Utilization of photogrammetry during establishment of virtual rock collection at Aalto University

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Abstract

In recent years, we can observe increasing popularity of the term industry 4.0 which is defined as a new level of organization and control over the entire value chain of the life cycle of products. Experts distinguished nine different technologies, which are essential for the development of industry 4.0. One of them is virtual reality, which is used during processes of data visualisation and digitization. These processes can also include geological collections. Due to limited access to different geological spots, the popularity of destructive techniques during rock testing and high complexity of the process of learning geosciences, geologists are looking for new methods of digitization of different samples of rocks and minerals. The aim of this master thesis was to create a virtual collection of selected rocks and minerals using photogrammetry and virtual reality (VR) technology and develop new tool and interactive learning platform for study mineralogy and petrography. To accomplish these aims and create 3D models of specimens, the author built professional photo studio and used photogrammetric techniques to digitize the samples. The main output of this research is a virtual 3D collection of rocks and minerals that consisting of 107 samples, and which is available via two different channels: Sketchfab portal online model repository and VR environment built in Unity game engine. The virtual collection will be utilised to teach students how to identify rocks and minerals at Aalto University.

Keywords Virtual Reality, Photogrammetry, Digitisation of data, Mining Industry, Industry 4.0, Rocks, Minerals, Geology, Education

Foreword

This master thesis is the output of six months of constant and intensive work as well as the culmination of my "student life". This journey would not be possible without a lot of different people and their support, hence at this point I would like to thank all of them.

First of all, I would like to express my gratitude to Professor Mikael Rinne, who wrote to me and offered the possibility of participation in EDUROCK project. I am really happy that you chose me and trusted during the whole venture.

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Espoo, 01.09.2019

Jeremiasz Merkel

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List of abbreviations

AR – Augmented Reality

A!OLE – Aalto Online Learning

BCG – Boston Consulting Group

CAGR – Compound Annual Growth Rate

CCD – charge-coupled device

CCT – Correlated colour temperature

CMOS – Complementary metal-oxide-semiconductor

CP – Control Point

DoF – Depth of Field

DSLR – Digital Single-lens reflex

EBIDTA – Earnings Before Interest, Taxes, Depreciation and Amortization

EOS – Electro-Optical System

FLAC3D – Fast Lagrangian Analysis of Continua in 3 Dimensions

GDP – Gross Domestic Product

GEODE – Google Earth for Onsite and Distance Education

GPS – Global Positioning System

GVA – Gross Value Added

HDR – High dynamic range imaging

IR – InfraRed

LED – Light-emitting diode

LMB – Left mouse button

LPS – Low pass filter

MIEDU – Mining Education and Virtual Underground Rock Laboratory

MR – Mixed Reality

ms – Milliseconds

MTS – Modulation Transfer Function

PPPs – Purchasing Power Parity

PSF – Point spread function

RGB – Red, green and blue

RTK – Real Time Kinematic

RV – Reality-Virtuality

SLR – Single-lens reflex

UAV – unmanned aerial vehicle / uncrewed aerial vehicle

WUSTL – Washington University in St. Louis

XR – Extended Reality

VFT – Virtual Field Trip

VR – Virtual Reality

VRML - Virtual Reality Mark-up Language

VUTE – Virtual Underground Training Environment

1 Introduction

1.1 Problem Statement

Due to the high complexity of geological processes occurring on the Earth and other astronomical objects, sciences like geology, geomechanics or mineralogy and petrology are one of the most difficult challenges for students, scientists and enthusiasts, who study these matters. Next to the huge amount of theoretical knowledge, which needs to be adopted during studies, the competent geoscientist should freely identify and differ basic rocks and minerals. The acquisition of this kind of skills requires a big workload and every person needs to put a lot of efforts and devote a lot of time to accomplish it. Also, active participation in various field trainings, workshops and practical exercises is required.

Unfortunately, an organization of it is a quite complicated venture. A lot of interesting, geological spots are in the middle of wilderness. Very often, also public collections of rocks and minerals are located in one particular place with exclusive and limited access. Additionally, due to high average density and large dimensions, vast majority of mineral/rocky specimens are very cumbersome and difficult to transport. Extensive collections can occupy huge spaces and fulfil numerous locations.

Given all the factors mentioned above, the rapid development of different manners of digitalisation of data can be observed in recent years also in the mining sector. Additionally, the digitalisation has been identified as one of the major trends changing society and business (Parviainen et al., 2017). Achievements gained in this field can be also applied to the digitalisation of various collections of rocks and minerals and facilitate results to much wider audience (Suorineni, 2015; Onsel at al., 2018; Onsel at al., 2019). The utilization of Virtual Reality for presentation of results can be a great approach (Kaiser et al., 2005).

Digitalisation of data is also one of top priority of Aalto University (Aalto, 2019). The main research programme which takes into consideration these issues is the Aalto Online Learning (A!OLE). It helps teacher and staff in developing novel technical solutions and pedagogical models for online/blended learning, organize workshops and public events, actively foster a strong support network at Aalto University and develop a lot of different pilots' projects connected with digitalisation of data and virtual reality (for example VR Hub etc.), (Aalto, 2019). One of them is the EDUROCK project (Educational Virtual Rock Collection). The main aim of this project is to establish 3D virtual collection of rocks and minerals kept at Aalto University, and this thesis is the central part of the EDUROCK project.

1.2 Aim and objectives

The goal of this thesis is to create a 3D virtual collection of rock and minerals. To accomplish this aim, the following objectives were established:

- ✓ O1: Selection of relevant specimens. Requirements of course "Geology and geomechanics" and present access to the collection were established as main selection criteria.
- ✓ O2: Deployment of facility, which enables fluent and effective acquisition of required data. To achieve this goal professional photo studio was built.
- ✓ O3: Identification and profound description of workflow, which can be applied during the execution of similar projects. A few different methods were considered. Finally, the photogrammetry was chosen as the greatest method to accomplish. The obtained workflow includes acquisition of photos, photo editing as well as a utilization of a proper photogrammetry software.
- ✓ O4: Creation of virtual reality environment facilities proper visualisation of results. To reach this goal Unity game engine was used.

Objectives mentioned above generate the following research questions:

- o RQ1: What kind of specimens can be captured by using the photogrammetry? Are there any limitations? If yes, is there any solution?
- o RQ2: What is the best configuration of the photo studio and its components?
- o RQ3: What are pros and cons of used workflow? What is a required workload and average time of the data acquisition?
- o RQ4: If a virtual reality is a proper way for the data visualisation? If VR can be applied as an educational aid? What is the educational potential of VR?

1.3 Scope of thesis

In this thesis, an author used photogrammetric techniques during a creation of 3D virtual rock collection for educational purposes. The study was limited to test a structure from motion photogrammetry. The tested photography equipment was confined to Canon EOS 5DS R (a professional full frame digital single-lens reflex (SLR) camera). The tested software was limited to the Reality Capture delivered by the Capturing Reality. The final output can be checked on personal computers/phones/tablets etc. by using the Sketchfab platform or in the virtual reality environment using the HTC Vive Pro headset.

1.4 Structure of the thesis

Chapter 1. Introduction – contains the problem statement, the scope of the project, aims and objectives of conducted researches and structure of the analysed master thesis.

Chapter 2. Background – describes interdependencies between The Fourth Industrial Revolution, Virtual Reality and Mining Industry. It also quotes similar projects and ventures, which can be treated as a valuable source of knowledge about current matters.

Chapter 3. Rock and mineral sample collection – includes detailed description of the gathered collection.

Chapter 4. Deployment of the photo studio and photo acquisition – presents the detailed workflow at this stage and describes all relevant parameters and applied settings.

Chapter 5. Creation of 3D models – covers practical matters and describes the software, which was used during a creation of 3D models.

Chapter 6. Development of VR environment – focuses on the description of workflow in Unity game engine and describes the final visualisation.

Chapter 7. Virtual collection on Sketchfab – includes the description of the collection available via Sketchfab platform.

Chapter 8. Discussion and conclusions – contains analysis and comments about the quality of the result, mentions limitations and states general conclusion about conducted research.

Chapter 9. Conclusions – includes conclusion, which were compiled ultimately.

Chapter 10. Recommendations and path forward – focuses on the recommendations of the author for future researches and lists potential amendments and improvements, which can be made then.

2 Background

2.1 Industry 4.0

Since the industrial trade fair Hannover Messe 2011, the term "Industrie 4.0" has ignited a vision of a new Industrial Revolution and has been inspiring a lively, ongoing debate among the German public about the future of the work, and hence society, ever since (Pfeiffer, 2017). Soon therefore, this term has gained huge popularity all over the world. The best proof for the proliferation of this concept is the motto of World Economic Forum Annual Meeting 2016 – "Mastering the Fourth Industrial Revolution" (weforum, 2019). The idea of Industry 4.0 has been described profoundly in the book of Klaus Schwab and could be great basis for deeper understanding of this thought (Schwab, 2016).

In human history three huge industrial revolutions happened[1] (von Scheel, 2016). The term industry 4.0 stands for the fourth industrial revolution which is defined as a new level of organization and control over the entire value chain of the life cycle of products; it is geared towards increasingly individualized customer requirements (Vaidya et al., 2018). It could also be considered as a paradigm shift in the industry that aims at combining all the production agents (machines, robots, and operators) in the shape of Cyber-Physical Systems by means of network connections and information management (Hermann et al., 2016). Based on analysis of The Boston Consulting Group there are nine technologies, which are transforming industrial production (Gerbert at al., 2015). All of them have been presented below (Fig. 1).

Fig. 1 The most important technologies of industry 4.0 (Gerbert at al., 2015)

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[1] The 1st revolution concerned water and steam power, the 2nd referred to electric power and the 3rd revolution involved automation of production and digitization.

2.2 Virtual Reality

One of them is Augmented Reality. In this context, use of this term could be a little inaccurate and too narrow. Nowadays, three main immersive technologies can be distinguished: virtual reality (VR), augmented reality (AR) and mixed reality (MR). VR generates scenarios where the users can interact with virtual elements. Current VR technologies build upon the ideas that date back to the 1960s and earlier. In 1968, Ivan Sutherland created the first head-mounted display that rendered simple wireframe models for the viewer's changing pose (Wolfartsberger, 2019). AR works in real scenarios, augmenting certain information by means of virtual elements and allowing the interaction with these elements. MR is a mixture of VR and AR that combines virtual and real worlds and allows virtual and real interactions (Roldán et al., 2019). Some authors (Curran, 2016; Scribani, 2019) differ also a term "extended reality" (XR), which is the umbrella term used for VR, AR and MR, as well as all futures realities such technologies might bring. XR covers the full spectrum of real and virtual environments (Scribani, 2019).

In 1994, Reality-Virtuality (RV) Continuum was created to explain the relationships between AR and VR (Milgram et al., 1994). Since then, the application of this concept goes beyond display. Hence, the modified and adjusted version of RV Continuum has been presented below (Fig.2).
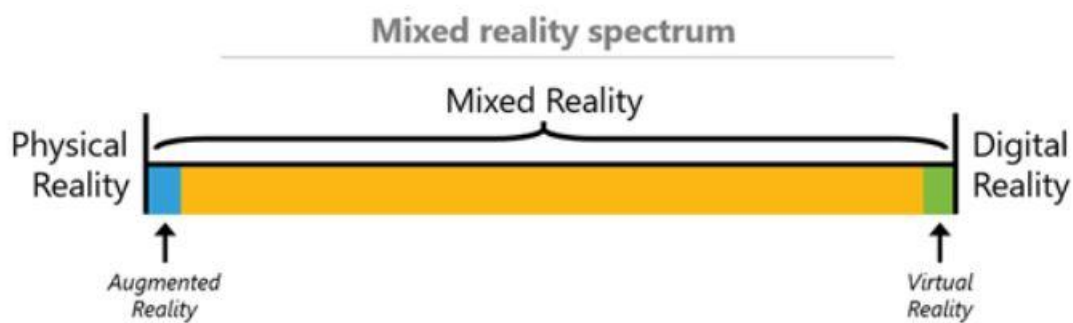
Fig. 2 Reality-Virtuality (RV) Continuum (Microsoft, 2019)

2.3 Mining Industry

Mining is an integral part of our economy, as well as one of the eldest industrial pursuits in human history. In the last 50 years, noticeable changes have happened - since 1970, extraction has raised three times (Fig. 3). Due to the prognosis of further population growth (which has projected the world population will be around 11.2 billion in 2100 (Roser at al. 2019)) and increase of general prosperity (Rosling, 2018) affected on general consumption of raw materials per capita, the further raise could be foreseen. The iron production is a great example of these trends – the consumption per capita is six times higher than 100 years ago and the population is four times bigger than 100 years ago (Hanghøj, 2014).

The importance and magnitude of the mining industry could also be visible in the following chart (Fig. 4) – heading into 2018 the world's 50 largest listed firms were worth collective nearly $900 billion (Els, 2017).
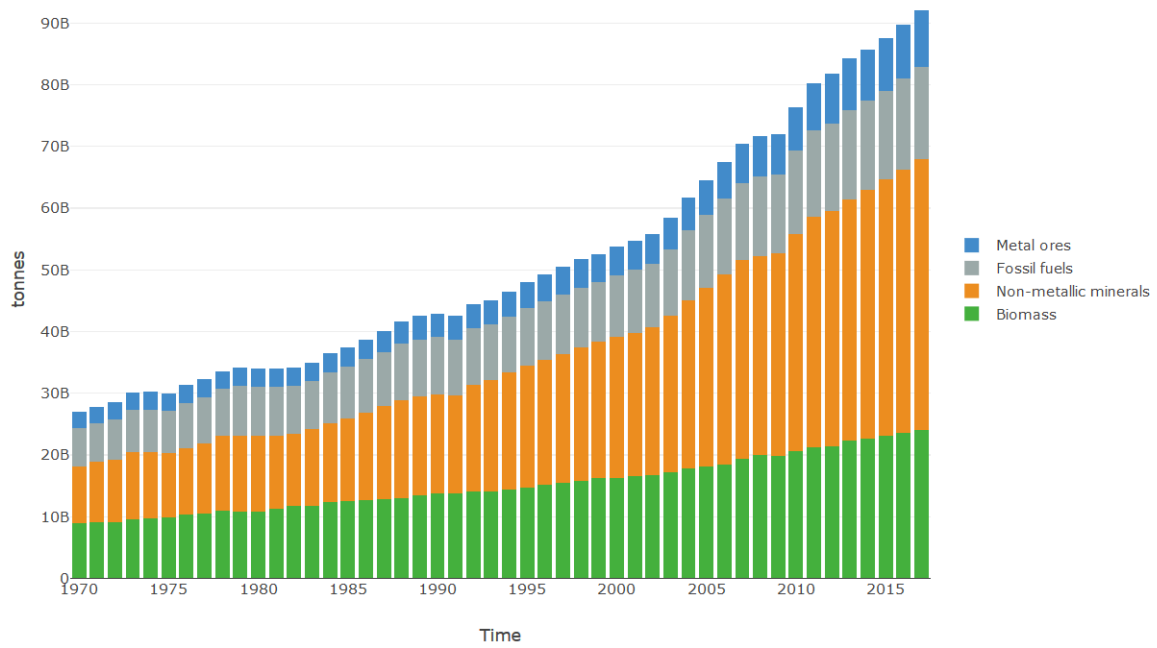
Fig. 3 Global extraction of raw materials in 1970-2017, by material group (materialflows, 2019)
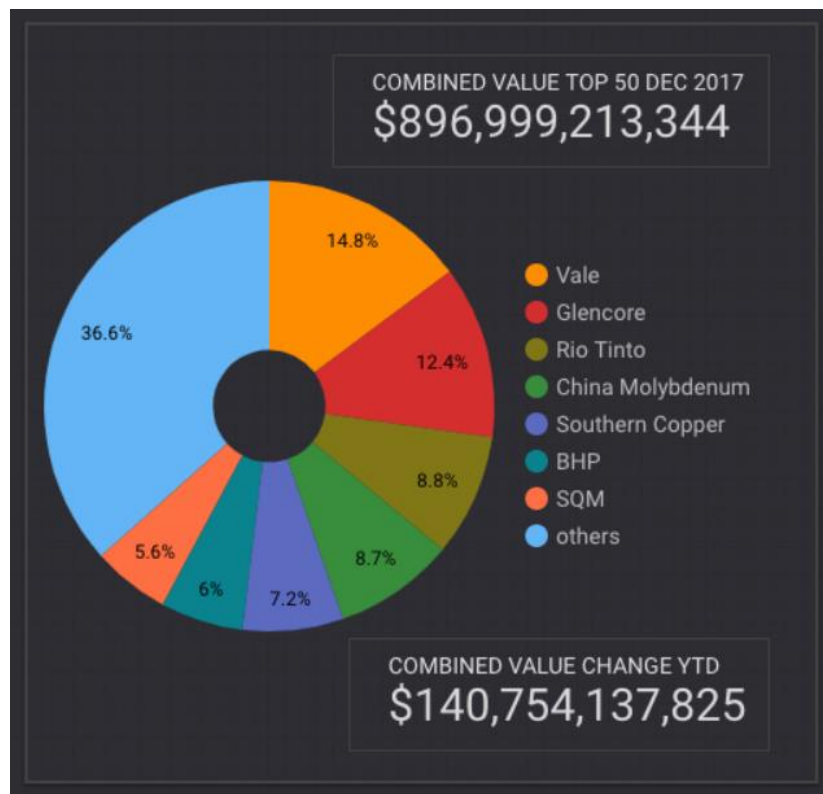
Fig. 4 Value of top 50 mining companies (Els, 2017)

Mining industry could also be very profitable regardless general country's standard of life (measured in the value of gross domestic product per capita (GDP/capita[2])). For example, in United States economy (a nearly a quarter share of the global economy in 2017 (World Development Indicators database, 2017)) the natural resources and mining sector provides 3.9% of GDP (bea, 2019). In some rich countries (for example Canada - $43.8k GDP/capita (gapminder, 2019)) the share of mining, quarrying and oil and gas extraction sector is even bigger and reaches 7.9% of GDP in 2015 (cannor, 2019)

In India ($6890 GDP/capita (gapminder, 2019) the third biggest economy in Asia (World Development Indicators database, 2017), the mining and quarrying industry's contribution (at current prices to gross value added (GVA)) is equal 2.7% (statisticstimes, 2019). Additionally, the mining industry was classified as the third most profitable sector in India by Earnings Before Interest, Taxes, Depreciation and Amortization (EBIDTA) in 2017 (39%), with an average result equal 54% in years 2012–2016, (thecalminvestor, 2019). In comparison, in the United States ($54.9k GDP/capita (gapminder, 2019)), mining (excluding oil and gas extraction) was classified as the fifth industry in terms of EBIDTA margins by industry (Klein, 2016).

2.3.1 Mining industry in Finland

In recent years, the significant growth of total excavation of mines in Finland could be observed (Fig. 5).
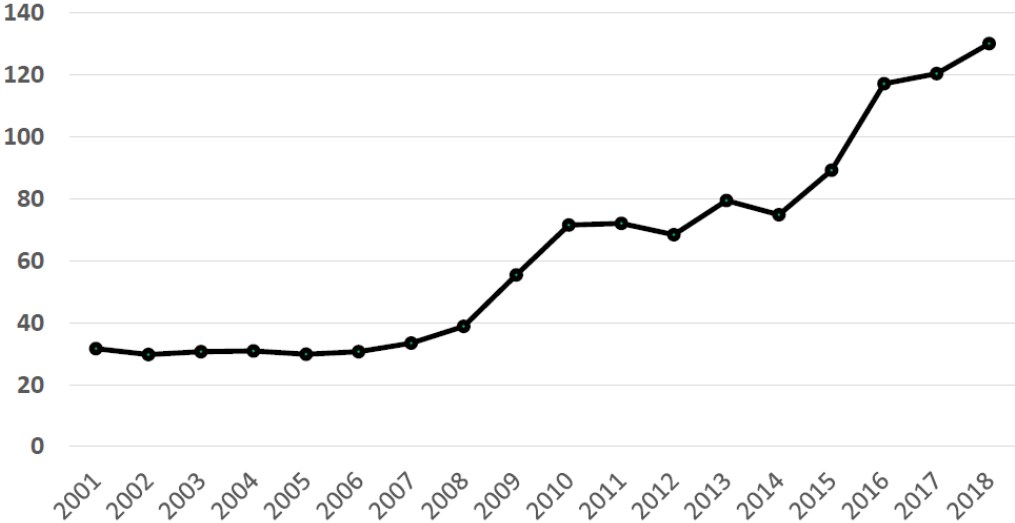
Fig. 5 Total excavation (million tons) of mines in Finland 2001 – 2018 (Liikama, 2019).

Canadian policy think-tank Fraser Institute has named Finland as the most attractive jurisdiction in the world for mining investment (fraserinstitute, 2019). Also, the Annual Survey of Mining Companies, which took into consideration 91 jurisdictions around the world allocated Finland in the top spot of Investment Attractiveness Index. This ranking combines the results of the Best Practices Potential Index (mainly based on geological conditions) and Policy Perception Index (concerns government policy on attitude toward exploration investment) (Stedman and Green, 2018).

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[2] PPPs (Purchasing Power Parity) inflation-adjusted (in all considerations)

2.4 Utilization of VR in the mining industry

Virtual, augmented and mixed reality visualization has been the subject of considerable computers graphics research since 1970 (Onsel at al., 2018). A useful review of these techniques is provided for example by Billinhurst et al. (2014). Engineering applications using VR technology include focus areas such as computer-aided design and manufacturing of products and systems, architectural design, ergonomic issues and data visualisation (van Wyk, 2015). There have been simple applications of virtual engineering for many years; Shu et al. (2019) for example used Virtual Reality Mark-up Language (VRML) to visualise the results of the numerical modelling of longwall coal mines in Fast Lagrangian Analysis of Continua in 3 Dimensions (FLAC3D). Applications of VR in mining included also the training of miners (Grabowski and Jankowski, 2015; van Wyk, 2015). In the case of the oil and gas industry, the first prototype of VR was available in late 1998. The overall goals of the international consortium were to apply and evaluate virtual environment technology for reservoir discovery, for the characterization of oil fields and the management of oil extraction (Kaiser et al., 2005).

To make one realize the growing importance of the fourth industrial revolution in the mining industry, it is sufficient to see the results of "Disrupt Mining Innovation Expo[3]". In every consecutive year, businesses connected with modern technologies place at highest ranks (disruptmining.com, 2019):

- ✓ 2017 Winner: CORE Geosystem Inc (the artificial real-time, automated data accelerating timelines for multiple mining stages and decision-making intelligence)

- ✓ 2018 Finalist: LlamaZOO Interactive Inc (MineLife VR a software platform which enables companies to represent a mine plan from exploration to reclamation in an interactive 1:1 scale using virtual reality, creating efficiencies and value across investor, government, and community relations; resource management; mine planning and reclamation; and business development (llamazoo, 2019)).

- ✓ 2019 Winner: Andritz (a unique and continuous way of training artificial intelligence to operate a mineral processing facility using ANDRITZ's digital twin)

Presently the field of application of VR in mining industry seems endless – the only limitation is humans' creativity and imagination. As always experience from other industries could be an additional inspiration. For more details see Masood and Egger (2019).

Additionally, the successful application of VR training system is critical to mine safety and production (Hui, 2017). Two of these terms are interlinked and could not be considered separately.

2.5 Improvement of safety and production

Nowadays, safety is a top priority of every venture. Due to the high complexity of mining operations and harsh conditions prevailing during exploitation, the mining industry is a very challenging environment. According to statistics from the U.S. Bureau of Labor Fatal work injuries in the private mining, quarrying, and oil and gas extraction industry increased by 26

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[3] "Shark-tank" style live event. In 2018, more than 1000 mining executives, investors, technologists and financiers took a part in this event. Disruptors from all sectors encouraged to pitch their potential technologies (resourceworld, 2019)

percent to 112 in 2017 whereas fatal work injury rate is equal 12.9 (Fig. 6). It means that the ratio is nearly 4 times higher than average and it is the 3ʳᵈ result among all other industries. In this context, it is also important to remember that the above statistics concerns the United States only, where safety standards are well-established and extremely restrictive.
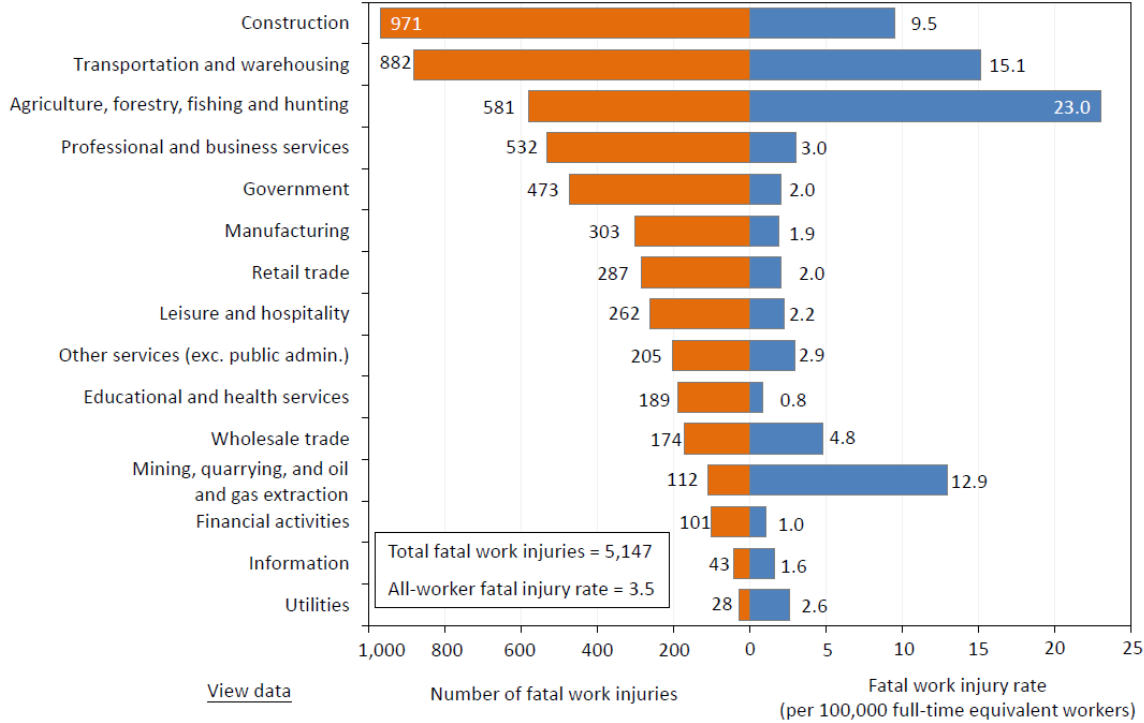
Fig. 6 Number and rate of fatal work injuries by industry sector, 2017 (U.S. Bureau of Labor Statistics, Current Population Survey, Census of Fatal Occupational Injuries, 2018)

The improvement of safety and efficiency in mining operations by using VR could be done in a few different ways, such as:

- ✓ Industrial and vocational trainings (direct impact)
    - o Virtual Reality-based pilot training for underground coal miners (Grabowski, Jankowski, 2014)
    - o Simulated Training Solutions – VR blast wall in Zambia at the Glencore's Mopani Copper Mines (Mulligan, 2018; Fade, 2018)
    - o Normet's shotcrete simulator for training purposes (normet.com, 2019)
    - o Chemical Injection System Operator Training Simulator (VR Training in Oil & Gas, https://www.youtube.com/watch?v=d3IAOhJ46TI, 2019)
- ✓ Proper data management (data mine and machine learning). One of the challenges of the industry is the management of knowledge. Due to much better visualisation and understanding of data, better planning, scheduling and design of mine could be done. All of these issues have a significant impact on efficiency, productivity and safety within the mine.
    - o MineLife VR represents the first time that spatial data of such a large and complex nature has been successfully synthesized into a life-sized, interactive,

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virtual reality experience. Geospatial mosaic data, landsat layout of facilities and infrastructure and communities and land holding all in one place (llamazoo, 2019).

- ✓ Remote supervision of the field

    - o Virtual Reality Room: a real 3D mining cinema (vale, 2019)

- ✓ Remote research collaboration

- ✓ Virtual Prototyping (VP). The idea of VP or Virtual Design Review allows users to examine prototypes in realistic way starting in the earliest design stages (Wolfartsberger, 2019)

- ✓ Educational purposes

    - o Virtual Underground Training Environment (VUTE), (more information could be found in paragraph "2.6 VR in the engineering education").

    - o VR-Mine (RWTH Aachen University and Tal Tech University), (the additional description of this project could be found in Muller at al. 2019)

Nevertheless, survey data cited by IDC Energy Insights suggests that while 3D visualisation is far from the top of the agenda for the digitisation of mining, it is now an established part of the industry's digital toolbox. 27% of companies that responded to the WWDX in Mining Maturity Scope Benchmark Survey 2016 noted that they had invested in 3D visualisation – far below the 68% that said they had invested in mine automation, but still a strong presence and on a similar level of prominence to drone deployment (26%) and investment in the Internet of Things (33%), (mining-technology, 2019).

Given the prognosis of further development of VR technologies we can be quite optimistic. According to Statista: "The augmented and virtual reality market amounted to a forecast 16.8 billion U.S. dollars in 2019 and is expected to expand drastically in the coming years, with forecasts for 2023 eclipsing 160 billion of U.S. dollars (Liu, 2019)". Also, DigiCapital estimates that the worldwide VR industry will hit a total value of $120 billion by 2020 (Akkaş, 2019). Even the most conservative prognosis forecast Compound Annual Growth Rate (CAGR) from 2019 to 2024 will be equal "+48.7%" (mordorintelligence, 2019)

The current state of affairs proclaims the high level of conservativeness among players in the mining industry. On the other hand, it means that companies, which bear risk and invest in these technologies will obtain technological advantage and higher profits ultimately.

2.6 VR in the engineering education

One of the first person, who took these matters into consideration at Aalto University was Jakub Jastrzębski, author of master thesis "Virtual Underground Training Environment (VUTE)". The VUTE thesis was the part of MIEDU – Mining Education and Virtual Underground Rock Laboratory – the project aiming to digitize educational resources of the Aalto University and utilizing them for educational purposes with the use of the VR technology (Jastrzębski, 2018). The current thesis is the continuation and development of this idea. The output of this research will be used during the course "Geology and geomechanics" conducted at The Department of Civil Engineering at Aalto University. In the Master programme this course is one of the six common curses and the first one of them. It provides the basic knowledge of geotechnics

(courses.aalto, 2019). One of the objectives of this course is teaching of recognition of different minerals and rocks ("after the course students can identify the most common rock-forming minerals and classify rock based on their mineralogical composition" (courses.aalto, 2019)). In previous years following difficulties have been observed during conducting of this course:

✓ Limited access to the collection (majority of samples are gathered into the lecture hall R9 at the Department of Civil Engineering (Rakentajanaukio 4) or into the warehouse situated in the basement of Aalto University Undergraduate Center (Otakaari 1) and they are available only in strictly specified time slots. Also, some of them are not accessible at all due to their vulnerability and high value (for example meteorites)).
✓ Lack of access to geological materials for disabled and other non-traditional students
✓ Limited numbers of samples (sometimes there is only one/two specimens of particular mineral/rock hence there is quite difficult for students to carefully study their properties)
✓ Inability of watching archive samplings intended for destructive testing
✓ Distinctive division of theoretical and practical parts (due to high complexity of sciences such as mineralogy or petrology it is quite difficult to study its separately)

Virtual Rock collection is intended to solve all of these inconveniences in future. The potential benefits will include following matters could be visible at Fig. 7.

Fig. 7 Spectrum of possibilities which are provided by virtual rock collection (based in de Paor, 2016).

Despite of unique features of this project, a few similar ventures have been discovered during conducting of profound researches:

✓ **The Fossett Laboratory for Virtual Planetary Exploration** is an innovative facility for teaching and research managed by the Department of Earth and Planetary Sciences. Three-dimensional data from the atomic to the planetary scale are collected, visualized and explored. It is possible due to utilization of traditional and aerial photography, remotely sensed planetary data, photogrammetry and Microsoft's HoloLens AR platform **GeoXplorer**. The user can view a variety of photogrammetric models of geological outcrops from around the world (microsoft, 2019). Also planning of the Mars Curiosity rover paths was done here (virtualplanet, 2019)

- ✓ **eRock** is a virtual geology project led by Adam Cawood and Clare Bond at The University of Aberdeen. This project aims to provide open-source geological data and visualizations for fellow researchers, educational institutions and the general public. Their models are currently embedded into their own site via the free online viewer Sketchfab[4] (e-rock, 2019)

- ✓ **Nathan Siddle** from University of Queensland's School of Earth Sciences is an inventor of the project "Photogrammetry for the Classroom: 3D scanning for Geology and Paleontology". The goal was to create virtual teaching materials using photogrammetry techniques – with Sketchfab (Veldhuizen, 2016).

- ✓ Also, the researcher **Marissa Dudek** (currently Undergraduate Research Assistant at James Madison University) has been creating three-dimensional models of geologic features for almost four years (Dudek, 2018; sketchfab.com/marissadudek, 2019)

- ✓ **GEODE** (Google Earth for Onsite and Distance Education). The main objectives of this project were to create metamorphic rocks virtual collection, create a "Grand Tour" of places on Earths, develop digital geology mapping tools and use Google Maps Engine and Google Earth to link big geoscience data to Google Earth (geode, 2019)

- ✓ Reconstructing 3D models of geologic targets for Virtual Field Trips (VFTs) (Youngwoo, Clary, 2017) conducted at **Mississippi State University** at Department of Geosciences. Results of this project (small geological samples and geologic outcrops) could be found at sketchfab.com/yow (Cho, 2019).

Virtual geological collections already exist online, and readers may simply link content to their own virtual trips, online courses and social media pages. More information about previous projects concern this issue could be also found in the study of De Paor (2016).

2.7 Creation of models

The definition says that photogrammetry encompasses methods of image measurement and interpretation in order to derive the shape and location of an object from one or more photographs of that object (Luhmann at al., 2014). History of photogrammetry is almost as long as that photography itself. In 1849, measurements of façade of the Hotel des Invalides was conducted by French military officer Laussedat. This event could be treated as a caesura and usually, Laussedat is described as the first photogrammetrist. In fact, it was not a surveyor but an architect, the German Meydenbauer, who coined the world "photogrammetry". In the first half of the 20th century, the rapid development of aviation was another decisive influence on the course of photogrammetry. This situation allowed impressive development in aerial photogrammetry, with tremendous economic benefit in the air survey. During this period a lot of orthomosaics of huge areas were made. More details about the historical development of this method can be found in the book "Close-range photogrammetry and 3D imaging" (Luhmann at al., 2014).

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[4] the world's largest platform to publish, share, and discover 3D content on web, mobile, augmented reality (AR), virtual reality (VR), (Sketchfab, 2019)

For the past few decades, several methods and techniques have been used to create three-dimensional (3D) models of real-world objects and scenes. Creating 3D geometry manually using a modelling software has been the usual method. This method is labour intensive, and renderings created using it appear computer-generated, lacking natural realism. During recent years, major advances have been made in Photogrammetric 3D Modelling. It is a relatively new way to create realistic 3D structures using ordinary two-dimensional (2D) photographs by an automated software process (Hellman and Lahti, 2018).

Given camera position and object distance, a few different types of the photogrammetry can be distinguished. One of them is close-range photogrammetry. It usually applies to objects ranging from a few decimetres up to 200–300m (Lerma et al., 2009; Luhmann at al., 2014). Collection methods can be both ground- or aerial-based, and the final output can be rendered either two- or three-dimensionally (xyht, 2019)

During the execution of this project Structure from Motion (SfM) was used. SfM is a technique that utilizes a series of 2-dimensional images to reconstruct the 3-dimensional structure of a scene or object (Humboldt, 2019). SfM photogrammetric technology allows the use of consumer grade digital cameras and highly automated data processing, which can be free to use (Micheletti, 2015). SfM is based on the same principles as stereoscopic photogrammetry (triangulation is used to calculate the relative 3-D positions of objects from stereo pairs). Special algorithms can automatically identify matching features in multiple images. These distinctive features are often corners or line segments. These futures are tracked and are used to produce estimates of the camera positions. Based on these data, a relevant point cloud is created (Humboldt, 2019). The schematic drawing of photogrammetry is presented below (Fig. 8).
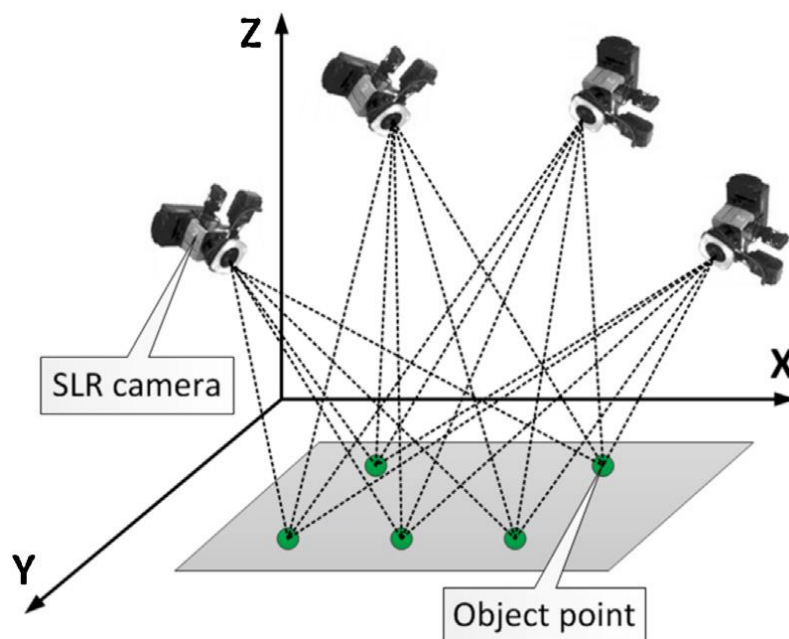
Fig. 8 Schematic drawing of photogrammetry (Li et al., 2013)

3 Rock and mineral sample collection

The collection of samples was conducted. The selection of the particular samples was based on requirements of the course "Geology and Geomechanics" conducted at Aalto University and also availability of additional specimens contained in the lecture hall. The more profound description of this course is enclosed in chapter "6.1 EDUROCK Unity project".

Ultimately, 115 samples of different rocks and minerals were collected and intended for further surveys/measurements. Next, the final evaluation and description of gathered samples were made (the accurate description of the collection is added to the "Appendix A: The list of rocks and minerals"). Subsequently, all gathered samples were transported to the laboratory. Additionally, 64 of them were washed. Also, ultrasonic cleaning was used in case of the smallest samples. Finally, all specimens were filed and gathered in the room with the photo studio into special containers (Fig. 9).

Fig. 9 Selected samples are kept into the special container.

4 Deployment of the photo studio and photo acquisition

4.1 Deployment of the studio

Creation of the suitable photo studio for the acquisition of relevant photos was one of the most important tasks during execution of this project. The accurate conditions including proper lighting and plain background should be provided during particular photo sessions. Also, the quality of photography equipment is very important aspect. Hence following equipment has been chosen (Fig. 10).

Fig. 10 The layout of the photo studio.

1. Canon EOS 5Ds R
2. Tamron SP 90mm F/2.8 Di MACRO 1:1 VC USD
3. Manfrotto 475B Pro Geared Tripod with Geared Column
4. X-Rite ColorChecker Passport Photo (MSCCPP)
5. Wooden table (800mm x 800mm)
6. Rotary table PhotoPizza D700 (Ø700mm)
   - ✓ The control unit
   - ✓ IR remote control
   - ✓ Power adapter
   - ✓ White plastic disc
   - ✓ A wirefor connecting the camera
7. Neewer 1500mm x 1500mm x 1500mm Photo Studio Shooting Tent Light Cube Diffusion Soft Box Kit

8. 3 x Lexxa Ketjuloiste 2X58W (2 x Master TL-D 90 Graphica 58W/965 1SL/10)

Below a detailed description of all components has been presented:

- ✓ Canon EOS 5DS R is a professional full-frame digital single-lens reflex (SLR) camera. This model is a specialized version that is intended for photographers looking to capture the maximum amount of details possible. This version also has a low-pass filter (LPS) cancellation effect, which delivers greater sharpness and finer detail. The main purpose of the application of LPF is to minimize the moiré and false colour artifacting inherent in digital imaging (canon, 2019)
- ✓ Tamron SP 90mm F/2.8 Di MACRO 1:1 VC USD is one of the best macro lenses produced by Tamron. In Tamron's nomenclature particular symbols on the lens have following meaning:
  - SP – this lens belongs to the professional class of Tamron's lenses
  - F/2.8 – The maximum aperture of this lens is equal f2.8. Value of this parameter describes the limit to how wide a lens could be open (canon, 2019). What is important the transmission (T stops) is equal to 3T stops (dxomark, 2019). Due to the character of this parameter (a T-stop is an actual measurement of light transmitted through the lens (diyphotography, 2019)) is more relevant than the maximum aperture.
  - Di – It means that the camera is digitally integrated (optimized for use with full-frame digital camera (photo.stackexchange, 2019))
  - Macro – the main application of this lens is macrophotography. Macrophotography is commonly defined as close-up photography of tiny objects with images that result in the subject being life-size or larger (canon, 2019)
  - 1:1 (Maximum Magnification Ratio). It means that the subject can be reproduced at full size on the camera's image sensor: half of the object can be projected onto the sensor as half of the image when the lens is sufficiently close to the subject (sony, 2019)
  - VC (Vibration Compensation)
  - USD (Ultrasonic Silent drive)
- ✓ Manfrotto 475B Pro Geared Tripod with Geared Colum is a studio tripod with three-faceted column for stability. Anti-rotating leg sections were used to provide stable and secure position. Also, rubber/metal spiked feet were applied for sturdy shooting.
- ✓ X-Rite ColorChecker Passport Photo (MSCCPP)
- ✓ Wooden table (800 mm x 800 mm). Due to a quite small size of the table (0.64 m^2) the additional fixings of the light tent had to be used – four straps have been attached to corners of the light tent and have been mounted to the ceiling.
- ✓ Rotary table PhotoPizza D700 was used, which has a diameter of 700 mm and load-carrying capacity equal to 200 kg. The apparatus consists of the control unit (powered by ESP32 UNO), InfraRed (IR) remote control, power adapter, wire for connecting cameras and white, plastic disc to protect the surface of the table from smutting and scraping. Utilization of the rotary table has enabled fluent movement of object and fixed angle of rotation.
- ✓ Neewer 1500mm x 1500mm x 1500mm Photo Studio Shooting Tent Light Cube Diffusion Soft Box Kit is a professional light tent. Utilization of this tool enables obtaining soft and diffuse light, which is an essential aspect of proper photography.

Relatively big size of the light tent was dictated by practical issue – due to the large surface area of the front wall of the light tent, there were a lot of different possibilities during the positioning of cameras.

✓ 4 x Lexxa Ketjuloiste 2X58W (2 x Master TL-D 90 Graphica 58W/965 1SL/10). To provide best lighting conditions 4 Lexxa fluorescent lamps have been used. Two of them have been located on sides and other two have been situated above (one directly above the light tent and the second in front of the anterior wall of the light tent). Each lamp has been equipped in two professional Philips bulbs with expected correlated colour temperature (CCT) of 6 500 K to provide the best light quality. Additionally, to enable the best performance, all lamps were activated at least 30 minutes before any photo session.

4.2 Image Capturing

To obtain the most accurate focusing following actions has been taken:

✓ Utilization of tripods – first, strict levelling of tripods and cameras using spirit levels have been made (one bubble level was located into the tripod and the second was attached to cameras). Additionally, internal protractors of tripods have been used to obtain the proper position of cameras. Also, all moving parts have been blocked to provide the highest possible level of stability.

✓ Settings of the rotary table. The main objectives were to obtain smooth motion of objects (faster process of acquisition of photos) and motionless position during shooting. Parameters have been established followingly (Tab. 1)

Tab. 1 Settings of the rotary table

Parameter	Value	Unit
Frame	36	-
Delay	500	ms
Pause	100	ms
Speed	5000	-
Accel	100	-
Mode	Seria	-
Direc	Right	-
Steps	209 000	-

Below a detailed description of all parameters has been presented:

o Frame: The number of frames per revolution. To obtain high accuracy and proper overlap of photos (at least 60% (80% or more is even better)) the value "36" has been chosen. It guarantees the rotation of 10 degrees.

o Delay: The most common shutter speed was equal 400 ms (0.4"). Hence setting of this delay has provided an additional 100 ms of pause.

o Pause: The pause has been implemented to provide proper stabilization of object before shooting.

o Speed: Rotation speed in single-frame shooting mode. It is affected by the calibration speed and the speed of infinite rotation. The value has been chosen arbitrarily to enable efficient workflow.

- Accel: Acceleration of rotation. This parameter depends on the number of frames, rotation speed and the size of the rotating disk of the turntable. The value has been choosen arbitrarily to enable efficient workflow.
- Mode: There are four available modes: inter, seria, nonST, PingP. To keep the accurate pace of workflow the whole process of scanning has been conducted in seria mode (high level of automation of the process).
- Direc: The direction of rotation.
- Steps: This parameter determines the total rotation length. The stepper motor is a very popular low-cost electric motor whose drive shaft rotates in discrete angular steps, usually a basic standard 1.8 degrees/step (200 steps/revolution) (Nickols F., Lin Y, 2018). The value of this parameter in case of present stepper motor differs from this definition[5]. Establishment of this parameter has been possible due to process of calibration.

✓ Settings of camera. Parameters have been established followingly (Tab. 2).

Tab. 2 Setings of the camera.

Parameter	Value	Unit
ISO	400	-
Shutter speed	400	ms
Aperture	f/20	-
Mirror lock up	125	ms
Manual Focus	✓	-

- ISO: This number refers to the sensitivity of the sensor or the film to light. For example, 3200 is very sensitive, which means that you can take photos in very low light often without the need for flash. The downside is that with digital the picture will be very noisy or pixelated. In bright sunlight, ISO 3200 would be far too sensitive (the image will be overexposed). It is recommended to use the lowest ISO as possible given lighting condition in order to reduce noise as much as possible.
- Shutter speed: Shutter speed refers to the time it takes for the shutter to open and close, and is a critical component in determining correct exposure (canon, 2019). Despite the utilization of a light tent and providing appropriate lighting, the exposure time has been extended to 400 ms. Hence total motionlessness of object during the shooting has been required.
- Aperture: The more information on the importance of the aperture can be found in the section "4.3.2 aperture".

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[5] The radius of the motor is equal to 10 mm. The radius of the rotary table is 350 mm. It means that perimeter of rotary table is 35 times bigger ($(2\pi*350) / (2\pi*10)$). In process of calibration, the number of steps has been established as 209 000. It means that to enable one full revolution of motor, approximately 5971 steps has to be made (209000 : 35). Therefore, during one step, the motor makes approximately a rotation of 0.06029° (360° / 5971).

- o Mirror lock up: Camera vibration caused by the mirrors reflex action when the picture is taken is called "mirror shock". Mirror lockup keeps the mirror up before and while shooting to reduce blurs caused by camera vibrations (Canon manual, 2019). Application of this setting has increased the quality of gained photos.
- o Manual focus: In the current project, focus has been established approximately in the middle of the sample. Modern lenses usually autofocus, but that does not necessarily mean that the desired objects will be in focus. The user may have to set a focus point or first focus and then recompose depending on the camera. Just as important as depth-of-field and the way it depend on camera position and setting (C. S. Johnson, 2017). More profound description of these issues could be found in paragraph "4.3.1 Depth of field".
- ✓ Utilization of additional equipment (to enable remote shutter release)

4.3 Priorities

4.3.1 Proper positioning of the sample

First, the planning stage was conducted. Every specimen was assessed and evaluated. Three separated surfaces, which would guarantee the stable position of the specimens were needed to be established. This approach guaranteed that every surface would be captured at least two times (in case of the three photo sessions). Additionally, after the changing of the position of the specimen, at least one of the surfaces which were visible at the last photo of the previous photo session needed to be shown. The larger surface area would guarantee a bigger probability of the proper alignment of particular photos. The initial positions of the sample during three consecutive photo sessions were presented (Fig. 11).

Fig. 11 Initial positions of the sample during three consecutive photo session.

Every sample was situated in the middle of the rotary table. The axis of rotation of the specimen should correspond with the axis of rotation of the table to maintain the central position of the sample during the revolution of the table. At the beginning of every session, one test photo was taken. Subsequently, a series of 36 photos (10° of difference in every shot) was made. In this scenario, 111 photos were captured, which guaranteed high level of overlapping (more than 80%). One series lasted approximately 2-3 minutes. Below, projection of all 111 positions of camera during the photo session of the garnet was presented (Fig. 12):
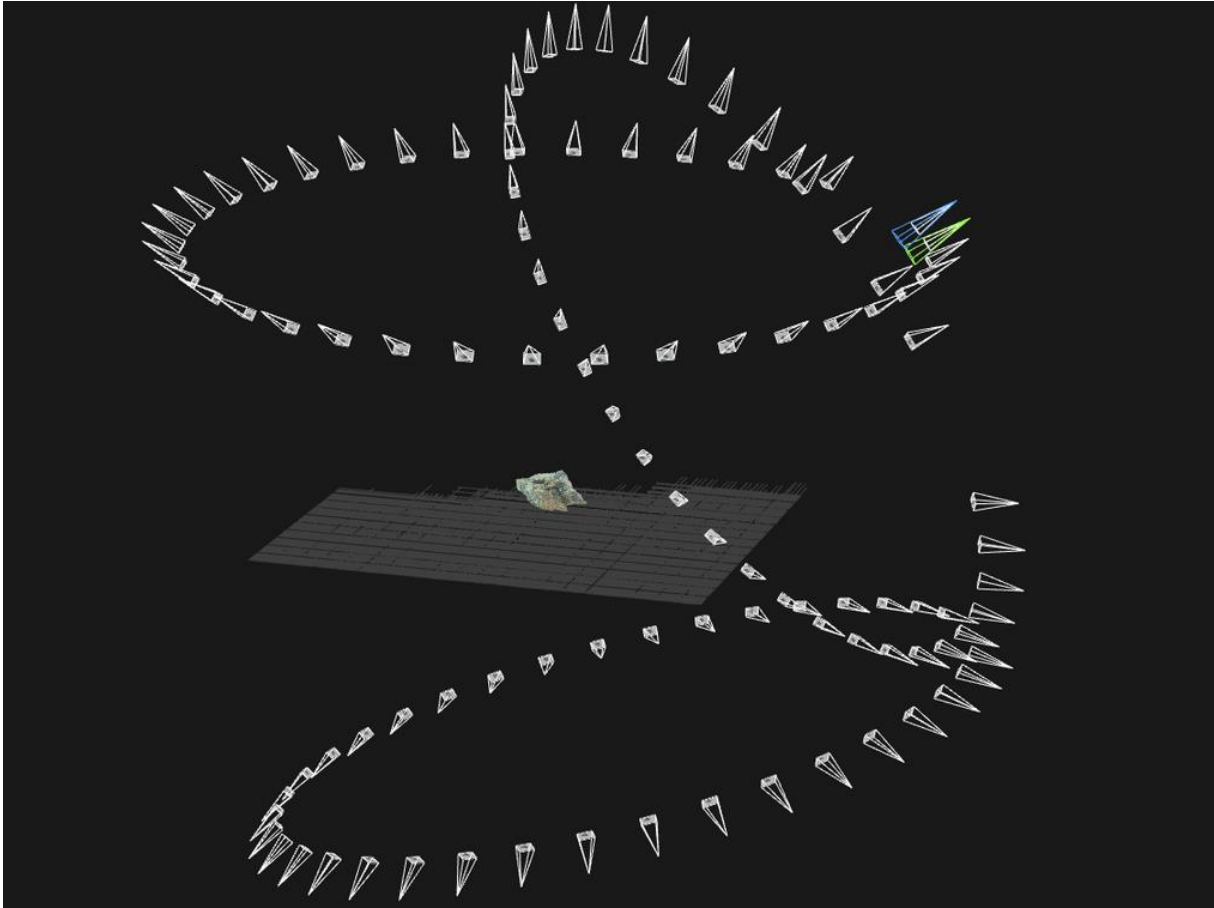
Fig. 12 Projection of the positions of the camera during three consecutive photo sessions of the garnet sample.

4.3.2 Depth of field

Only objects at a specific distance from the camera are in perfect focus, but due to human eye limitations, objects at other distances may appear to be in focus in a photograph. In most cases, one-third of the focus is in front of this point and two-thirds behind (Matt Granger, 2019; Chris Bray, 2019). Nevertheless, contrary to popular belief, it is not a rule and the extent may differ significantly. The range of distances where things are in acceptable focus defines what we mean by depth-of-field (DoF) (Johnson, 2017).

To establish the actual depth of field, DoF calculators can be used. In this thesis the Photopills calculator has been applied (photopills, 2019). Obtained results have been presented below (Fig. 13).

Tab. 3 Settings of the depth of field calculator.

	Value	Unit
Camera	Canon EOS 5DS R	-
Focal length	90	mm
Aperture	f/20	-
Subject distance	73	cm
Teleconverter	-	-

Fig. 13 Obtained depth of field (based on photopills, 2019)

There are two main parameters, which influence the on depth-of-field: the aperture and the distance from the subject to the camera. Of course, changing the focal length does change the compression of the background and the relative size of the subject to the background given more or less background in the photography, but the actual depth-of-field in this photo remains nearly constant. Hence the only merit to say that the wider lenses have the greater depth of field is if the frame wasn't adjusted and it is no longer the same shoot (Granger, 2019). Also, the size of the sensor does not influence the depth-of-field.

Due to some confines during placement of samples (dimensions of photo studio, limitations of tripods and magic arm kit, features of chosen lens, required quality standards of photos etc.) the choice of proper aperture was a crucial aspect. More relevant description could be found in the next section.

4.3.3 Aperture

The F-number is the ratio of the focal length to the aperture in the optical system (merriam-webster, 2019). This is an expression for the aperture as a fraction of the focal length. It could be express followingly:

$$N = \frac{f}{\delta}$$

Where:

        N – F-number
        f – focal length
        δ – diameter of the aperture

Focal length (f) of a thin lens is the distance behind the lens that rays from a distant object i.e. parallel ray, are focused to form an image (Fig. 14).
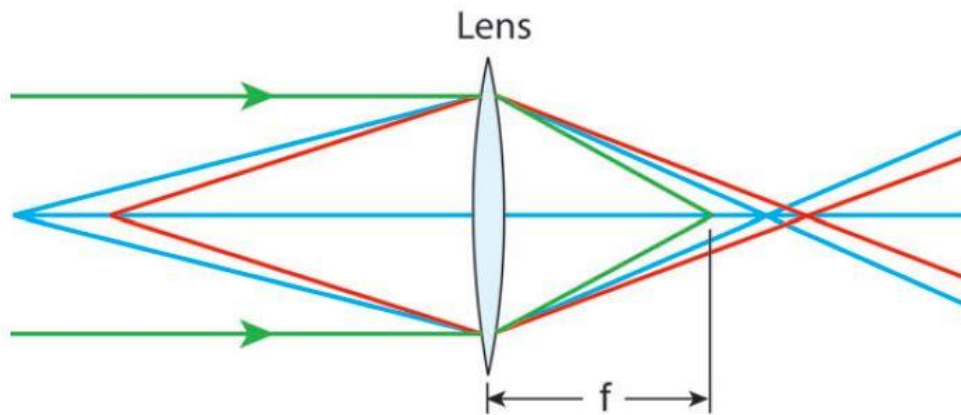
Fig. 14 Parallel light rays from the left focus at the distance f behind the lens (Johnson, 2017).

The F-number is a measure of the relative aperture so that a value of N ensures the same intensity of light on the sensor regardless of the focal length of the lens.

Since the F-number is a ratio involving the diameter of the circular aperture opening, and not the area, the ability to easily double or halve a number to calculate a stop has been lost. To calculate area, we square the radius (half the diameter). We end up with a square root of 2 ratio for successive f values. The mathematical proof is presented in the footnote[6].

In conclusion, f-number corresponds to a smaller relative aperture. Changes in f-number follow a progression whereby the area of aperture changes by a factor of 2 from step to step (f-stops), (Luhmann at al., 2014), Fig. 15. So, in other words If you multiply the radius of any particular aperture opening by $\sqrt{2}$, you will be doubling the area of the aperture and doubling the

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[6] A_1 is a twice the area of A_2. For simplicity, the diameter of A_1 (d_1) and its focal length (f) has been assumed as 1, so the F-number of this lens would be 1. Also, focal length of the lenses is the same. To figure out the F-number of A_2, we need to determine how smaller the diameter is compared to that of A_1

$Area\ of\ a\ circle = \pi r^2 = \pi \left(\frac{d}{2}\right)^2$

$Radius\ (r) = \frac{diameter\ (d)}{2}$

$A_1 = \pi \left(\frac{d_1}{2}\right)^2 = \frac{\pi (d_1)^2}{4}, \quad A_2 = \pi \left(\frac{d_2}{2}\right)^2 = \frac{\pi (d_2)^2}{4}$

$A_1 = 2 \cdot A_2$

$\frac{\pi (d_1)^2}{4} = 2 \cdot \frac{\pi (d_2)^2}{4} \qquad /: \frac{\pi}{4}$

$(d_1)^2 = 2 \cdot (d_2)^2$

$d_1 = \sqrt{2} \cdot d_2 \rightarrow d_2 = \frac{d_1}{\sqrt{2}}$

This means, for A_2 to be half of area of A_1, the diameter d_2 must be divided by $\sqrt{2}$, which is approximately 0,7. To double the area, the diameter needs to be multiplied by $\sqrt{2}$. If this approach is kept for halved areas, the list of F-numbers that are one stop apart will be obtained (Armendariz, 2013):

$F-numbers: \frac{f}{1.0}, \frac{f}{1.4}, \frac{f}{2.0}, \frac{f}{2.8}, \frac{f}{4.0}, \frac{f}{5.6}, \frac{f}{8}, \frac{f}{11}, \frac{f}{16},$

exposure. If you divide the radius of any particular aperture opening by $\sqrt{2}$, you will be halving the area of the aperture and halving the exposure.
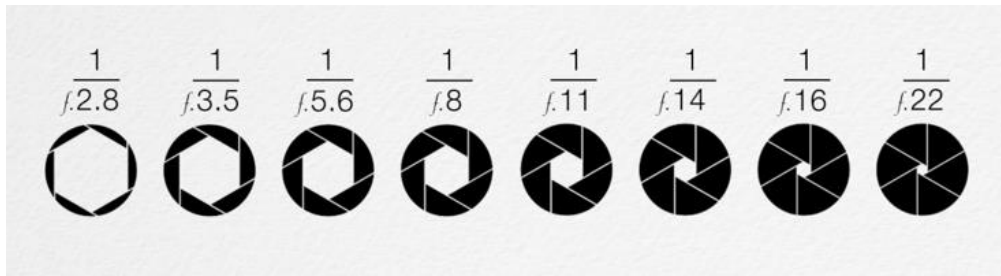

Fig. 15 Standard f/number sequence (jeffnewcomerphotography, 2019)

In the fine-art photography settings of aperture are used to obtain Bokeh effect (the art of creating aesthetically pleasing blur in the image). It is popular especially in portrait photography. In the present thesis, the choice of proper aperture was crucial to obtain sufficient depth of field. Ultimately the value f/20 was chosen, to achieve the following effects:

- Achievement of relatively large depth of field
- Significant reduction in the amount of light reaching the sensor

To mitigate the effect of light reduction following measures needed to be taken:

- ✓ Providing appropriate lighting
- ✓ Increasing the exposure time
- ✓ Increasing light sensitivity (ISO)
- ✓ Stabilizing camera and object (utilization of tripods, magic arm, rotary table et cetera)

Conclusions and recommendation for future projects involving photogrammetry:

To achieve the desired depth of field, the proper aperture should be set. Also, the choice of proper distance from the subject to the camera as well as the selection of lens providing a suitable field of view are essential. Another potential improvement of DoF issue is described in the next section.

4.3.4 Focus stacking

Due laws of physics there is no possibility to capture an image that simultaneously offers high magnification (>1X), high resolution and large depth-of-field. There are ways to combine a series of photographs obtained with different focal points to produce an image that appears to have a much larger DoF than any one of the component images. This technique is called focus stacking. However, this is much more challenging that combining images obtained with different exposures to generate an image with higher dynamic range (HDR) or stitching together images to increase the field of view to obtain a panoramic view.

When the focal point is shifted, objects that are out of focus may shift, become larger and fuzzy. Combining a set of such images requires cautious cropping and pasting (or erasing), and the attempts may result in failure.

Luckily there are a lot of commonly available programs like CombineZP (freeware), HeliconFocus, Photoshop CC or Zerene Stacker. The photographer needs to provide a set of

images with different points of focus and store them as a "stack". The program scales and rotates the images as needed and align them. The sharp parts of each image are selected and then blended to make the final composition (Fig. 16). The main problems during utilization of this technique are related to the high level of complexity (the production of a satisfactory composite could require even 40 images as well as due to different factors (overlap of images, different distances from the lens et cetera), the automated result could be insufficient. Therefore, manual manipulation of the composite images, or selection of images from the stack, could be applied. The whole process can be quite complicated and requires experience and trial and error.

The prerequisite for utilization of this method is to capture enough photos, in which the regions of good focus overlap. Changing the lens' focal distance manually could be challenging and may lead to relatively poor results. Hence utilization of additional equipment like focusing rail is recommended as it increases precision significantly and decreases capturing time (C. S. Johnson, 2017). Also, application of CamRanger wireless DSLR control system could be a solution (camranger, 2019).

Fig. 16 Idea of focus stacking (Nature Photography Mastery, 2019)

5 Creation of 3D models

5.1 Photo editing

There are plenty of photo editing software available online (envira, 2019) for example:

- Canon Digital Photo Professional
- Adobe Lightroom
- Adobe Photoshop
- Skylum Luminar
- Capture One
- On1 Photo RAW
- Corel PaintShop Pro
- ACDSee Photo Studio Ultimate
- Gimp
- Canva
- PicMonkey
- Pixlr Editor
- Snappa
- Fotor
- Inkscape
- DxO Optics Pro 10
- Serif Affinity Photo

In the current thesis, the Canon Digital Photo Professional 4 software was used.

All photos were being taken in two different formats simultounsly: RAW and JPEG. A RAW file is the image data exactly as captured on the sensor (canon, 2019). The real adventage here is that conversion programs permit the user to set the white balance, sharpening, contrast, and even, to some extent, the exposure after fact, taking adventage of the full dynamic range encoded in 12 or 14 bits. The RAW file acts as a "digital negative" for the archival purpose (Johnson, 2017). Unfortunately, these features have also a big impact on the size of the file (often more than 60 MB).

By contrast a JPEG is much smaller but unfortunately it has also some disadvantages like for example: a need of prior establishment of the colour balance, contrast, sharpness, saturation and quality before shooting; encoding the image with only 24 bits total (8 bits per color) and a significant compression which always reduces image quality to some extent (Johnson, 2017).

Due to the high complexity of issues connected with the photo editing process, the profound description of this matter is not included in this Master's thesis. The most basics corrections concern adjustment of "contrast" and "highlights" parameters. On the other hand the whole process is quite subjective and depends on a lot of different factors (a resolution of the screen, personal preferences, experience of user etc.). Nevertheless, quality of JPEGs was described as high hence even these files could be used during the creation of 3D models with an excellent result. While an execution of this project, more than 10 000 photos were taken and saved in JPEG and RAW formats, therefore during the further development of this digital collection, photos could be edited and adjusted according to own expectations and requirements.

5.2 Photogrammetric reconstruction

5.2.1 Introduction

Due to the high complexity of calculations conducted during the creation of 3D models, selection of proper software was a very important issue. There are plenty of widely available photogrammetric software nowadays. Alas only few of them are free software. Most common is Visual SFM (Structure from Motion). It is not very stable, at least when the dense point cloud is calculated by the separate CMVS (Clustering Views from Multi-view Stereo) program (Hellam and Lahti, 2018). They work well together but the end result is not as good as with commercial programs. Additionally, these programs could crash due to programming errors and they do not generate a 3D polygonal models. Therefore additional software like for example MeshLab is needed (Hellam and Lahti, 2018).

The use of commercial software is an alternative solution. The most popular photogrammetric softwares are: Agisoft PhotoScan, AutoDesk ReCap, Bentley Context Capture, Pix4D, Reality Capture or 3D Flow Zephyr Aerial. Also, because of the growing popularity of unmanned aerial vehicles (UAV) there is plenty of photogrammetry software designed especially for building 3D maps and models using drones on the market.

On the basis of expert opinions (Kuzmin, 2018; Lau, 2018; Lievendag, 2018), discussions from various internet forums, analysis of research (Hellam and Lahti, 2018) and suggestions of technical advisors, Reality Capture software has been chosen for the purpose of this Master's thesis.

RealityCapture is a software solution which automatically produces high-resolution 3D models from photographs or laser-scans. RealityCapture is also one of the fastest photogrammetry solution among academic and commercial applications (capturingreality, 2019). This software provides a wide selection of tools, the best user interface and user experience. Reality Capture is also the quickest at producing workable results, and along with the large set of tools and parameters is the most cost-effective product. It also has a high rank (grade: 7/10, 61 opinions) at Steam platform[7] (store.steampowered, 2019).

The biggest drawback of this software concerns requiring a proper context between photo sets. When a large scene is photographed, it easily generates separate components that the process is not able to combine into a single 3D point cloud. It is possible to create control points, which should enable the program to tie together pixels in separate photos but it is relatively complex and time-consuming process. Also obtained output could be irrelevant and present poor quality (Hellam and Lahti, 2018). It can be reduced by having good photos, i.e. photos with enough overlap taken in structured manner.

Ultimately RealityCapture Promo version was used. This version provides possibility of working with maximum 2500 images per project and guarantees free updates. Unfortunatelly it does not offer any technical support.

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[7] Digital distribution platform developed by Valve corporation.

5.2.2 Workflow

Below the simplified workflow used during the execution of this stage was presented (Fig. 17).

Fig. 17 The workflow in Reality Capture (based on Reality Capture)

I.	Loading of photos
II.	Alignment of images
III.	Reconstruction of a model in normal detail
IV.	Lasso selection and removal of unnecessary models
V.	Texturing of the model
VI.	Simplification of the model
VII.	Reprojection of the texture
VIII.	Exporting of the mesh

Below the proper description of particular steps of the applied workflow was enclosed:

I. Loading photos. First, relevant photo sets were uploaded. Due to comparatively big size of images it could be time-consuming process. Photos may also include Global Positioning System (GPS) information, but in the current thesis it was not essential. GPS data (including longitude, latitude, and height) could provide additional information for calculation of accurate camera locations. Unfortunately this approach requires high-quality positioning system like for example Real-Time Kinematic (RTK) positiong. In other cases, provided output can be poor and inaccurate.
Below one example of the uploaded photo was presented (Fig. 18).

II. Alignment. The second phase is aligning photographs. During this step, the calculation of the position and orientation of the camera during different shoots are established. This is done by comparing the digital Red, Green and Blue (RGB) colour values of pixels shared between adjacent photos. Due to a high pixel count, only a limited number of pixel is chosen for the comparison. Usually, the number of the corresponding pixels is parametrised and the 3D points are usually called tie points, since they tie different images together by their pixel values (Hellam and Lahti, 2018).
Below the final output of this stage was presented (Fig. 19)

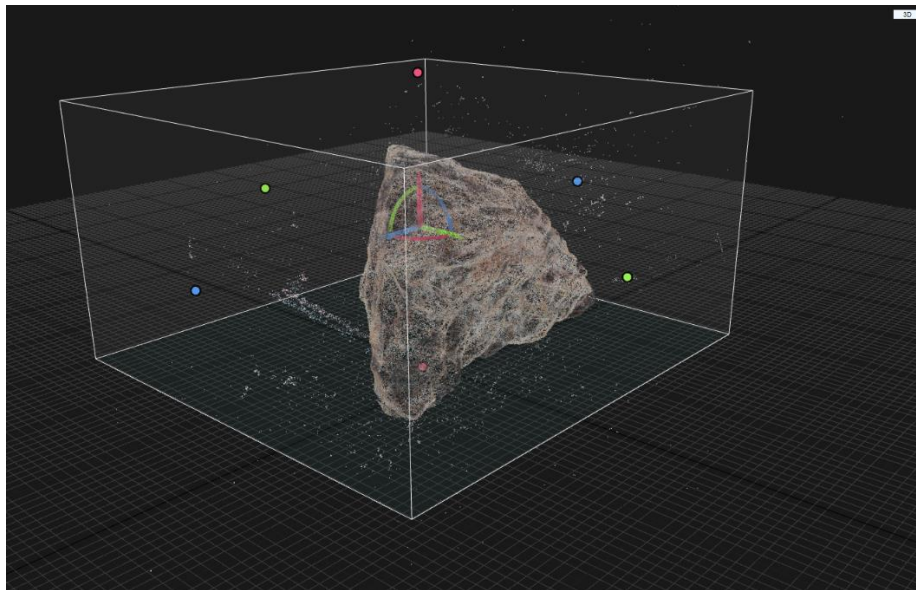**Fig. 18** One of the photo of the garnet specimen.

Fig. 19 The view obtained after the acomplishment of the alignment stage.

In case of the poor alignment (for example after generation of two or more separated components from one set of photos) manual adding of control points (CPs) can be a solution. Unfortunately, the whole process requires a lot of time and a high level of accuracy/precision. The basic approach assumes creation about 3-4 control points and place them on at least 3-4 images for every CP by dragging from the Control Point window to the selected images. Control points should be set very carefully cause only high accuracy and precision could provide sufficient performance. Therefore, high zoom level during placement of particular CPs is recommended. Subsequently small

components could be delated, and process of alignment could be run again. Finally, all images should be gathered in one component. Also proper settings of "max features per images" and "preselector features" parameters can be an additional solution and increase the chance to combine multiple components.

Wrong positioning of control points could cause improper alignment. Below incorrect merging of two different components has been presented (Fig. 20).

Fig. 20 Incorrect merging.

Despite reconstructing a model of the upper part of the sample, sides have not been merged correctly, which can be seen clearly due to the blurred arrow in the foreground.

III.   Calculation of the 3D model. First, a sparse point cloud is calculated by a trigonometric algorithm using the tie points, camera locations and the lens data. A point cloud is a set of points in a three-dimensional space, in which every point has X, Y, Z coordinates as well as a colour value. Next, the dense point cloud is calculated with a significantly larger amount of image pixels being used in this phase. This usually takes the longest time in the process (around 15-20 minutes). Depending on the algorithm, if the software uses all the pixel values in the reconstruction process, it has to process millions of pixels hundreds of times (Hellam and Lahti, 2018). Unfortunately, algorithms used in Reality Capture are considered as confidental (Ďuríčková, 2018 – personal communication) hence there is no possibility to provide a detailed description of the utilized algorithm.

Despite a lot of successful projects (Kersten and Lindstaedt, 2012; Remondino F. et al., 2012; Gonizzi-Barsanti et al. 2014) this approach sometimes attracts criticism of automated photogrammetric processing of large data set. The quality of automatically derived 3D point clouds or surface models is normally satisfactory although no standard quality analysis tools are generally implemented and used to evaluate the value of the achieved (3D) products. Moreover, not all software solutions allow a rigorous scaling and geo-referencing procedure and there is generally a lack of standard term when

reporting results. Also, object distortions and deformations, scaling problems and non-metric products are very commonly presented but not understood or investigated. Therefore, it is imperative that users move beyond black-box approaches of photogrammetric (or SfM/MVS) tools and begin to understand the importance of acquisition principles, data processing algorithms and standard metrics to describe the quality of results and truly quantify the value of 3D documentation (Remondino et al, 2017).

Next step is construction of the dimensional polygonal geometry, a mesh, matching the point cloud. Different feature detection algorithms allow finding planes and straight corners in the 3D geometry (Hellam and Lahti, 2018). The output of this stage is shown in Fig. 21. After the accomplishment of this stage, the utilization of "lasso selection" is highly recommended to delete unwanted structures and simplify the mesh.

IV.   Lasso selection and removal of unnecessary models

After the reconstruction stage, the obtained models very often had additional elements (caused for example by the presence of a scale bar or imperfections of the background). Therefore the additional editing of the obtained model was required. The final effect of this action was presented in the picture below (Fig. 22).
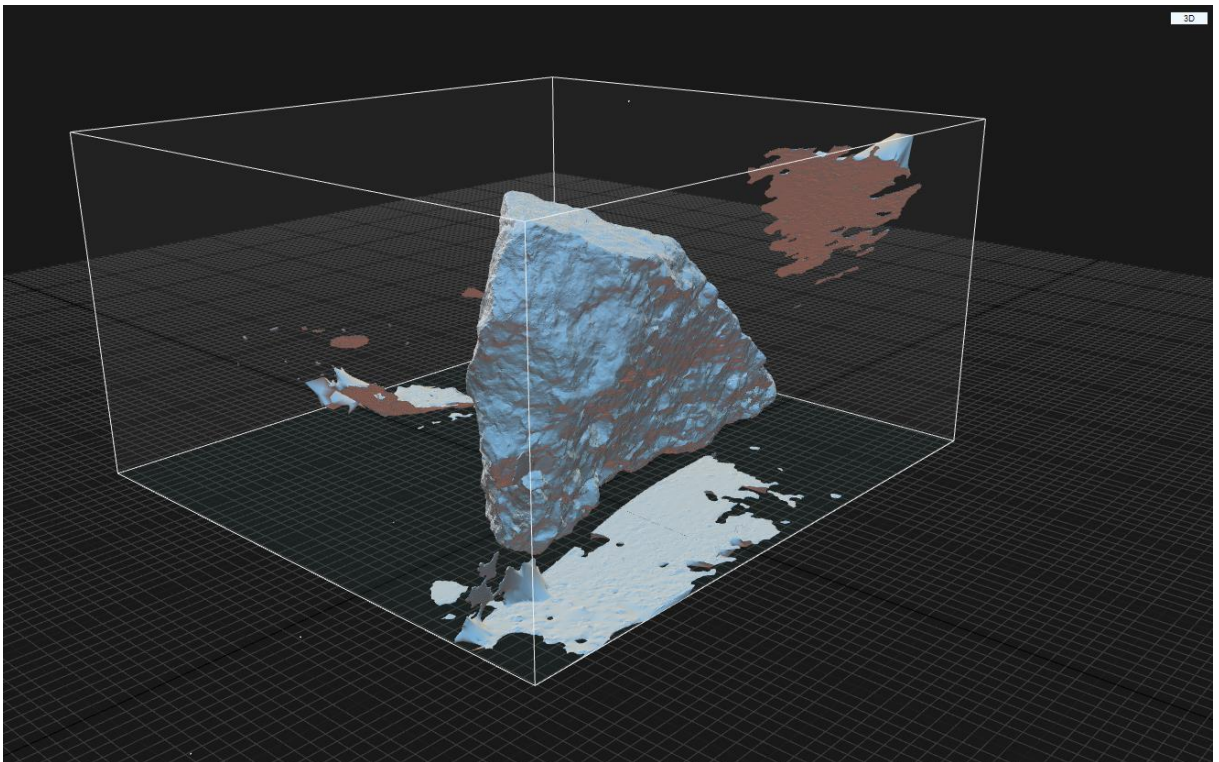

Fig. 21 Unwated structures created after normal reconstruction.

V.   Texturing. The next stage is creating one or more 2D images (texture maps), which are used to cover the 3D model with a texture adopted from photographs. This process is also time-consuming since if we are about to create a 3D environment which is to be explored in a game engine, at least one or preferably several 8K texture maps are required. 8K maps is a square images of 8192 pixels in length and height, which totals to 64 megapixels (MP). In computer graphics, texture map images are usually powers of two on the sides so that the computer can load and render them most efficiently (Hellam and Lahti, 2018).

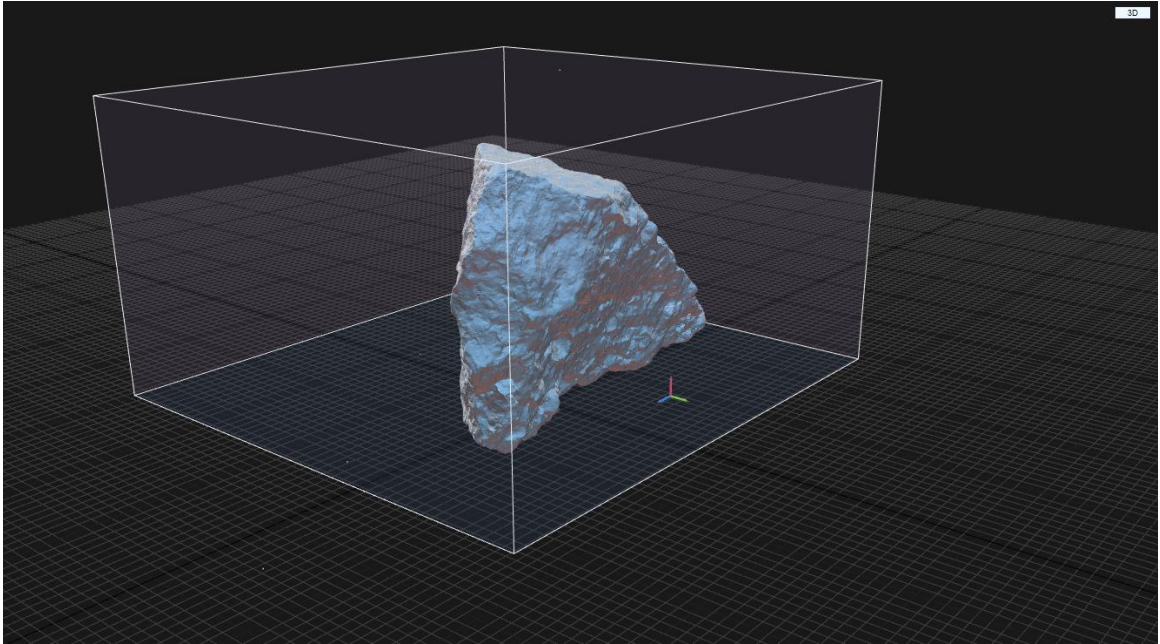Below the model with the proper texture is visible (Fig. 23).

Fig. 22 The shape of the model after implementation of the lasso selection option.
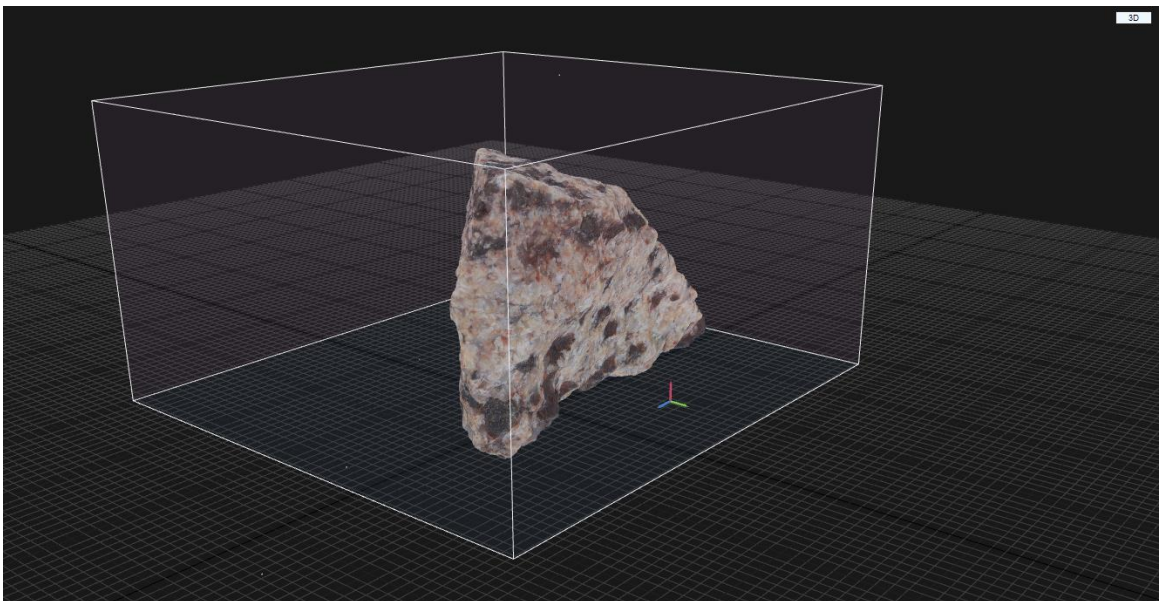

Fig. 23 The model of garnet specimen with proper texture.

VI.   Simplify tool. To enable efficient work with obtained models and a significant decrease in files' size, a simplified tool was used. It guarantees the creation of a model with a target triangle count equal to 200 000. This number was chosen arbitrarily after testing of a few different values (lower and higher).

The simplification process has a big impact on the numbers of triangles of the particular model. In the case of the specimen of the garnet, this number decreased 56.5 times (11.3 million of triangles versus 200 thousands). Unfortunately also the quality of texture was decreased significantly. A difference between low-quality model and high-quality model is visible below (Fig. 24):

VII.   Texture reprojection. To keep the highest possible level of an exactitude, a texture reprojection mode was chosen. It projects the first texture into the simplified model of rock/mineral. Hence, relatively "small" models with detailed surfaces can be obtained (the model still has only 200 thousand triangles but the texture contains the same number of details as in the case of the high-quality model).
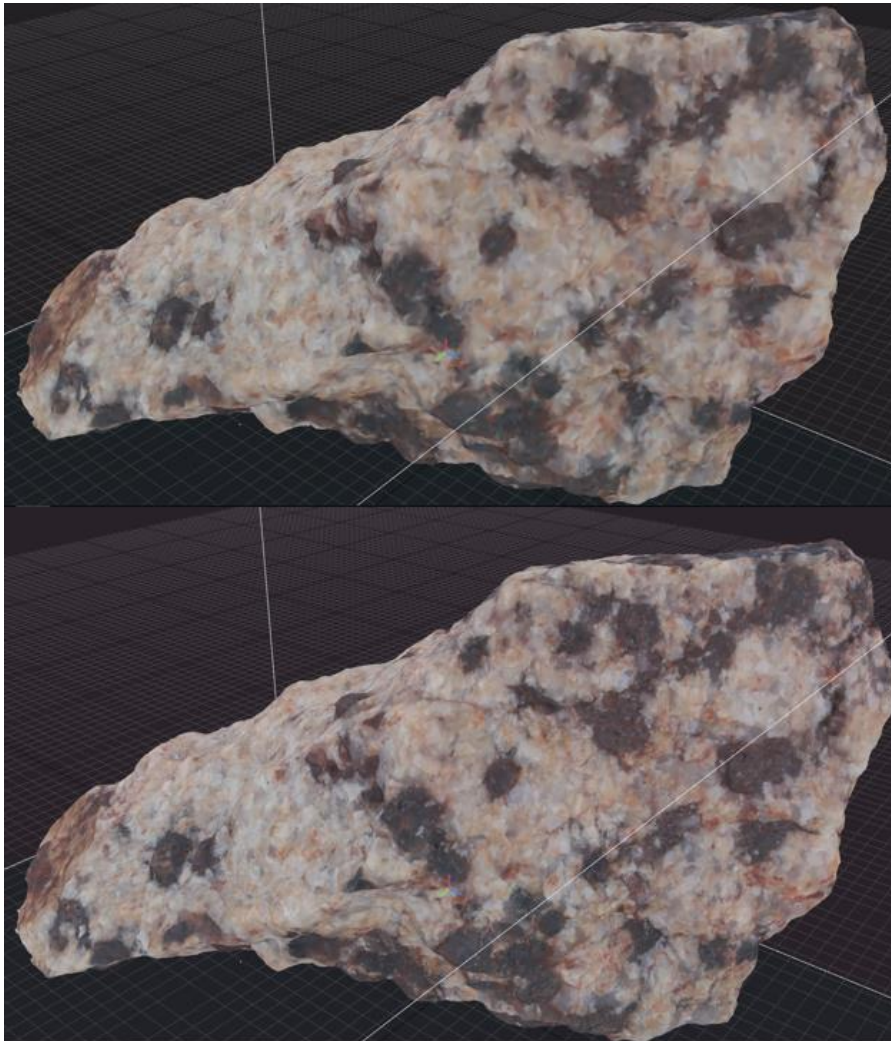

Fig. 24 The comparisson between texture of the low-quality model (upper picture) and the high-quality model (lower picture)

VIII.   Mesh exporting. The last step concerns exporting of models. The final output of every model contains two components: 3D object and texture/textures files. They are esential to implement these models into the Unity environment later. Also uploading of models into sketchfab portal can be made during execution of this step.

The simplified instruction of this stage was attached in the "Appendix B: simplified instruction".

5.2.3 Summary

The cumulative duration of this stage was presented below (Tab. 4). The time was calculated for the sample of garnet. The duration of the particular operations for various samples can differ but the general proportions should remain approximately constant (Fig. 25).

Tab. 4 Average time of particular operations

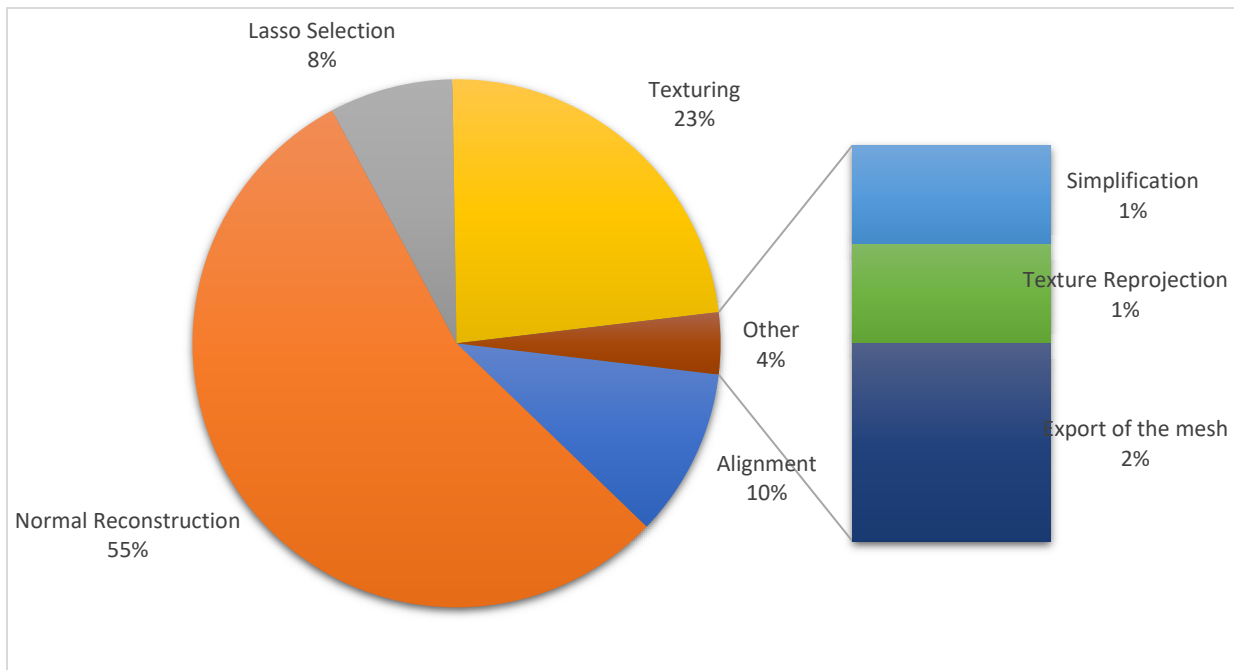| Name of the operation	Time	
	mm:ss	seconds (s)
Alignment	02:44	164
Normal Reconstruction	14:33	873
Lasso Selection	02:00	120
Texturing	06:11	371
Simplification	00:15	15
Texture Reprojection	00:15	15
Export of the mesh	00:30	30
	26:28	**1588**

Fig. 25 The duration of particular steps during the execution of photogrammetric reconconstruction.

The normal reconstruction is the most time-consuming operation (more than half od the duration of the whole process). Also texturing lasts long (23% of the time). Between particular stages, some additional operating time can be added. It means that potential, future improvements in this field can reduce the time of calculation significantly. Currently, due to a relatively long time of execution of particular stages of the photogrammetric workflow, the fluency of the operation was identified as one of the biggest disadvantages.

6 Development of virtual reality environment

Unity 3D is the world's leading real-time engine (Unity3D, 2019). In 2018 Unity 3D has a 48% of market share, followed by Unreal Engine with 13% (Jastrzębski, 2018). Ultimately, the first software was selected because it was used also during conducting previous projects (for example VUTE). The present project was developed entirely using the Unity 3D editor ver. 2019.1.8f1.

First, samples were uploaded to Unity's assets folder (3D object + texture(s)). Subsequently, the software was open to enable the loading of desirable objects. To enable proper interaction with specimens, additional components were added to each model (Fig. 26). The components with "VRTK" indication refer to scripts of the controllers. Components like "Mesh" and "Box" collider, or "Rigidbody" give the object particular physical properties like for example the ability to crash with surfaces of other bodies. Also, different textures could be visible there. In case of Jasper sample, five independent texture files were required (Jasper_u1v2, Jasper_u2_v1, Jasper_u1_v1m, Jasper_u3_v1, Jasper_u2_v2).
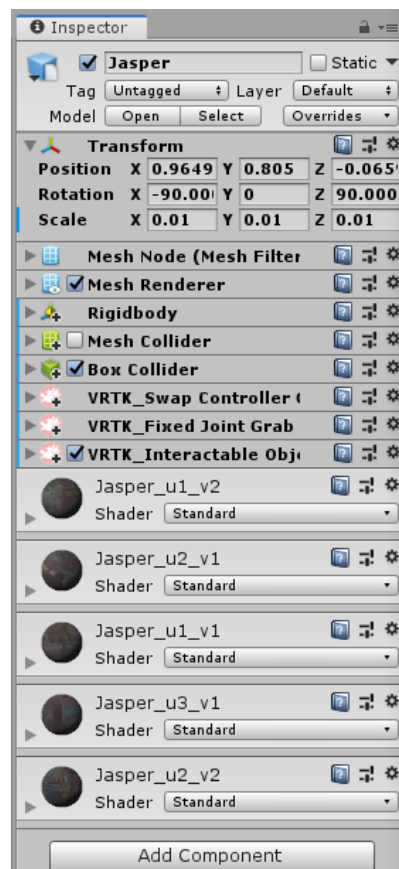

Fig. 26 Required components of 3D model of jasper.

After the implementation of the following settings, the model was scaled by using the "transform" option. Unfortunately, due to the narrow depth of field, it was not possible to create a model of scale bar and create relevant control points. In the case of rocks and minerals, the most important is to enable easy identification of the specimen, hence the scaling can be made subjectively. Nevertheless, in the case of the application of this method to for example archiving of core samples (requirement of a high level of accuracy of the obtained model and the closeness of the model to the original sample), the other solution should be found.

In comparison with original size of loaded object it was miniaturize 1 000 000 times (100 times in every dimension (x, y, z)). The obtained size enables an effortless and fluent interaction with object. Additionally, due to a slight magnification in regards of the original dimensions of the physical object, all important features are well visible, what significantly increase a probability of valid identification of specimen. Next, obtained models were divided and matched to different scenes. Every scene contains 5 rocks and 5 minerals (only the first scene contains 6 rocks and 6 minerals).

6.1 EDUROCK Unity project

This project contains Virtual Reality environment adjusted for the requirements of course "Geology and geomechanics[8]". The main objective of the current master thesis was to create an environment which will support preparation of students to the final exam of this course. Therefore, present surrounding has a strictly imposed structure related with a current shape of the exam, nevertheless in the future it could be developed and adjusted for needs of particular projects. Due to high level of complexity the unity engine, it provides nearly unlimited possibilities restricted only by the imagination and technical skills of creators.

Basically, the current scenario includes two basic stations with following categories: rocks and minerals. Every station contains 5 different specimens. It means that in every scene, 10 samples can be found. The accurate description of content of particular scenario can be found at EDUROCK_v1.unity file. The general view of the basic, mineral station was presented below (Fig. 27).

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[8] The original name is „ENY-C2004 Geologia ja gemekaniikka"

Fig. 27 The view of the mineral station with 6 different specimens.

In case of minerals, following queries need to be determined:

- ✓ Name of mineral
- ✓ Mineral group
  - o Elements
  - o Sulphides
  - o Halides
  - o Oxides
  - o Hydroxides
  - o Carbonates
  - o Sulphates
  - o Phosphates
  - o Silicates

In case of rock, following queries need to be determined:

- ✓ Name of rock
- ✓ Rock group
  - o Igneous rocks
  - o Sedimentary rocks
  - o Metamorphic rocks
- ✓ Mineral composition (main minerals)

During the identification of particular specimens, users can use additional information which are visible in the back of every sample. In the future a significant development of this content is foreseen.

The general task consists of an identification of particular specimens and describe the most general features as the affiliation to the particular mineral group in case of minerals or description of mineral composition and the affiliation to the particular rock group in case of rocks. The identification of specimen should be made on the basis of a visual perception. Lacking information about features, which are not visible in VR (for example hardness, fracture, streak etc.) can be found in special sheets, which are situated behind particular samples. To response for other questions, general knowledge in the field of geology/mineralogy/petrology is needed and should be presented during theoretical part of the course (or acquired by students during a self-study).

The main idea is to render and simulate prevailing conditions during exam and to provide students opportunity to solve a problem with similar level of a complexity and a difficulty. The obtained project can be treated as a basic environment for the further development of other ventures connected with these issues. Also, a specific functionality, a spatial arrangement and type of provided information can be changed freely and adjusted for individual needs.

7 Virtual collection on Sketchfab

Sketchfab is a community of over one million creators and the world's largest platform to publish, share, and discover 3D content on the web, mobile, AR, and VR (sketchfab, 2019). According to the author, the access to the knowledge/results of research projects should be free and common therefore the collection is published via present portal and is generally available for students, researchers, professionals and enthusiasts of various sort of geosciences. Hopefully, in the future it will enable major development and further growth of the analysed collection. The latest version of the collection consists of 102 specimens (situation as at 9th September 2019).

The Sketchfab portal enables simple interaction with the chosen model. The user can choose the preferred navigation (orbit vs. the first person) and also the proper mode (normal, theatre mode or fullscreen). It also enables different actions like rotation, zoom in/out of specimen etc. Obtaining more relevant information about the model can be done by clicking on the proper point attached to the model. One of the biggest advantages of the present collection is remote and continuous access to this study aid. Therefore, it could be implemented as an important part of self-study during different courses like for example geology and geomechanics, foundations of geology, mineralogy and petrology etc. Below the sample of the garnet uploaded on the Sketchfab is presented (Fig. 28).

Fig. 28 The sample of the garnet available via the Sketchfab (Sketchfab, 2019).

8 Discussion

8.1 Resume

The output of the present research is shown below (Fig. 29). Also, the optimal workflow, established during the accomplishment of this project is presented below (Fig. 30).
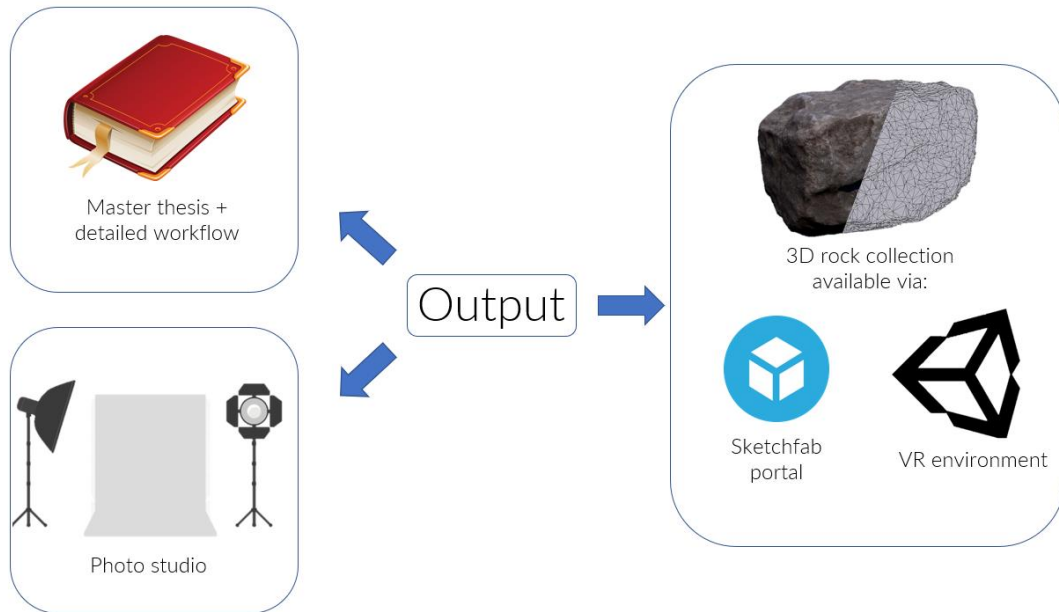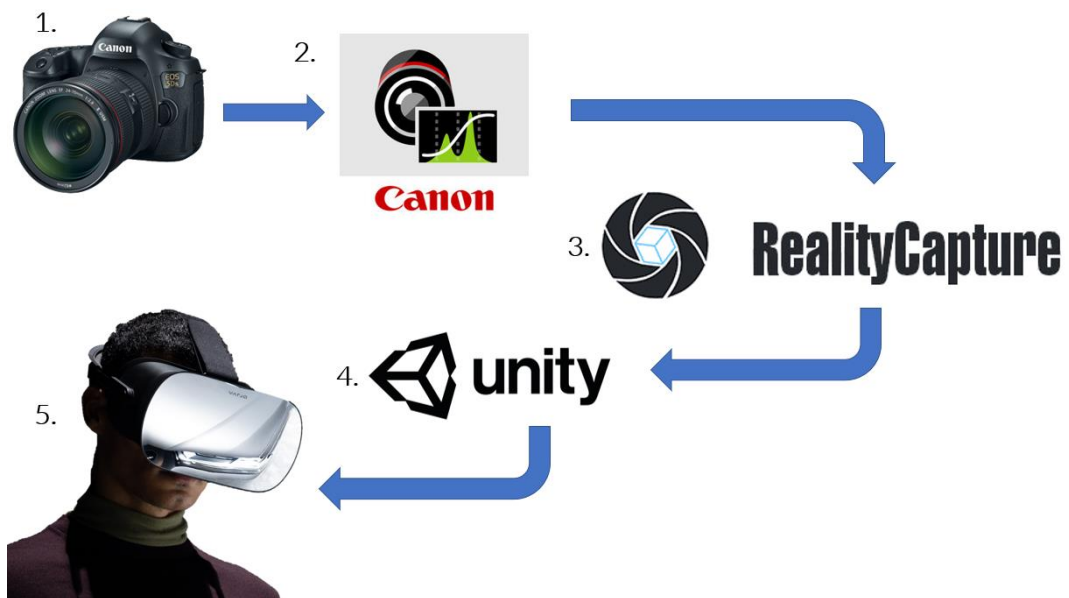

Fig. 29 Output of present research

Fig. 30 Simplified workflow during execution of present master thesis (based on canon, 2019; varjo, 2019).

8.2 Limitations

During the execution of this project some limitations were observed.

8.2.1 Limitations of photoshoot

The main limitations in the case of photo sessions concern the size of the object and the narrow depth of field. The potential solution of this problem is the focus stacking which was described in paragraph "4.3.4 Focus stacking". Also, a different arrangement of various component of photo studio can be a solution.

8.2.2 Limitations of photogrammetry

During a testing, a few difficulties have been identified:

✓ Capturing of inner caverns/voids. In case of a complicated geometrical shape of the particular sample, some regions were not mapped with the required quality. This problem was mainly caused by the poor coverage of inner surfaces during the shooting (these surfaces are visible only in few photographs hence it was not possible to recreate it in detail). Below the effect of an insufficient coverage is presented (Fig. 31).
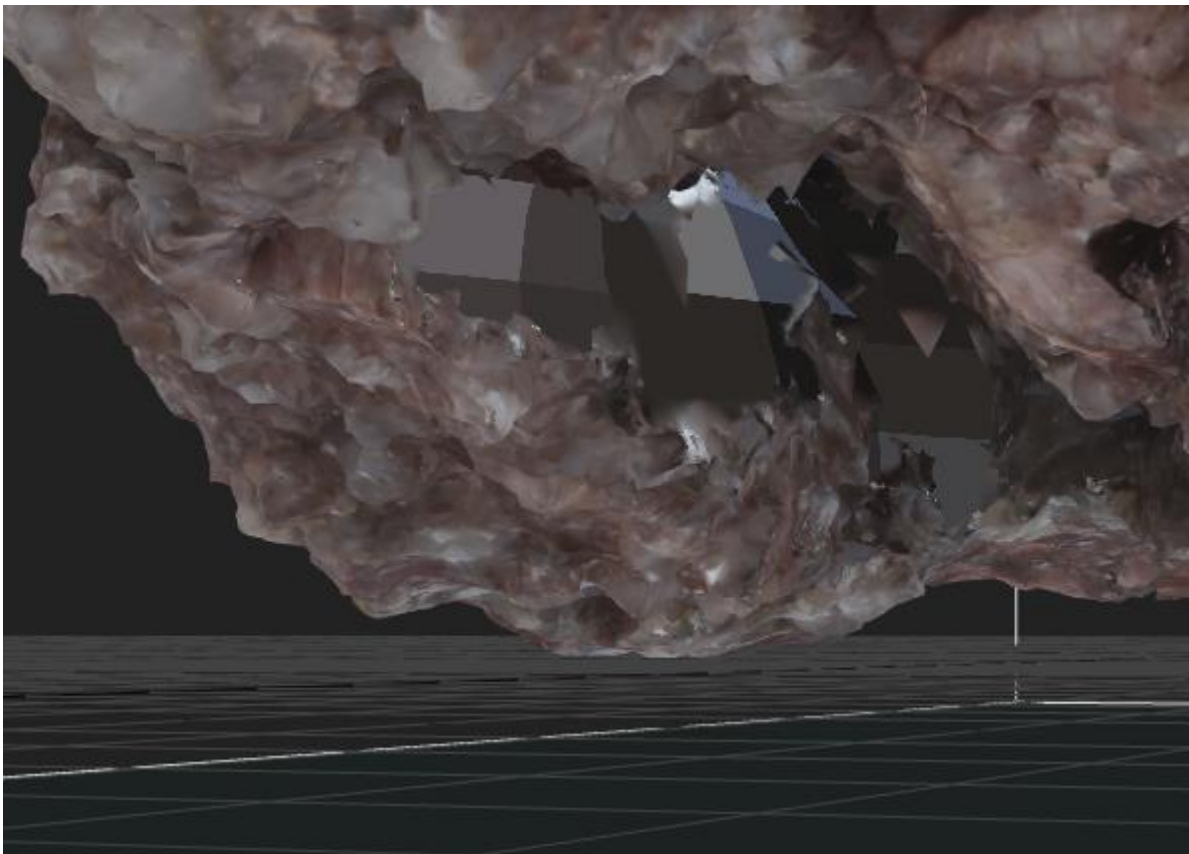
Fig. 31 Effect of an insufficient coverage during shooting.

In this case, the additional photo session of these surfaces can be a solution (it should be done on the beginning/end of a particular session to keep a sufficient overlapping between consecutive photos. From the other hand a lot of voids are hidden and illuminated poorly hence a usage of the additional lighting is recommended. In this situation obtained photos can have other colour balance/white balance, therefore it can

be problem during the alignment of these shoots. Fortunately, this situation concerns only specified samples (in the current project only a sample of the dolomite has this kind of the structure), therefore this phenomenon is not classified as a common problem

✓ Capturing of reflective surfaces. Also, this kind of surfaces can be problematic. In the most cases (for example halite, fullerene, pyrite or hematite) obtained results were satisfying (the only problem concerns a lack of the real glitter/glow). Nevertheless, the number of details, which are visible on surfaces of the particular sample was high. The biggest limitation concerns glass surfaces. It is well visible on the sample of the ozokerite (edges of the glass coaster are jagged and irregular (Fig. 32)).

Fig. 32 Jagged and irregular surfaces of the glass coaster.

In the further development of this project, the opaque/delusterant spray can be a solution. It will cover all surfaces of the sample and decrease reflectiveness significantly. Additionally, after 24 hours it will disappear, therefore a utilization of this method will not have any destructive effect on the particular specimen.

✓ Poor alignment of photos. In the vast majority of specimens (more than 90%), three series of photos were made. It means that every surface was captured at least from two different angles. Unfortunately, in case of a few samples, due to their specific geometrical shape (for example thin, tabular rocks like greenschist, black schist or riebeckite granite) it was possible to take only two series of photos (only in two different positions the sample was static and settled). Hence, due to the poor overlapping of different photos, the software was not able to find sufficient number of common points in different shoots, therefore it was not possible to merge two different components together. Therefore, two separated point clouds were created independently on the basis of two different series. One of them has been presented below (Fig. 33).
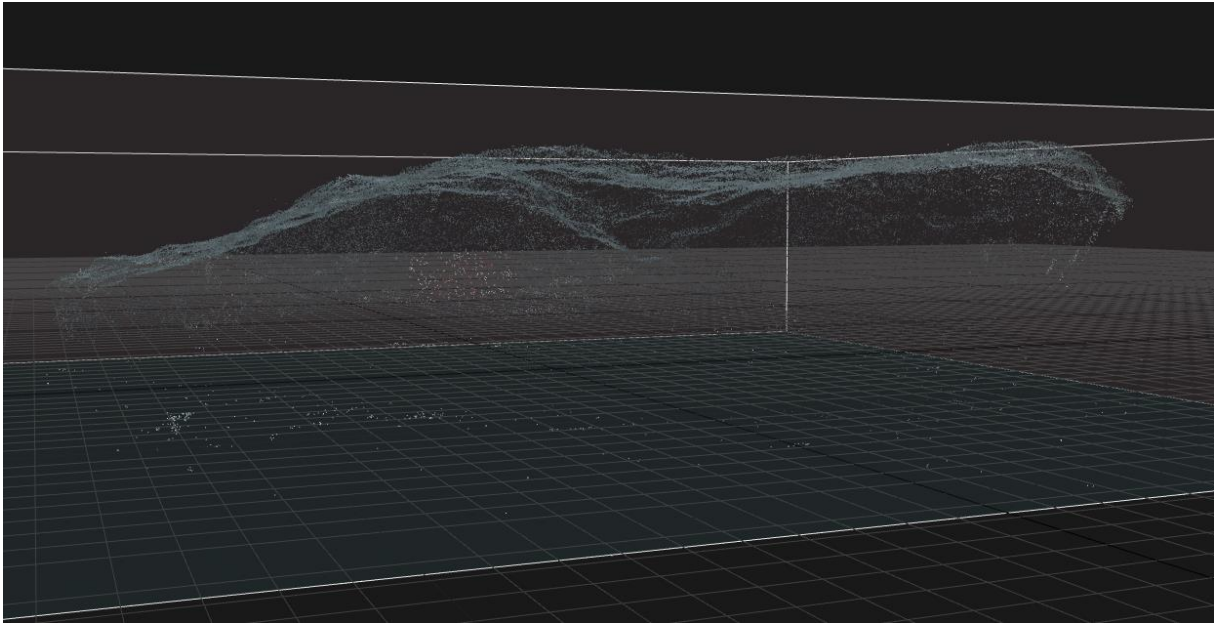
Fig. 33 Point cloud obtained on the basis of one photo series (37 photos).

The result clearly shows that camera was situated over the sample. It caused the full coverage of upper parts of the sample, but lower parts are totally invisible. Hence, it is not possible to create a proper model of the specimen based on the only one series.

8.2.3 Limitations of VR /software

In coming years, the prognosis of the dynamic development of virtual reality is established. Nevertheless, it is still a quite new technology hence during the execution of this project a few technical problems were observed. One of them was connected with the lack of a fluent motion (a blurred vision) during the examination of VR environment. The current industry standard is 90 FPS, which means that VR headset renders a minimum of 90 pairs of-high quality images each second (Jastrzębski, 2018). In some complicated scenes the number of FPS was lower. Hence the simplification of specimens was conducted. Additionally, during the execution of this project, one of the latest, high class personal computer was used. It means that in case of the application of the less efficient PC the time of calculation etc. would increase significantly.

9 Conclusions

The main output of this research is a virtual 3D collection of rocks and minerals kept at Aalto University. Also, the professional photo studio to capture similar objects in future was built. The rock and mineral collection consisting 107 samples is available via two different channels: Sketchfab portal and VR environment. The used workflow and all relevant issues were described in this master thesis.

Rocks and minerals are great objects to be digitised by using photogrammetric techniques. Majority of them have vivid colours and distinctive textures. Also, the size of the specimens kept for educational purposes is quite favourable. The main limitation concerns capturing of reflective/shining surfaces and inner caverns/voids. Nevertheless, during the creation of EDUROCK collection the majority of samples were captured correctly.

The proper configuration of the photo studio is an essential issue. To achieve satisfying results, application of additional equipment like for example a light tent, a rotary table, lamps etc. can be done. The main factors, which have the most significant influence on the final quality of the models, are: even and sufficient lighting and accurate depth of field. During the execution of the similar ventures, it is recommended to use the knowledge and experience, which were gained during the accomplishment of this project.

After proper configuration, the workflow of the creation of 3D models is relatively fluent and time-effective. The most time-consuming part of the whole operation is the creation and texturing of the model. Nevertheless, many stages can be done remotely using relevant software and a lot of processes are done automatically without real involvement of the human (for example a creation of the 3D model in Reality Capture). The main problem concerns transitional phases.

The implementation of models into the VR environment can be a little complicated and requires some level of proficiency in using Software (Unity game engine). On the other hand, due to the high complexity of this kind of computer programmes, the potential possibilities of development are nearly endless, hence in the future, only our imagination and creativity will be our limitations. It means that VR has enormous educational potential and it is defined as an effective tool for the data visualisation.

Due to satisfying course of the EDUROCK project and high-quality of the final output, it is expected that in the future, photogrammetric techniques will be used widely during the process of acquisition of a similar kind of data.

10 Recommendation and path forward

There are a few different aspects, which can be surveyed and developed in the future:

Firstly, the evaluation of the current results should be done. This part can include following actions:

- o Acquirement and evaluation feedback from users
- o Implementation of required amendments and corrections
- o The development of VR environment

Secondly, the constant promotion of EDUROCK project should be conducted. It can contain:

- o Cooperation with different institutes/universities/museums
- o Sharing the output of the project
- o The active participation in conferences/events

Thirdly, the evaluation of different alternatives (comparative analysis) can be done. The alternatives can include:

- o Raspberry Pi
- o Smartphones
- o Others

Fourthly, the extending of the collection is foreseen. To accomplish this aim, the following tasks need to be done:

- o Photo sessions of last lacking specimens (mainly schists)
- o Adding very rare specimens (meteorites etc.)
- o Creating a collection of rocks from different parts of Finland/World

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Appendices

Appendix A: The list of rocks and minerals

	Name	Rock/Mineral	Washing	Captured	RAW	Unity	FBX
1	muscovite	M		x	x	x	
2	biotite	M	x	x	x	x	
3	plagioclase	M	x	x	x	x	
4	feldspar	M	x	x	x	x	
5	diopside	M	x	x	x	x	
6	beryl	M	x	x	x	x	
7	garnet	M	x	x	x	x	
8	epidote	M	x	x	x	x	
9	gypsum	M/R		x	x	x	
10	hypersthene	M	x	x	x	x	
11	chlorite	M		x	x	x	
12	cordierite	M	x	x	x	x	
13	quartz	M	x	x	x	x	
14	kyanite	M	x	x		x	
15	flint	M	x	x	x	x	
16	hornblenda	M	x	x		x	
17	talc	M					
18	tremolite	M	x	x		x	
19	hematite	M		x		x	
20	magnetite	M		x		x	
21	chromite	M		x	x	x	
22	limonite	M		x		x	
23	pyrite	M		x		x	
24	molybdenite	M		x		x	
25	sphalerite	M		x		x	
26	graphite	M		x	x	x	
27	sulfur	M		x		x	
28	arsenopyrite	M		x		x	
29	chalcopyrite	M		x		x	
30	galena	M		x	x	x	
31	pyrrhotite	M		x		x	
32	calcite	M	x	x	x	x	
33	dolomite	M	x	x		x	
34	siderite	M		x		x	
35	flourite	M		x		x	
36	apatite	M	x	x		x	
37	conglomerate	R	x	x		x	
38	sandstone	R	x	x	x	x	
39	coal	R		x	x	x	
40	granulite	R	x	x	x	x	
41	organic limestone	R	x	x	x	x	
42	marlstone	R		x	x	x	

#	Name	Type					
43	quartzite	R	x	x	x	x	
44	quartz-sericite schist	R	x	x	x	x	
45	phylite	R	x	x	x	x	
46	mica-schist	R	x	x	x		
47	granite-gneiss	R	x	x	x	x	
48	claystone	R		x	x	x	
49	sercite-schist	R	x	x	x	x	
50	amphibolite	R	x	x	x	x	
51	limestone	R	x	x	x	x	
52	soap stone	R	x	x	x	x	
53	black schist	R	x	x	x	x	
54	serpentynite	R	x	x	x	x	
55	scapolite	M	x	x	x	x	
56	tourmaline	M	x	x	x	x	
57	wollastonite	M	x	x	x	x	
58	uvarovite	M	x	x	x	x	
59	pegmatite	R	x	x	x	x	
60	obsidian	R	x	x	x	x	
61	ryolite	R	x	x	x	x	
62	marble	R		x	x	x	
63	granite	R	x	x	x	x	
64	diorite	R	x	x	x	x	
65	mica andesit	R	x	x	x	x	
66	dunite	R	x	x	x	x	
67	gabro	R	x	x	x	x	
68	peridotite	R	x	x	x	x	
69	diabase	R	x	x	x	x	
70	anthracite	R		x	x	x	
71	basalt	R	x	x	x	x	
72	diatomacrous earth piimata	R		x	x	x	
73	anhydrite	R		x	x	x	
74	azurite/malachit	M	x	x	x	x	
75	pholoite	R	x	x	x	x	
76	topaz	M	x	x	x	x	
77	riebeckite granite (ailsie)	R	x	x	x	x	
78	peat/turf	R		x	x	x	
79	oil shale	R		x	x	x	
80	volcanic tuff	R		x	x	x	
81	syenite	R	x	x	x	x	
82	oolitie hematite	R		x	x	x	
83	manganese ore	R		x	x	x	
84	olivine	M	x	x	x	x	
85	zeolite	R		x	x	x	
86	lignite/brown coal	R		x	x	x	
87	lava	R	x	x	x	x	
88	halite (rock salt)	M		x	x	x	

89	barite	M	x	x	x	x	
90	rhodonite	M	x	x	x	x	
91	jasper	R	x	x	x	x	
92	vesuvianite	M	x	x	x	x	
93	sapropel	R		x	x	x	
94	pumice stone	R		x	x	x	
95	opal	M	x	x	x	x	
96	kaolinite	R		x	x	x	
97	cassiterite	M		x	x	x	
98	rutile	M	x	x	x	x	
99	Sebastian sample	R		x	x	x	
100	dacite	R	x	x	x	x	
101	mud	R		x	x	x	
102	magnesite	M/R		x	x	x	
103	ilmenite	M		x	x	x	
104	anorthosite	R	x	x	x	x	
105	volcanic bomb	R	x	x	x	x	
106	layered clay	R		x	x	x	
107	ozokerite	R		x	x	x	
108	phlogopite	R	x	x	x	x	
109	limestone	R	x	x	x		
110	pumice liparriiti	R		x	x	x	
111	greenschist	R	x	x	x		
112	fullerene sungiitti	M		x	x	x	

Key:

- ➢ The first column contains information about an ordinal number of a particular sample.
- ➢ The second column contains information about name of a particular specimen. The green colour in the second column means that ability of the recognition of this specimen is required during the course "Geology and geomechanics".
- ➢ The third column indicates if the analysed specimen is mineral or rock.
- ➢ The X mark in the fourth column means that the photo session of this particular sample was conducted, and output was saved. Colours in the fourth column have following meaning:
  - o Green – the 3D model of a particular sample was created and saved into Reality Capture.
  - o Light green – the following sample has some kind of defects (for example not all surfaces are shown correctly.
  - o Orange – due to technical/other reasons the following specimen was not captured. In the future adding of missing samples is planned.
- ➢ The X mark in the fifth column means that photos of this sample were saved in RAW format as well as in JPEG format.
- ➢ The sixth column contains information if analysed sample was implemented into Unity Game Engine environment.
- ➢ The seventh column shows if simplified mesh file was created and saved.

Capturing photos

A. At least thirty minutes before photo sessions, switch the light on to provide the best possible lighting conditions.

B. Choose one specimen, which will be captured during a present photo session. The most favourable size of the sample is in the range between one and ten centimetres. At the very beginning, the process of preliminary cleaning should be conducted.

C. Identify at least three surfaces, which will be used as a basis during consecutive photo sessions. After changing the position of the sample at least one surface of the specimen from the previous photo session should be visible in the obtained configuration.

D. Place the sample, in the middle of the rotary table. The vertical axis of rotation of the specimen should correspond with the axis of rotation of the table to maintain the central position of the sample during the revolution of the table.

E. Use tripods and screen of the camera to provide the most favourable configuration of the camera and the sample. During the whole revolution of the table, the whole sample should be visible on the screen of the camera.

F. Connect the camera, the rotary table, the charger and the socket.

G. Choose the "manual focus" option and set the sharpest point in the middle of the sample. You can use the "zoom in" option in the live view mode to conduct this stage more profoundly and accurately.

H. Switch on the rotary table and choose the proper settings.

I. Take one photo under the prevailing conditions to evaluate the quality of the present settings.

J. Use a pilot from the rotary table to commence a series of thirty-six consecutive photos.

K. Conduct another, two photo sessions to capture the sample from three different perspectives ultimately.

Processing photos

Due to the high complexity of issues connected with the photo editing process, the profound description of this matter is not included in this Master's thesis. The most basics corrections concern adjustment of "contrast" and "highlights" parameters. Canon Digitial Professional or Adobe Photoshop Lightroom Softwares can be used for example during the execution of this step. Nevertheless, in the case of the obtaining of high-quality JPEGs, these photos can be used during the creation of 3D models.

Creating models

Below the simplified instruction of the creation of models by using the Reality Capture software was attached.

A. Loading photos. First, relevant photo set needs to be uploaded. Choose the tab "Workflow", click the left mouse button (LMB) on the icon "Folder" and choose the proper folder from the computer.
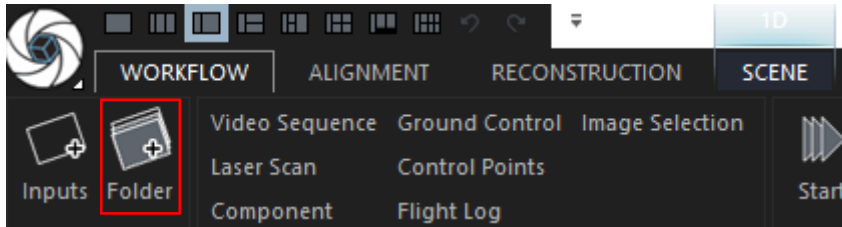

B. Aligning images. The proper alignment of the photos is needed. Choose the tab "Alignment" and click LMB on "Align Images". Also, the key "F6" can be used.
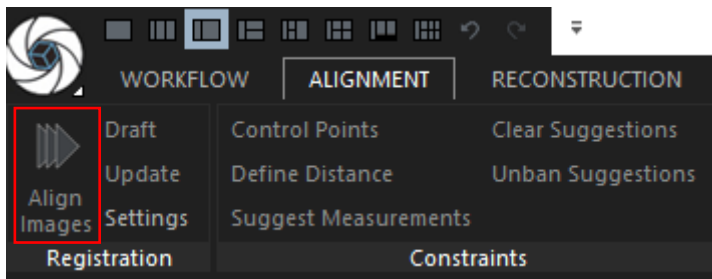
C. Normal reconstruction. To create the 3D model, the reconstruction process needs to be conducted. Choose the tab "Reconstruction" and click LMB on "Normal Detail". To create a 3D model for the currently selected component, also, the key "F7" can be used.
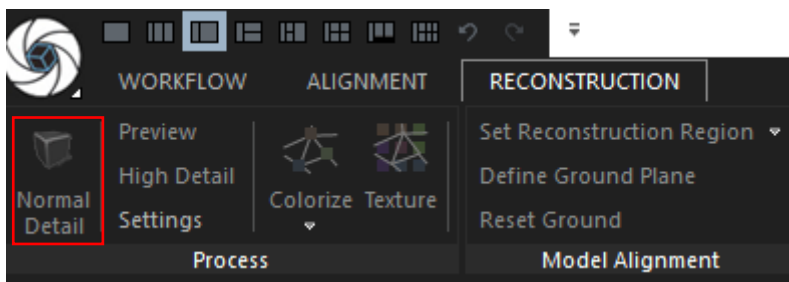
D. Lasso selection. Now the "cleaning" operation needs to be conducted. Choose the tab "Reconstruction" and click LMB on "Lasso". Left-click, hold and drag in a circular way to select model triangles. To delete unwanted structure click LMB on the "Filter selection" option.


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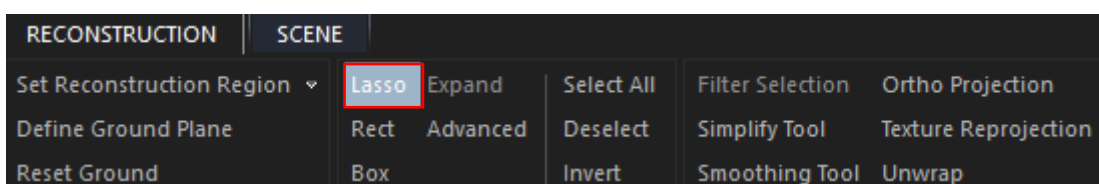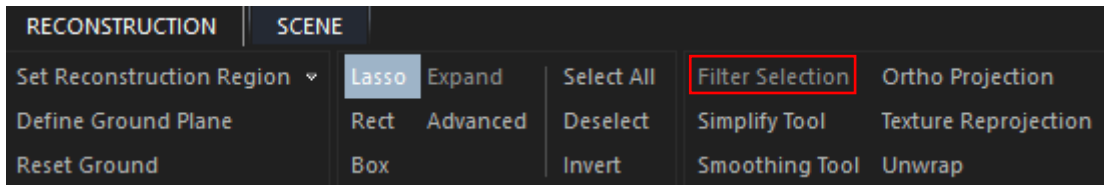
E. Removal of unnecessary models. For further work, only the final model is needed. Choose the unwanted models and click LMB on the "delete" option, marked by red colour.
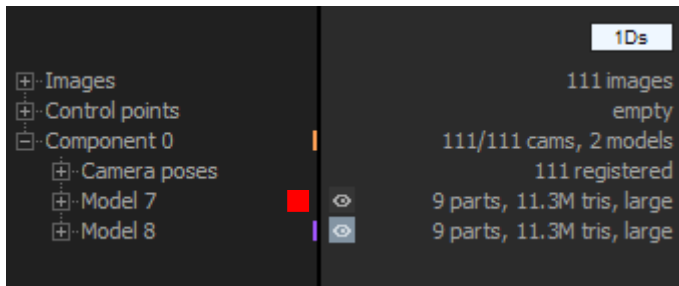

F. Texture. Next, the texture needs to be created. Choose the tab "Reconstruction" and click LMB on "Texture". Also, the key "F9" can be used.
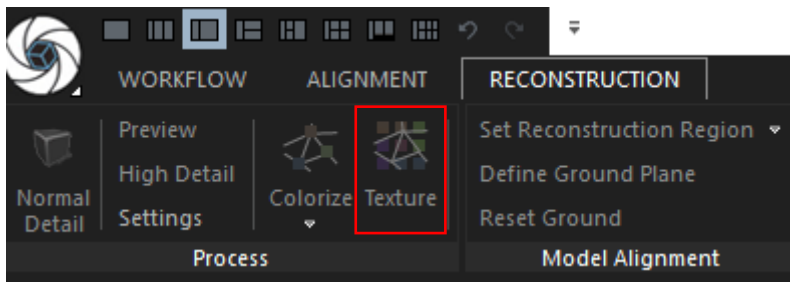

G. Simplification of a model. To simplify the present model, choose the tab "Reconstruction" and click LMB on the "Simplify tool". Next, go to the tab "Simplify tool" and click LMB on "Simplify".
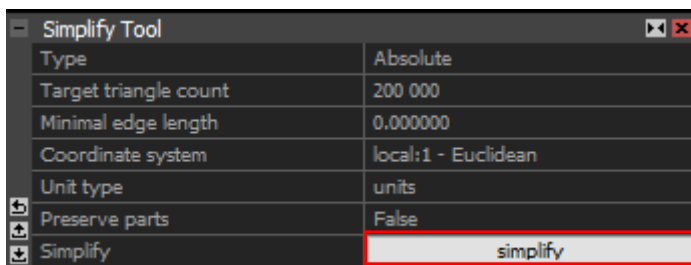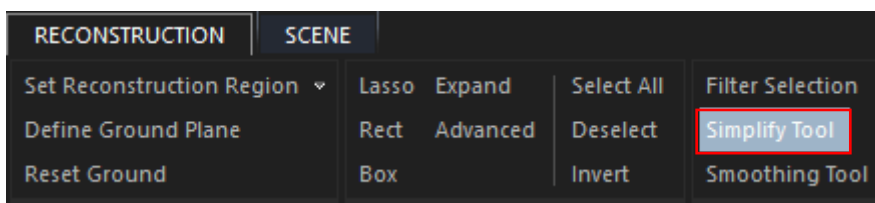
H. Texture reprojection. To reproject the structure, choose the tab "Reconstruction" and click LMB on the "Texture Reprojection". Next, go to the tab "Reproject model texture" and click LMB on "Reproject".
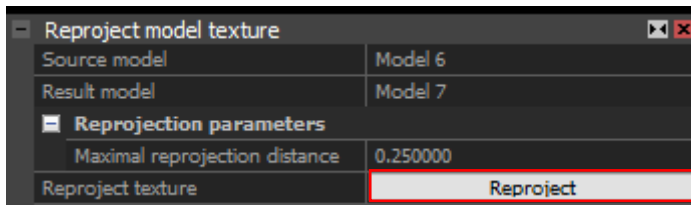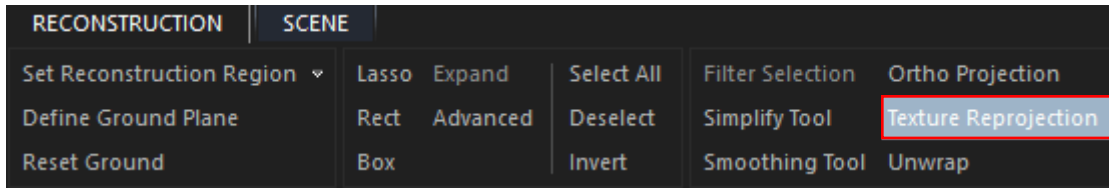

I. Mesh exporting. To finalize the process, export of the model needs to be done. Choose the tab "Reconstruction" and click LMB on the "mesh" (it is located in the export field). Next, save the result.
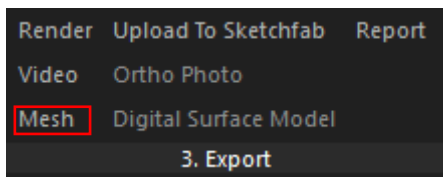
Uploading model on Sketchfab

To upload obtained model to Sketchfab platform, choose the tab "Reconstruction" and click LMB on the "Upload to Sketchfab" (it is located in the export field). Next, follow the instruction visible in the screen to fulfil all requirements of Sketchfab.
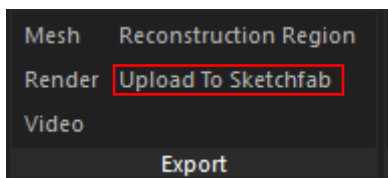
All models should be upload at EDUROCK AALTO account (sketchfab.com/EDUROCK_AALTO).