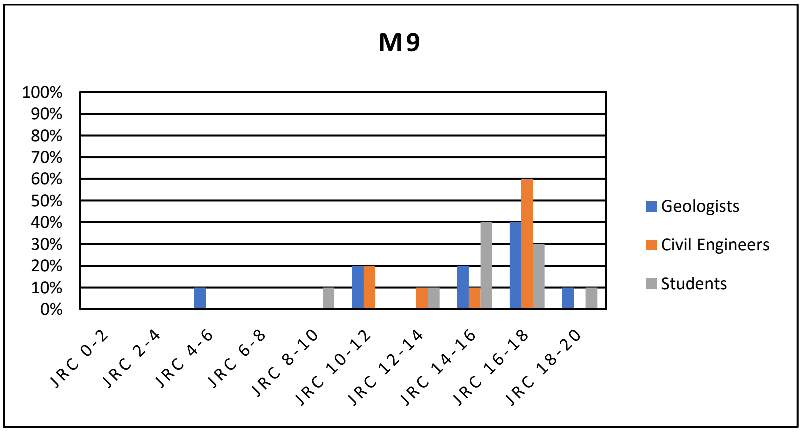

Figure 39: Results of M9, shown as column diagram in percent.

The evaluation of the JRC for model M10 is shown in the Figure 40. 40% of geologists and students agreed on a JRC of 16-18. 30% of geologists and civil engineers classified the sample M10 with a JRC of 18-20. Rest of the values show a large scatter range and show 10% for the JRC of 4-6 by geologists, 10% for the JRC of 6-8 by civil engineers and students and 10% of civil engineers and students determined a JRC of 10-12. 20% of the students agreed on a JRC of 8-10 and 20% of geologists and civil engineers on the JRC of 12-14 for the model.

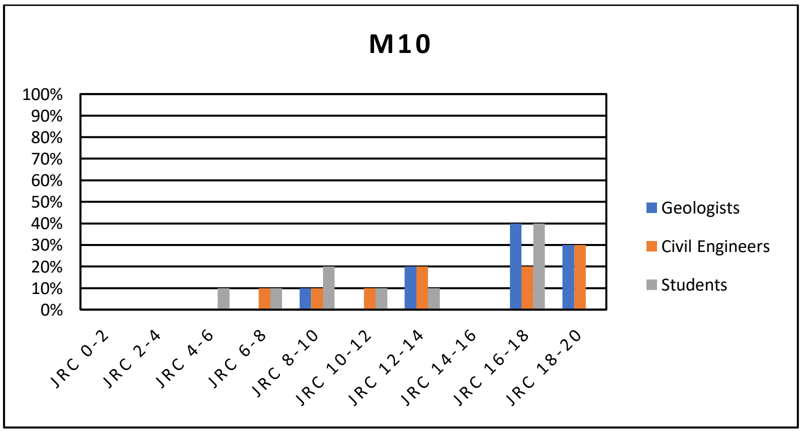

Figure 40: Results of M10, shown as column diagram in percent.

The JRC values for model M11 are presented in Figure 41 below. The classification by the geologists has resulted as followed: 30% selected the JRC of 14-16, each 10% divides the model into the JRC values 6-8, 10-12, 12-14, 16-18 and 18-20. 30% of civil engineers agreed on a JRC of 14-16 and 20% on a value of 8-10 and 12-14, 10% classified the range of 4-6, 10-12 and 14-16. 40% of students divides the sample into a JRC of 8-10, each 20% into a JRC of 14-16 and 16-18 and 10% each agreed on a JRC of 6-8 and 12-14.

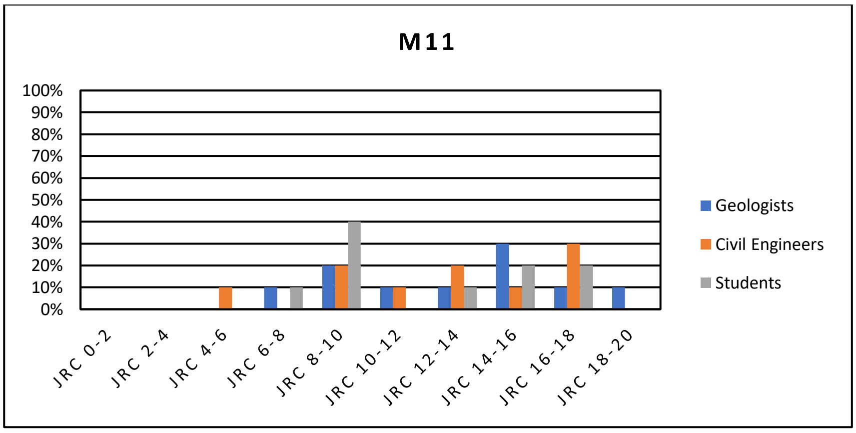

Figure 41:Results of M11, shown as column diagram in percent.

Figure 42 below is showing the results of the JRC estimation for model M12. 30% of geologists classified the model with a JRC of 12-14, 20% with a value of 8-10, 14-16 and 16-18. 10% determined the JRC range of 18-20. 30% of civil engineers estimated the sample with a JRC of 10-12 an 18-20. The remaining 40% is split into four JRC values, 8-10, 12-14, 14-16 and 16-18. 30% of students agreed on a JRC of 8-10 and 18-20, 20% on the other hand classified the sample with a JRC of 6-8 and 16-18.

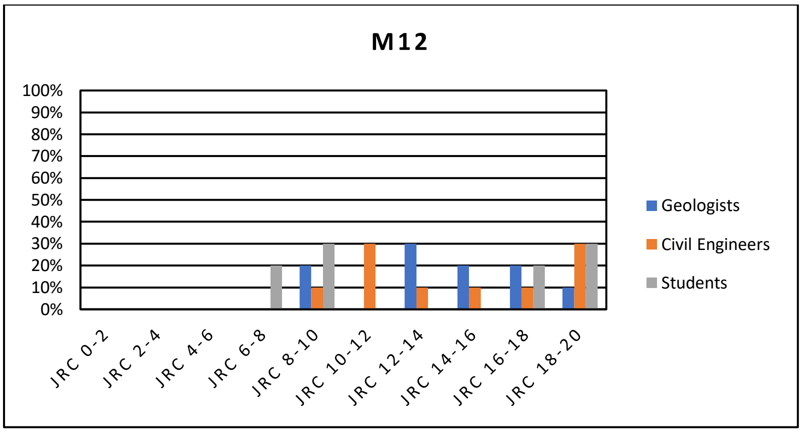

Figure 42: Results of M12, shown as column diagram in percent.

4.5.3 Evaluation of the Results from the Classification acc. to ÖNORM EN ISO 14689-1

The results of the roughness estimation by using the ÖNORM EN ISO 14689-1 (referred as ÖNORM in the diagrams) is presented in the figures below. The classification is split into the small-scale features which are classified into either rough or smooth and into the large-scale features which are divided into undulating, wavy or flat. All results are shown in percentage values and as column diagrams.

Figure 43 is showing the results for model M1. For the large scale features the results show that 100% of students and civil engineers agreed on a flat surface and 90% of geologists on a flat and 10% on a wavy surface. In the right diagram the results for the small-scale features are presented and can be summed up as follows: 100% of geologists and students classified M1 as smooth, whereas 90% of civil engineers estimated the sample as smooth and 10% as rough.

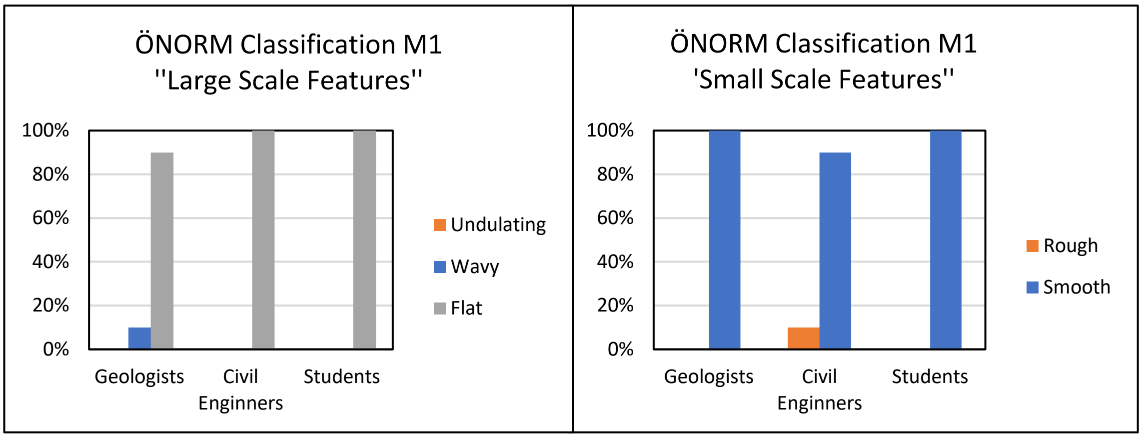

Figure 43: Results for large- and small-scale features in a column diagram – M1

In the following Figure 44, the results for model M2 are presented. On the large scale 80% of geologists agreed on a wavy and 20% on an undulating surface. 70% of civil engineers identified M2 as wavy and 30% as undulating. 60% of students rated the model as wavy and each 20% as undulating and flat. 50% of geologists classified M2 as rough and 50% as smooth, 70% of civil engineers as rough and the remaining 30% as smooth and 60% of students estimated the sample as rough and 40% as smooth on a small scale.

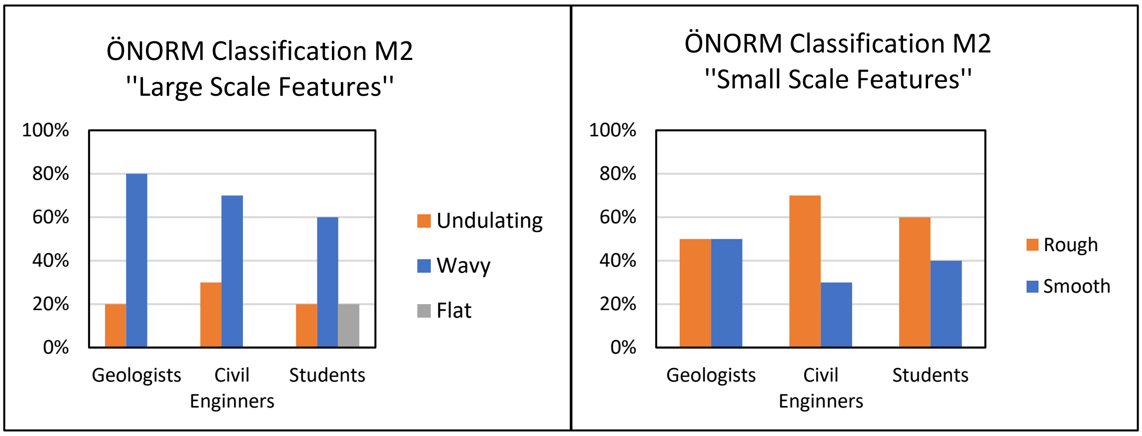

Figure 44:Results for large- and small-scale features in a column diagram - M2

The results for the large scale and small-scale features for model M3 are shown in Figure 45. The results for the large-scale features are showing a scatter range between all the tested groups. 60% of geologists classified the sample as wavy, 30% as undulating and 10% as flat. 70% of civil engineers graded the model into undulating and 30% as wavy, whereas 70% of students rated the model into wavy and 30% into undulating. On a small scale 60% of civil engineers and students agreed on a classification of rough surface and 40% on a smooth surface. 60% of geologists classified M3 as rough and 40% as smooth.

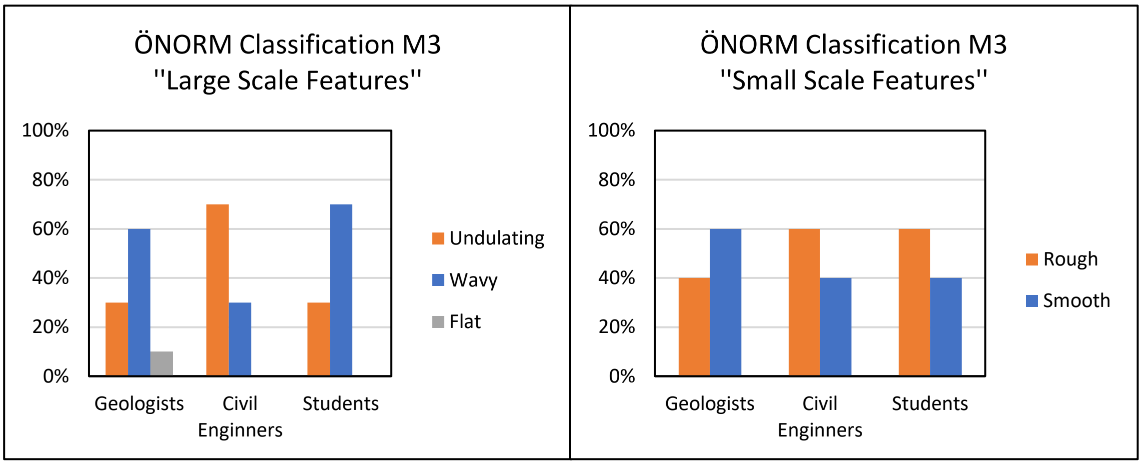

Figure 45:Results for large- and small-scale features in a column diagram – M3

Figure 46 is showing the results for the ÖNORM classification of model M4. On a large scale 100% of geologists, 80% of civil engineers and 90% of students classified the model as wavy, whereas only 20% of civil engineers and 10% of students rated the model as flat. 100% of geologists agreed on a smooth surface for sample M4. 70% of civil engineers classified the model smooth and 30% as rough. 80% of students graded M4 into smooth and the remaining 20% as rough.

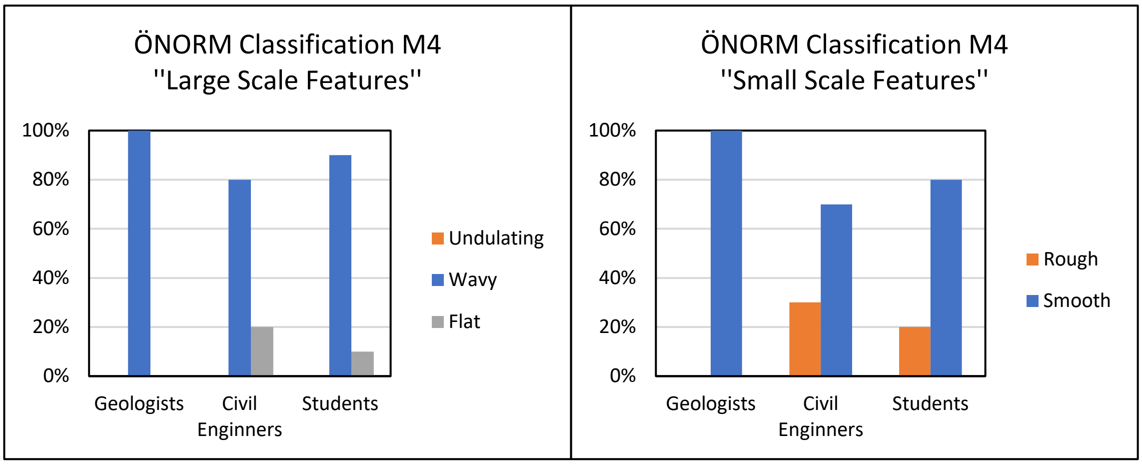

Figure 46:Results for large- and small-scale features in a column diagram – M4

The ÖNORM classification of model M5 is shown in Figure 47. 60% of geologists, 70% of civil engineers and 50% of students classified the sample as wavy, 10% of geologists, 30% of civil engineers and 20% of students as undulating, 30% of geologist and 30% of students as flat on a large scale. On a small scale 90% of geologists agreed on a rough surface and 10% on a smooth surface, 60% of civil engineers agreed on a rough and 40% on a smooth surface, whereas the classification of the students is split into 50% rough and 50% smooth.

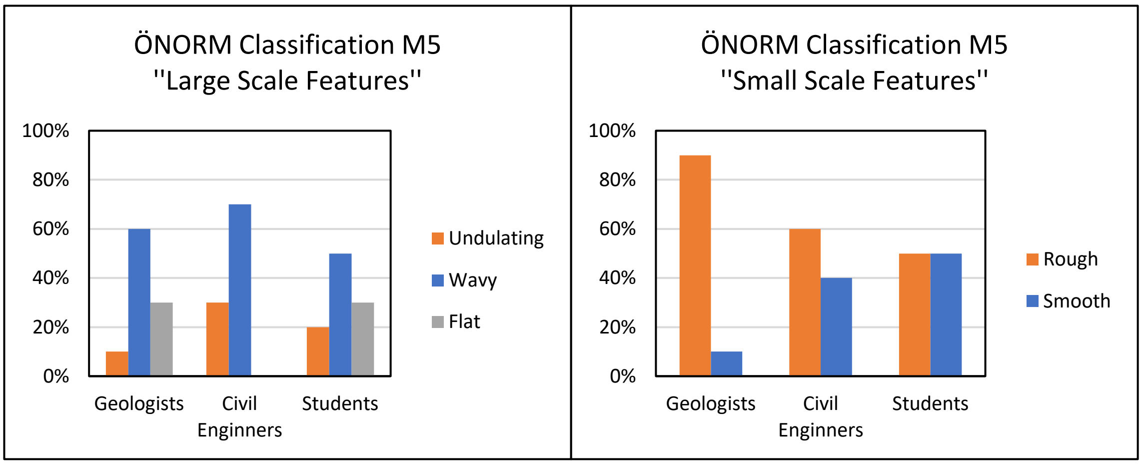

Figure 47: Results for large- and small-scale features in a column diagram – M5

In the following Figure 48, the results for model M6 are presented. On the large scale 100% of geologists agreed on a wavy surface. 90% of civil engineers identified M6 as wavy and 10% as flat. 90% of students rated the model as wavy and 10% as flat. 90% of geologists classified M6 as smooth and 10% as rough, 50% of civil engineers as rough and the remaining 50% as smooth. 70% of students estimated the sample as smooth and 30% as rough on a small scale.

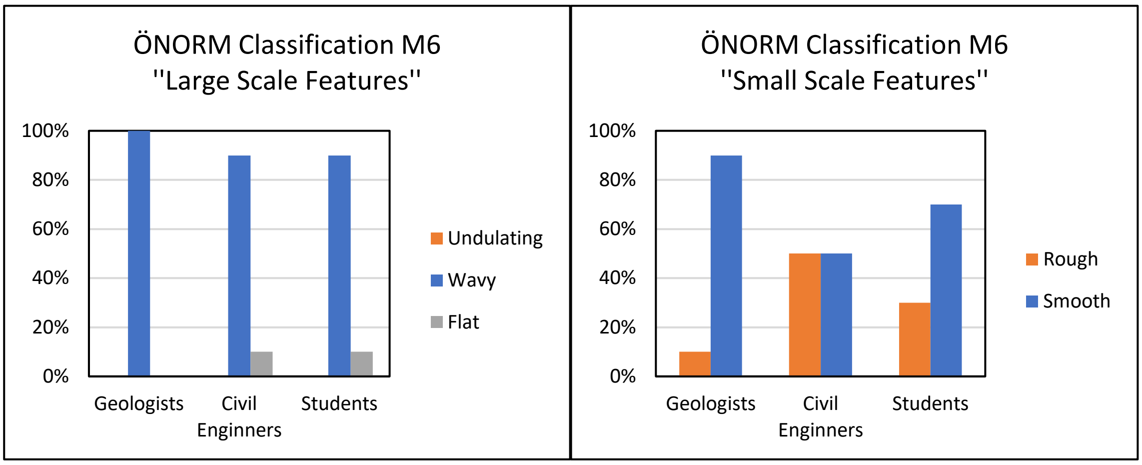

Figure 48:Results for large- and small-scale features in a column diagram – M6

Figure 49 is showing the results for the ÖNORM classification of model M7. 60% of geologists agreed on a wavy, 20% on an undulating and 20% on a flat surface. 100% of civil engineers classified the model as wavy. 80% of students graded M7 into wavy, 10% as undulating and 10% as flat. On a small scale 90% of geologists, 100% of civil engineers and 100% of students classified the model as smooth, whereas only 10% of geologists rated the model as rough.

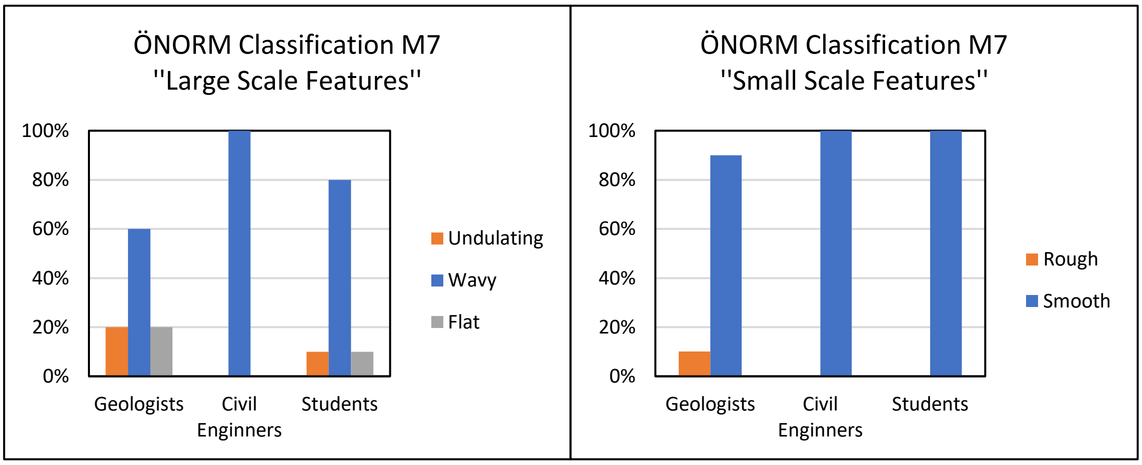

Figure 49:Results for large- and small-scale features in a column diagram – M7

In the following Figure 50, the results for model M8 are presented. On the large scale 80% of geologists and students agreed on a wavy and each 10% on an undulating or flat surface. 80% of civil engineers identified M8 as wavy and 20% as undulating. 80% of geologists classified M8 as smooth and 10% as rough, 100% of civil engineers as smooth and 80% of students estimated the sample as smooth and 20% as rough on a small scale.

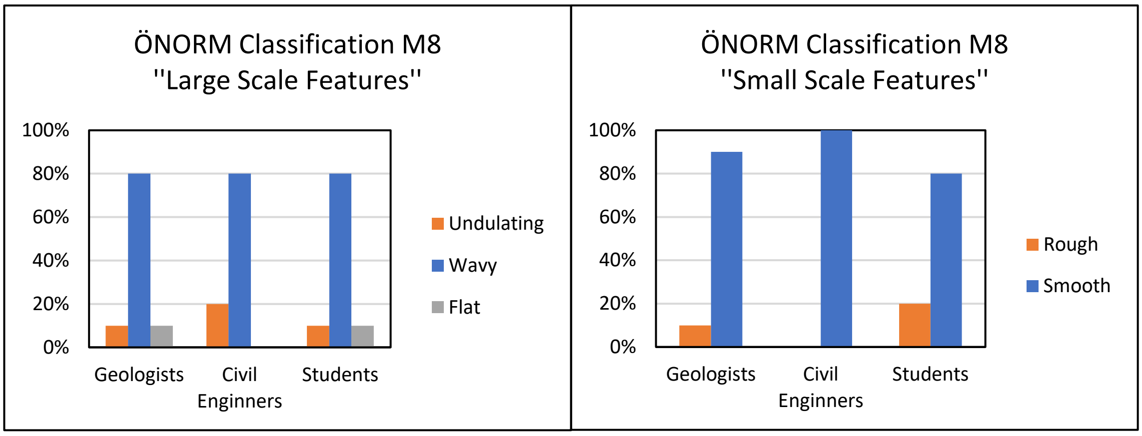

Figure 50:Results for large- and small-scale features in a column diagram – M8

The results for the large scale and small-scale features for model M9 are shown in Figure 51. 50% of geologists classified the sample as wavy and 50% as undulating. 70% of civil engineers graded the model into undulating and 30% as wavy, whereas 60% of students rated the model into undulating and 40% into wavy. On a small scale 80% of civil engineers and students agreed on a classification of rough surface and 20% on a smooth surface. 70% of geologists classified M9 as rough and 30% as smooth.

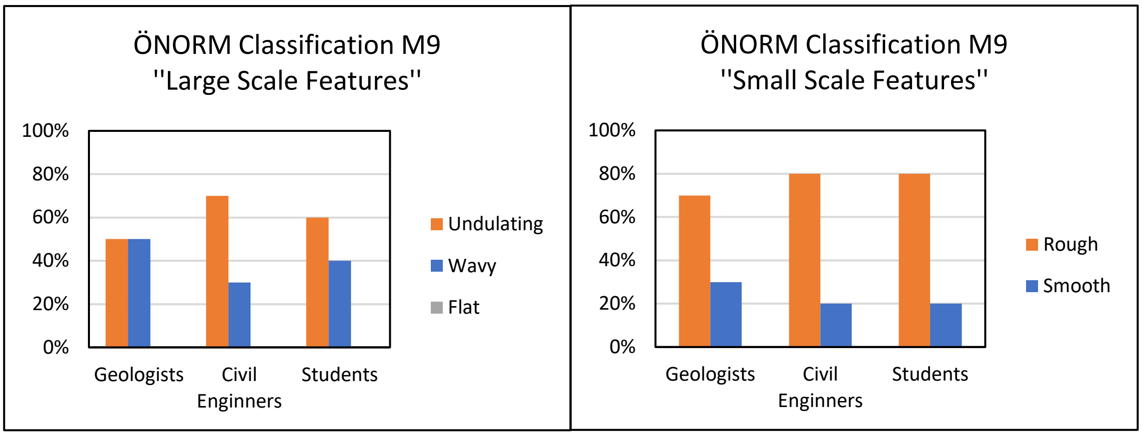

Figure 51:Results for large- and small-scale features in a column diagram – M9

In the following Figure 52, the results for model M10 are presented. On the large scale 70% of geologists agreed on an undulating and 30% on a wavy surface. 50% of civil engineers identified M10 as wavy and 40% as undulating and 10% as flat. 60% of students rated the model as undulating and 40% as wavy. 100% of geologists and students classified M10 as rough, 80% of civil engineers as rough and the remaining 20% as smooth and on a small scale.

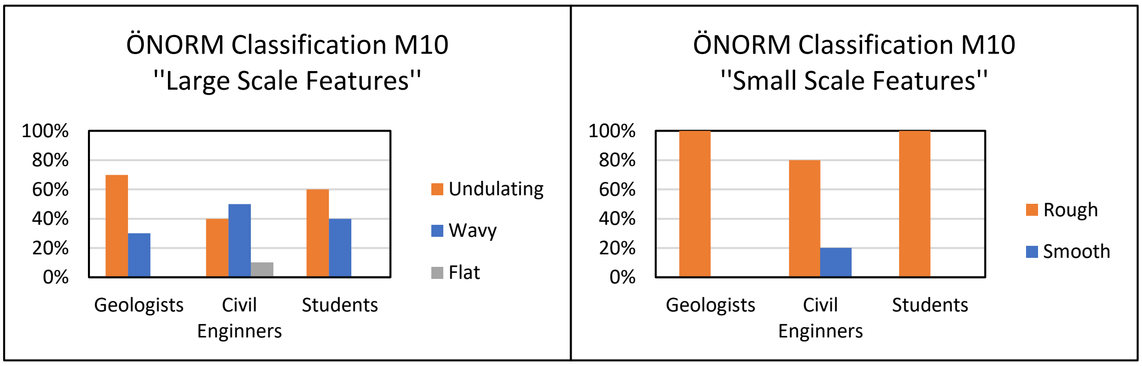

Figure 52:Results for large- and small-scale features in a column diagram - M10

In Figure 53 the results for model M11 are presented. On the large scale 70% of geologists agreed on an undulating and 30% on a wavy surface. 90% of civil engineers identified M11 as undulating and 10% as wavy. 60% of students rated the model as undulating and 40% as wavy. 80% of geologists and classified M11 as rough and 20% as smooth, 70% of civil engineers as rough and the remaining 30% as smooth and 100% of students agreed on a rough surface on a small scale.

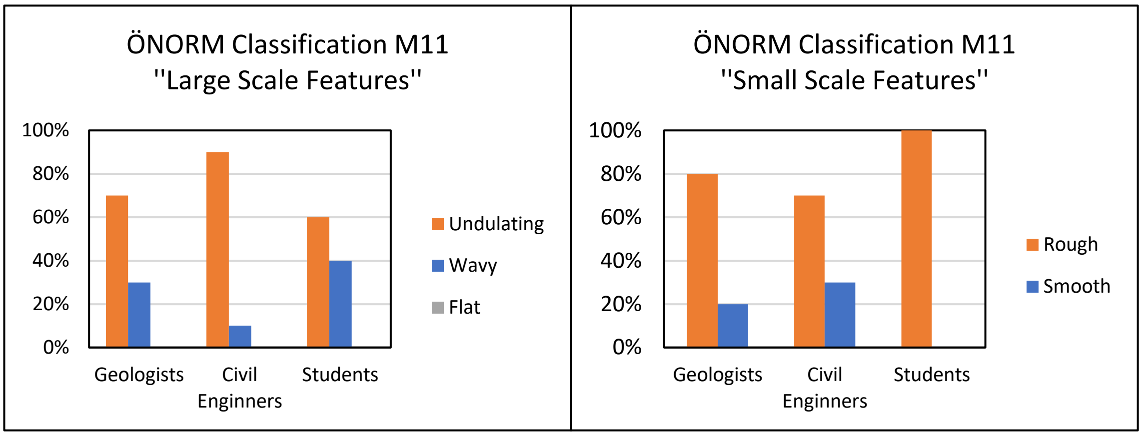

Figure 53:Results for large- and small-scale features in a column diagram - M11

In the following Figure 54, the results for model M12 are presented. On the large scale 70% of geologists agreed on an undulating, 20% on a wavy and 10% on a flat surface. 50% of civil engineers identified M12 as undulating, 40% as wavy and 10% as flat. 80% of geologists classified M12 as undulating and 20% as wavy. 70% of geologists identified the model as rough and 30% as smooth, 80% of civil engineers as rough and 20% as smooth. 90% of students estimated the model as rough and 10% as smooth on a small scale.

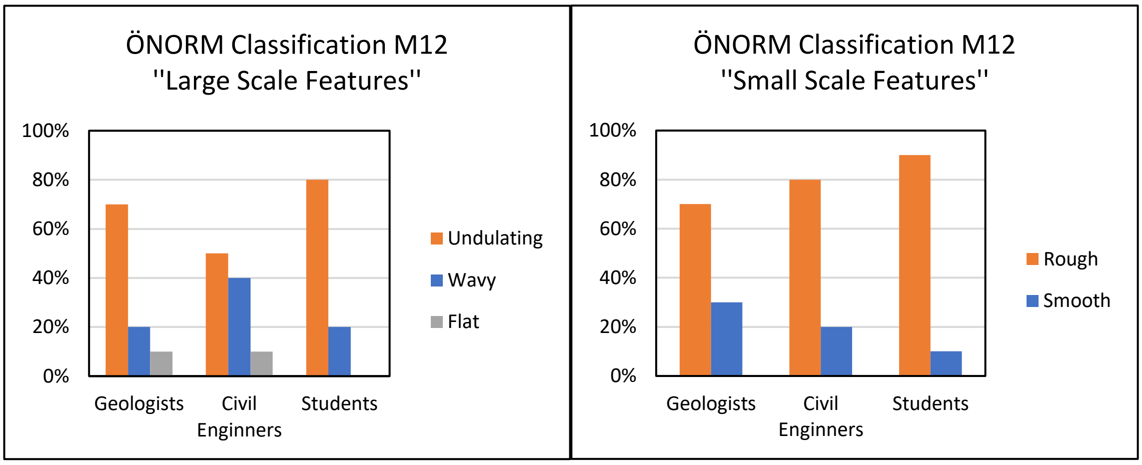

Figure 54:Results for large- and small-scale features in a column diagram - M12

4.6 Interpretation of Survey Results

In the following chapter the results of the roughness estimation using the Barton Comb and the EN ISO14689-1 are discussed and compared. Also, a comparison between the three different professions is made.

The results of the roughness classification with the Barton Comb are pictured in terms of corresponding Joint Roughness Coefficient ranges and are showing a disagreement for the JRC for all models. No model shows 100% agreement. All observer groups classified the samples by 6 to 8 different corresponding JRC ranges. Only the models M1, M2, M3, M8 and M9 show a conformity of 60-70%. For all other samples, the match is under 50%. The model with the biggest scatter range for the JRC range is M12. A maximum of 30% agreed on the same JRC ranges even though the models M12 and M11 originated from the same rock specimen. M1 and M3 represent the samples with the biggest matching rates of about 70%. Summarizing, the group of students showed the best correlation, 70% or under, when it comes to roughness classification with the Barton Comb. Geologists, who represent the group with the highest work experience, are showing a match of only 50% or under. The group of civil engineers show a maximum match of 60% for two samples (M8 and M9) the rest of the samples shows a conformity under 60%.

The results of the roughness classification using the ÖNORM is split into two scale features, the large scale on the one hand and the small scale on the other hand. In a first step the large-scale feature results are discussed. All groups show a match of at least 50%. Geologists reached a match of 100% for model M4 and M6, civil engineers for model M1 and M7 and students for model M1. For the estimation with the small scale the match of at least 50% for all groups was reached. Geologists reached an agreement of 100% for the models M1, M4 and M10, civil engineers for the model M7 and M8 and the group of students for model M1, M7, M10 and M11. Students and Geologists reached a match of 80% or more for 8 out of 12 models, whereas civil engineers reached 80% or more for only 5 out of 12 models.

Summarizing, the roughness classification using the ÖNORM EN ISO 14689-1 showed a higher match compared to the Barton Comb method. The Barton Comb match is under 50% and the ÖNORM match reached at least 50%. An agreement of 100% was reached for 6 out of 12 samples for the estimation of small-scale features, for 4 out of 12 samples for the large scale features of at least one observer group and 3 out of 12 samples for the large scale and small scale features for at least one observer group, on the other hand the classification with the Barton Comb did not reach a 100% agreement at all. The group with the lowest scatter range is represented by the group with the least working experience, by the students, for both estimation methods. It should be mentioned that the roughness estimation using the Barton Comb offers 10 potential roughness categories with corresponding JRC value ranges, whereas the ÖNORM method only offers 3 options on a large scale and 2 options on a small scale which have to be combined for the roughness classification. This fact could also lead to the higher scatter range using the Barton Comb method. Further it needs to be mentioned that about 66% preferred the ÖNORM EN ISO 14689-1 for roughness estimation and only about 10% choose the Barton Comb method. Most of the participants mentioned that the ÖNORM EN ISO 14689-1 is easier to handle. These numbers also match with the fact that the classification results using the ÖNORM EN ISO 14689-1 showed a lower scatter range. Barton only pictured 10 different possible profiles, which should be representative for all appearances of rock roughness's. The observer needs to match one of the estimated profiles only by comparing it to the corresponding roughness profiles suggested by (Barton and Choubey, 1977), although every roughness surface looks a different way and every rock is composed differently. On the other hand, the roughness estimation with the ÖNORM EN ISO 14689-1 is giving 3 different estimation parameters which are: a descriptive explanation of the nomenclature, the classification if it feels smooth or rough and the 6 profiles which are representing the roughness surface.

5 Conclusion and Outlook

5.1 Conclusion

The roughness classification by comparing two methods can be summarized as follows. The selection of suitable samples to generate a model with photogrammetry is an important step. In this master thesis the rock samples originated from the Semmering Basetunnel. Using mainly open-source software, beside Netfabb, lead to the number of programmes which were used in the end. In total four programmes, Meshroom, CloudCompare, QGis and Netfabb were needed to create a model. To minimize the number of software programmes and the time factor one can use licenced software like for example, “Sirovision’’. With this kind of software one can generate a model for 3D printing or milling with photogrammetry and no other software needs to be used. Also, finding the right method for printing or milling is an important step. One needs to consider the cost- and time-factor and the look of the sample. The ,,natural’’ rock needs to be represented by the models.

To sum up the results, the survey shows that both ways of roughness classifications do not lead to precise results with a low scatter range. It depends on the observers view of what feels smooth or rough, undulating, flat or wavy and what surface is reproduced and visually corresponding to the JRC profiles. Both classifications are dependent on the observer and do not represent an objective classification method. In summary it can be said that the roughness classification is dependent of the experience and profession of the observer. The survey showed that the group of students, who have the least experience, show the highest agreement. Summarizing the roughness classification using the ÖNORM EN ISO 14689-1 showed a higher match compared to the Barton Comb method. The Barton Comb match is under 50% and the ÖNORM match reached at least 50%. Just one out of the 30 participants works with roughness classifications on a daily basis. Due to the number of disagreements in roughness classification, which were demonstrated through this survey it is important to explore a more objective way of roughness classification in the future.

5.2 Outlook

For future roughness estimation it is important to minimize the influence of personal opinion and to find a more objective way of roughness classification. It is conceivable to extend this survey to a larger number of participants and to compare the traditional roughness estimation with only using photogrammetry or laser scanning. The fact that traditional roughness estimation by using the Barton Comb or the ÖNORM EN ISO 14689-1 lead to subjective results and require direct contact with the rock it is imaginable that the trend of roughness classification in future will probably be using digital photogrammetry or laser scanning. Due to technological advances digital photogrammetry and laser scanning lead to high resolution 3D models and provide a perfect base for an objective way of rock mass characterization. The joint roughness can be obtained directly from the 3D model and not like usually measured with a Barton comb. Figure 55 shows an example of a joint roughness extracted high resolution digital photogrammetry surface model and the comparison with the standard profile line combined and measured with a Barton comb. As shown in Figure 55 the differences are not big between this methods but with a high resolution digital photogrammetry with smart phones, tablets or digital cameras combined with an app or a software the personal opinion or the personal feeling within the roughness estimation gets eliminated and the scatter range will be reduced (Francioni, 2019).

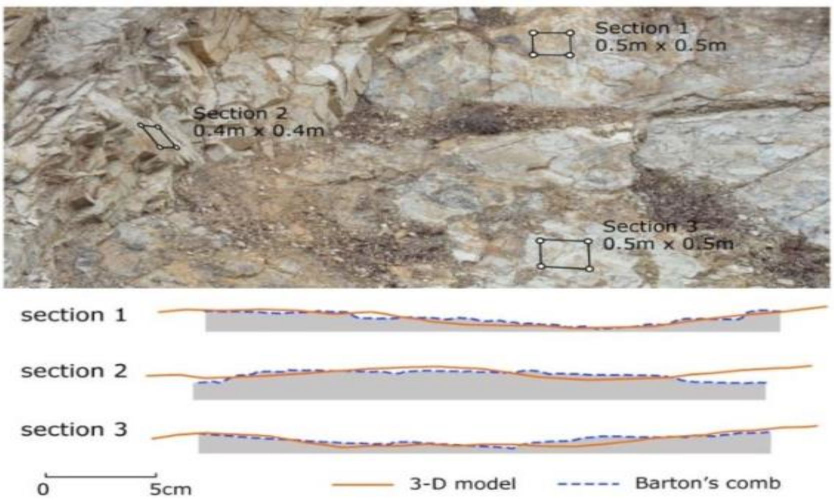

Figure 55 Comparison of roughness profiles between a 3D model and the Barton Comb method. (Dong Hyun Kim, 2013)

6 List of literature

Aspose Pty Ltd, 2001-2020. Fileformat. [Online]
Available at: https://docs.fileformat.com/cad/stl/
[Accessed on 12.10.2020].

Athan, T. &. B. R., 2020. [Online]
Available at: https://docs.qgis.org/3.10/en/docs/user_manual/index.html [Accessed on 17.06.2020].

Barton, N.R and Bandis, S. (2017) Nonlinear shear behavior of rock joints using a linearized implementation of the Barton-Bandis model. Journal of Rock Mechanics and Geotechnical Engineering; 1-11.

Barton, N.R. (1977) The Shear Strength of Rock Joints in Theory and Practice. Rock Mechanics, 10, 1-65.

Beer, A. J. (2002) Technical Note Estimation of the Joint Roughness Coefficient (JRC) by Visual Comparison. Rock Mechanics and Rock Engineering,; 65-74.

CloudCompare, C. C. Cloud Compare v2.6.1. Available at https://www.danielgm.net/cc/[Accessed on 17.06.2020].

Custompartnet, 2020. Custompartnet. [Online]
Available at: https://www.custompartnet.com/wu/milling. Accsessed
[Accessed on 10 10 2020].

Eberhardt, S. M., Stead, D. , Morrison, T. (2007) Rock Mechanics: Meeting Society's Challenges and Demands. Rock Mechanics Symposium, Vancouver Canada.

Francioni, M., Simone, M. , Stead, D. , Sciarra, N. , Mataloni ,G. , Calamita, F. (2019). A New Fast and Low-Cost Photogrammetry Method for the Engineering characterization of rock slopes. Remote sending article.

Guy, D. (2020). Definition of Raster Image. [Online]
Available at: https://www.photokonnexion.com/definition-raster-image/ accessed on 10.10.20 [Accessed 10 10 2020].

Haneberg, W. C. (2007) Directional roughness profiles from three-dimensional photogrammetric or laser scanner point clouds, Rock Mechanics: Meeting Society's Challenges and Demands Rock Mechanics Symposium, Vancouver Canada.

ISRM, (1978) Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts.

Kim, D.H., Gratchev I., Propat, G.V. (2013) The determination of Joint roughness coefficient using three dimensional models for slope stability analyses;Slope Stability;Australian Centre for Geomechanics, Perth.

Knödel, K. , Lange, G., Voigt, H.J. (2007)Environmental Geology, Handbook of Field Methods and Case Studies.

Konecny, G. (1984) The photogrammetric camera experiment on spacelab 1. Bildmessung und Luftbildwesen (3a), 195–200.

Lanthony, Y. (2019). Turtorial: Meshroom for Beginners. Available at: https://sketchfab.com/blogs/community/tutorial-meshroom-for-beginners/ [Accessed on 15.08.2020].

Lebsack, M. (2017). Netfabb User Manual. Available at: https://knowledge.autodesk.com/support/netfabb/learn-explore/caas/simplecontent/content/netfabb-user-manual-german-deu.html [Accessed on 16.08.2020].

Maerz, N.H., Franklin, J. A., Bennet, C. (1990) . Joint roughness measurement using shadow profilometry. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts,

Melnikova, R., Ehrmann, A. (2014) Finsterbusch, K.3D printing of textile-based structures by Fused Deposition Modelling (FDM) with different polymer materials,

Meshroom Manual, (2015). Meshroom Manual. [Online]
Available at:
https://meshroommanual.readthedocs.io/en/latest/tutorials/sketchfab/sketchfab.html
[Accessed 17 05 2020].

O'Connell, J. 3D Printing Infill: The Basics Simply Explained, Available at: https://all3dp.com/2/infill-3d-printing-what-it-means-and-how-to-use-it/[Accessed on 15.10.2020].

ÖNORM EN ISO 14689-1. (2004) Geotechnische Erkundung und Untersuchung- Benennung, Beschreibung und Klassifizierung von Fels- Teil 1: Bennenung und Beschreibung.

Palmström, A. (2001) In-Situ Characterization of rocks. Chapter 2: Measurement and characterization of rock mass jointing.

Poropat, G. (2009) Measurement of Surface Roughness of Rock Discontinuities, ROCKENG09: Proceedings of the 3rd CANUS Rock Mechanics Symposium, Toronto, May.

Ritter N., Tagged Image File Format with Georeferencing, Available at:https://docs.safe.com/fme/html/FME_Desktop_Documentation/FME_ReadersWriters/geotiff/geotiff.htm/[Accessed on 15.12.2020].

7 Appendix

Meine Masterarbeit beschäftigt sich mit der Rauigkeitsbestimmung von repräsentativen Proben in der Ingenieurgeologie. Ziel dieser Arbeit, beziehungsweise dieses Fragebogens ist es die Streubreite der zwei Bestimmungsmöglichkeiten zu ermitteln. Die zwei Bestimmungsmöglichkeiten sind der Bartonkamm (Profilometer) mit einer JRC Tabelle (Beilage 1) und die ÖNORM EN ISO-14689 1 (Beilage 2). Ich bedanke mich schon im Voraus für eine gewissenhafte Beantwortung und einen ordentlichen Umgang mit den Modellen und dem Bestimmungswerkzeug. Danke !

Bitte kreuzen Sie, die am ehesten zu Ihnen passende Profession an.

☐ Geologe/in ☐ Geotechniker/in ☐ Student/in

Wie viel Jahre an Erfahrung haben Sie in Ihrer Profession?

____

Haben Sie bei Ihrer täglichen Arbeit mit Rauigkeitsbestimmungen zu tun?

☐ JA ☐ NEIN ☐ TEILWEISE

Bitte bestimmen Sie, dass Ihnen ausgehändigte Handstück mit dem **Barton Kamm** und der **Beilage 1**. Tragen Sie ebenso die Probenbezeichnung (siehe unter dem Handstück) ein.

Probenbezeichnung: ________________________________

Probenbestimmung: ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

Bitte bestimmen Sie, dass Ihnen ausgehändigte Handstück mit der **ÖNORM EN ISO-14689 1 (Beilage 2)**. Tragen Sie ebenso die Probenbezeichnung (siehe unter dem Handstück) ein.

Probenbezeichnung: ________________________________

Probenbestimmung: ① ② ③ ④ ⑤ ⑥

Welche dieser beiden Methoden waren für Sie unkomplizierter bzw. nachvollziehbarer bei der Bestimmung der Handstücke?

☐ Barton Kamm ☐ ÖNORM EN ISO-14689 1 ☐ Keine

Wenn Sie die Rauigkeit auf Ihre eigene Art und Weise bestimmen würden, mit welcher Methode würden Sie dies machen? Abgesehen vom Barton Kamm und ÖNORM EN ISO-14689 1.

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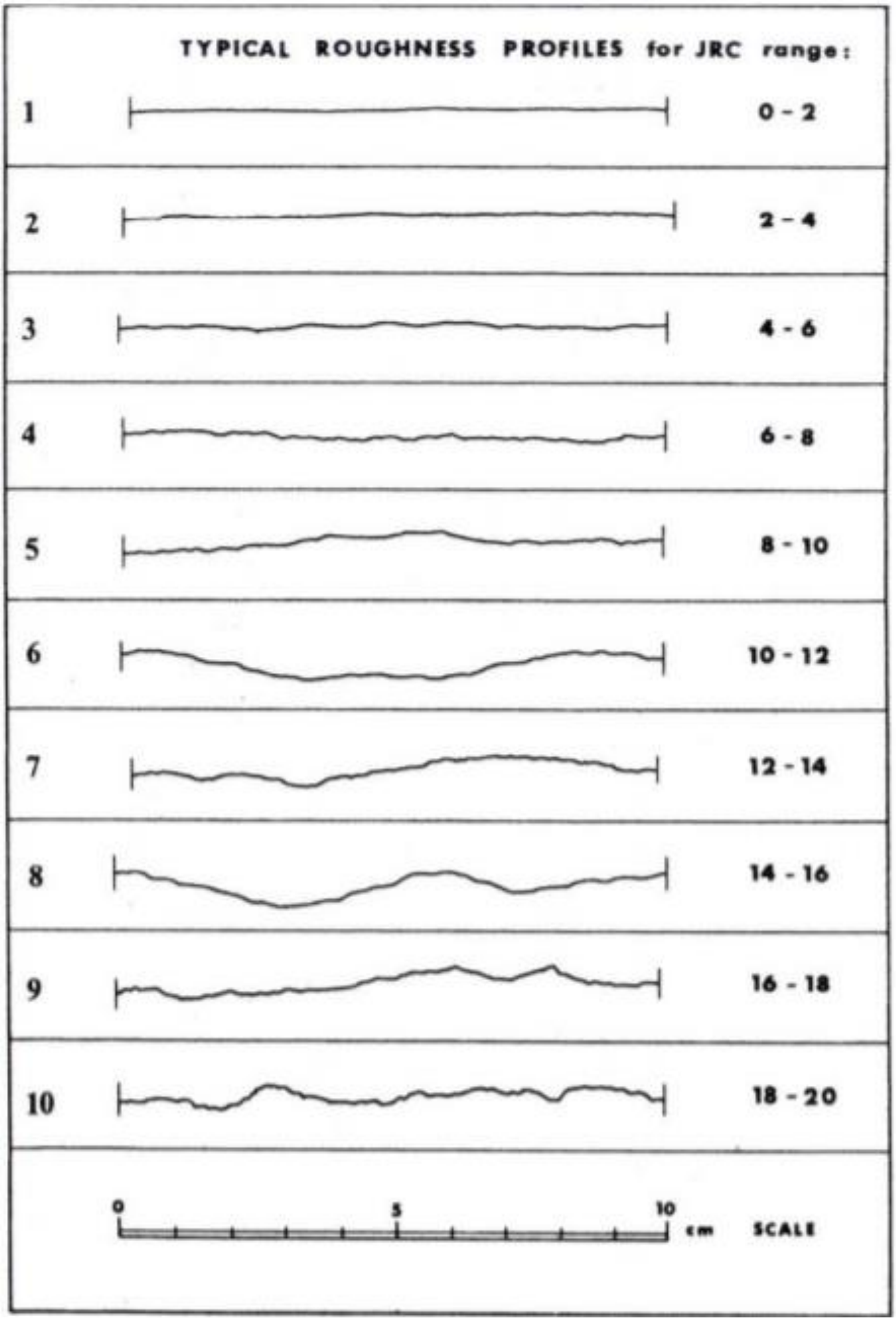
A 1: Questionnaire page 1

Probenbezeichnung	ÖNORM EN ISO-14689 1	Barton Comb

A 2: Questionnaire page 2



A 3: Questionnaire page 3

4.3.3.5 Rauigkeit

Die Oberfläche der Trennflächen ist auf der Grundlage von drei Betrachtungsmaßstäben:

a) kleiner Maßstab (einige Millimeter) — raue oder glatte Oberfläche;

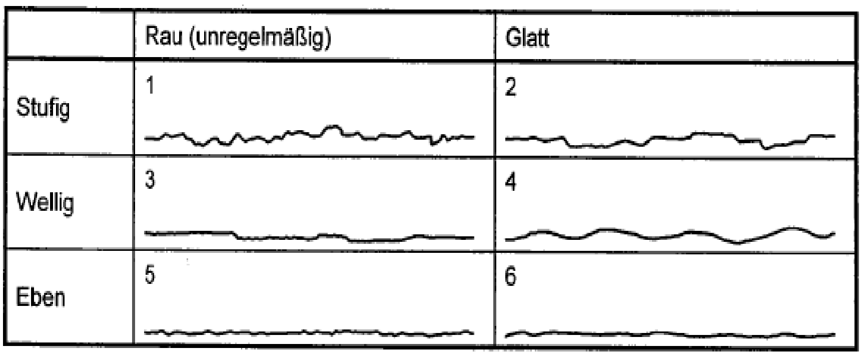
b) mittlerer Maßstab (einige Zentimeter) — eben, stufig oder wellig;

c) großer Maßstab (einige Meter) — eben, stufig oder wellig.

und mit den Bezeichnungen nach Bild 2 zu beschreiben. Die Oberfläche einer Trennfläche kann somit mit einer Kombination von Bezeichnungen des großen oder mittleren und kleinen Maßstabs beschrieben werden und Beschreibungen wie z. B. „stufig glatt" oder „eben rau" ergeben. Für eine völlige Klarheit der Beschreibung kann es erforderlich sein, Wellenlänge und Höhenmaß der größten maßstäblichen Trennflächen zu messen. Es ist zu beachten, dass alle „glatten" Trennflächen Harnische haben können. Harnische sind Streifen auf der Oberfläche einer Trennfläche als Folge von Bewegung und Druck. Harnische können poliert sein und Licht reflektieren.

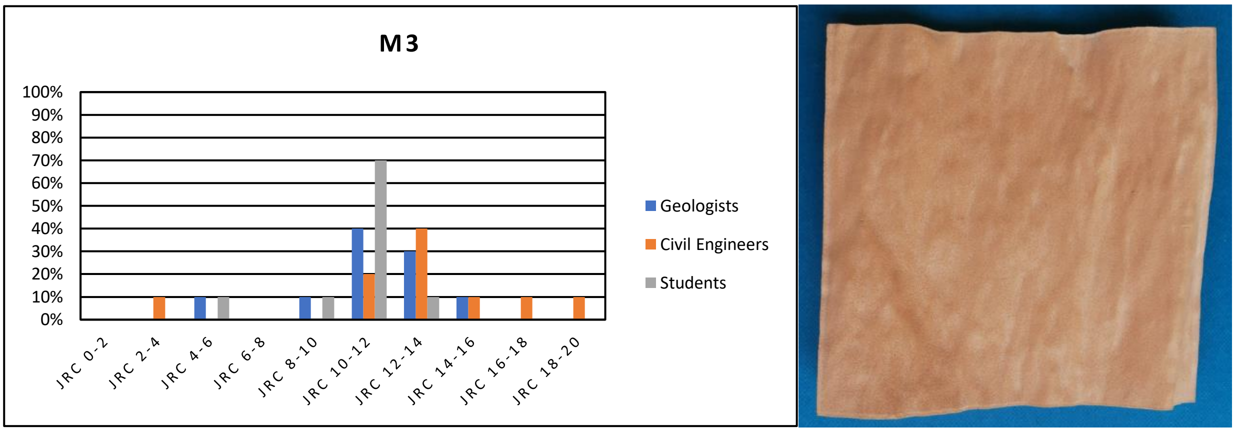
Es sollte nur dann von „Harnischen" gesprochen werden, wenn eindeutig belegbar ist, dass eine Verschiebung infolge einer Scherung entlang einer Trennfläche stattgefunden hat.

Der senkrechte und waagerechte Maßstab in Bild 2 ist gleich.

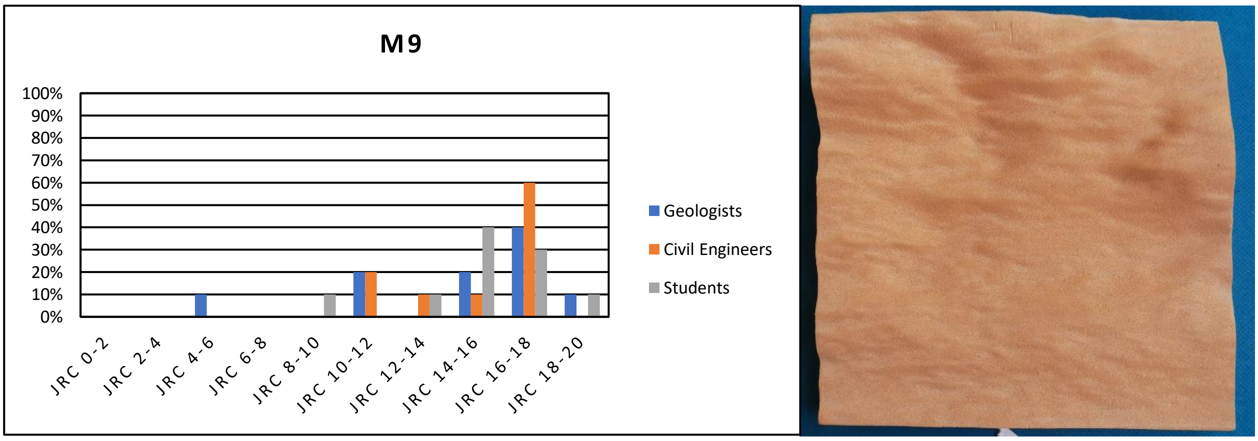


Legende
1 stufige, raue Oberfläche
2 stufige, glatte Oberfläche
3 wellige, raue Oberfläche
4 wellige, glatte Oberfläche
5 ebene, raue Oberfläche
6 ebene, glatte Oberfläche

A 4: Questionnaire page 4



A 5: Column diagram and an image of the final milled model M3.



A 6: Column diagram and an image of the final milled model M9.