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Published in:
54th U.S. Rock Mechanics/Geomechanics Symposium, 28 June - 1 July

Published: 22/09/2020

Document Version
Peer-reviewed accepted author manuscript, also known as Final accepted manuscript or Post-print

Please cite the original version:
Janiszewski, M., Uotinen, L., Merkel, J., Leveinen, J., & Rinne, M. (2020). Virtual Reality Learning Environments for Rock Engineering, Geology and Mining Education. In *54th U.S. Rock Mechanics/Geomechanics Symposium, 28 June - 1 July: physical event cancelled* Article ARMA-2020-1101 American Rock Mechanics Association. https://www.onepetro.org/conference-paper/ARMA-2020-1101

ARMA 20–1101

Virtual Reality learning environments for rock engineering, geology and mining education

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ABSTRACT: Virtual reality (VR) can be used to enhance teaching in engineering education as it enables designing interactive and immersive exercises integrated with digitized learning spaces. In this paper, we demonstrate two VR learning systems related to rock engineering, geology and mining education developed at Aalto University, Finland. First is the Virtual Underground Training Environment created for the training of structural mapping and rock mass characterization. It consists of a photorealistic 3D model of the Underground Research Laboratory of Aalto University and virtual replicas of mapping tools. It was tested on students and the results demonstrated that training in VR reduces scatter in measured learning outcomes and increases the active learning time by +50%. The second VR learning system was developed for teaching students how to identify rocks and minerals. A collection of more than 100 rock and mineral specimens was digitized using photogrammetry and turned into a digital online learning asset. The two virtual learning systems demonstrate that VR can be a powerful tool to enhance learning in engineering education. Besides the educational potential, the photogrammetric digital models generated for the VR learning systems can be used for remote inspection and rock mass characterization, visualization, and communication of multidimensional data.

1. INTRODUCTION

Rock mass characterization, structural mapping, and identification of rock types and minerals are common challenges in engineering education for rock engineering, geology and mining. The best environment to train would be a real-life environment with as much variability as possible, and with many correct examples of key concepts and equally many examples of items that may be mistaken as something else. Usually, such environments and samples cannot be used due to limitations of accessibility, time and costs.

Virtual reality (VR) offers a possibility to use the environments and samples in teaching without limitations. The environment or samples are scanned and turned into 3D assets. Then the teaching content and the assets are added into a VR environment to form an interactive 3D learning environment. The benefits of using VR include safety, cost savings, time savings, repeatability, student-paced teaching, context-specific instructions and instant feedback.

In this paper, we demonstrate two VR learning systems consisting of digitized learning spaces and materials to aid in the teaching of rock engineering, geology and mining education at Aalto University, Finland. The first is a virtual underground tunnel environment for rock mass characterization and mapping. The second one is a virtual collection of rock and mineral samples for identification and learning the properties.

2. BACKGROUND

Recently, we have seen a rapid development of virtual reality and augmented reality technology, including applications related to mining and rock engineering (Onsel et al., 2018; Onsel et al., 2019; Mysiorek et al., 2019, Zhang et al., 2019). Virtual reality can also be used to enhance teaching in engineering education as it enables designing interactive and immersive exercises integrated with digitized learning spaces.

The Aalto University Rock Mechanics team have developed a photogrammetric method for scanning rocks surfaces to characterize their properties (Sirkiä et al., 2016; Dzugala et al., 2017; Uotinen et al. 2019), and to create photorealistic 3D models for educational VR systems (Jastrzebski, 2018; Merkel, 2019; Janiszewski, 2019; Janiszewski et al., 2020).

3. VIRTUAL UNDERGROUND TUNNEL ENVIRONMENT (VUTE)

Virtual Underground Tunnel Environment (VUTE) is a VR learning system developed for the training of structural mapping of discontinuities and rock mass characterization as part of Mining Education and Virtual Underground Rock Laboratory (MIEDU) research project.

The key component of VUTE system is a digital twin of the Underground Research Laboratory of Aalto University (URLA) (see Fig. 1a), which is located in a granitic rock mass, 20 m below the Otaniemi campus of Aalto University in Espoo, Finland. The tunnel is used for field exercises in various mining and rock engineering-related courses at Aalto University.

URLA was digitized using Structure-from-Motion (SfM) photogrammetry (Fig. 1b). SfM is a photogrammetric method, which utilizes a series of 2D images to reconstruct 3D scenes and objects. SfM photogrammetric method allows the use of consumer-grade digital cameras and highly automated data processing (Micheletti et al., 2015).

The 3D tunnel model was implemented into the Unity game engine (Fig. 1c) and two interactive exercises related to rock mass characterization were designed to increase the active learning time and to reduce the costs of teaching.

In VUTE, there are two options for user movement. If the VR hardware enables room-scale experience, the user can move freely by walking around with their real-life motion reflected in the VR environment (see Fig. 2); if the movement in real-life is restricted the user can move by teleporting (see Fig. 3).

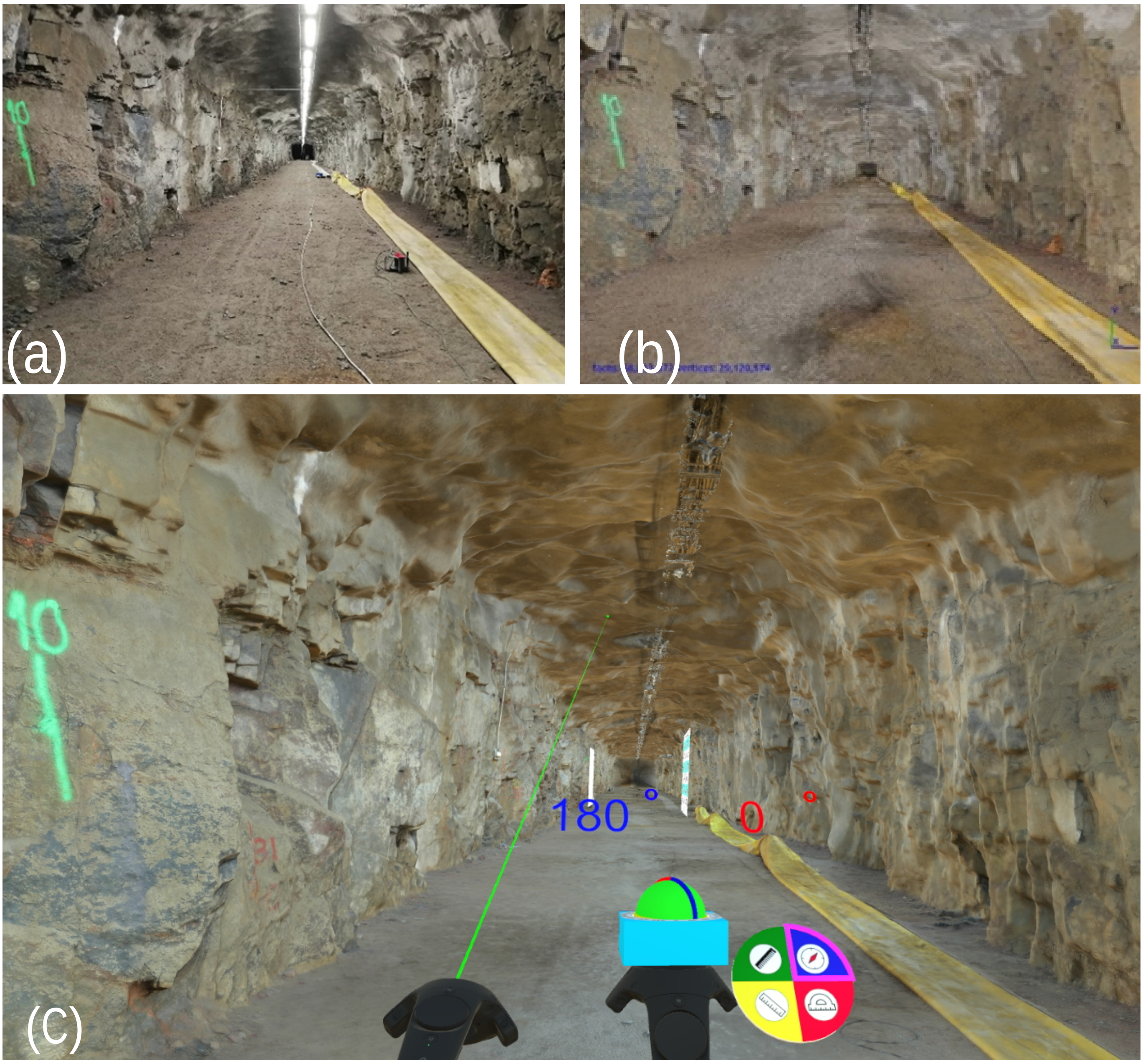

Fig. 1. (a) Underground Research Laboratory of Aalto University (URLA), (b) digital twin of URLA, (c) Virtual Underground Tunnel Environment (VUTE) built in the Unity game engine (modified after Uotinen et al. 2020).

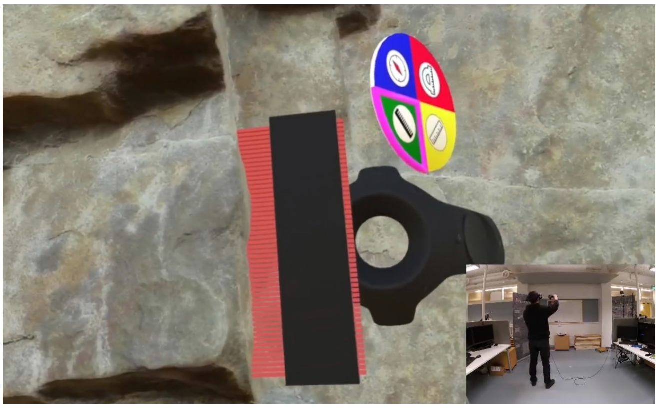

Fig. 2. An example of the room-scale set-up of VUTE.

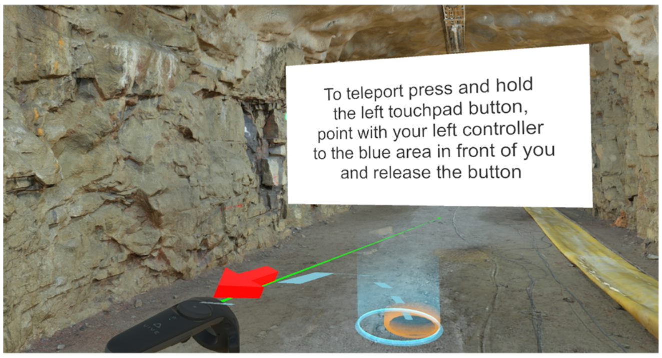

Fig. 3. VUTE teleportation movement tutorial.

3.1. *Structural mapping in VR*

The first virtual exercise is aimed at teaching structural mapping of the discontinuity planes on the tunnel surface. Virtual replicas of mapping tools were created, which enable virtual measurements of the orientation, spacing, and roughness of joints (Fig. 4). The users are asked to count the joint sets in a 10 m long tunnel section on the tunnel wall, and measure four properties of each joint set with a proper tool (see Fig. 5). The results are then filled in a virtual answer sheet (Fig. 6).

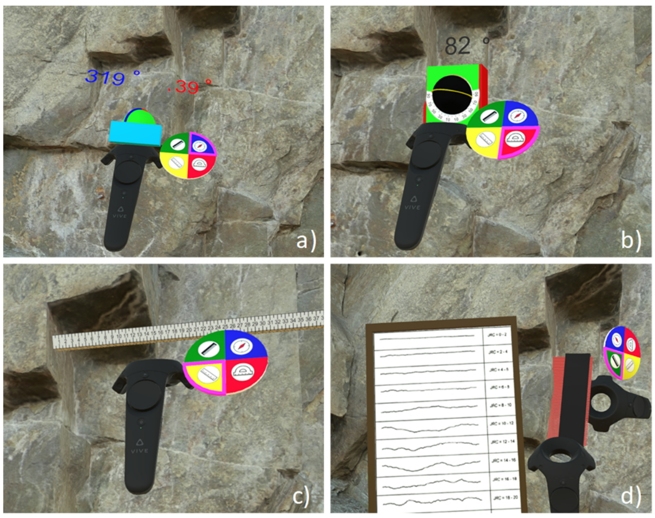

Fig. 4. Virtual tools for mapping the properties of the discontinuities on the tunnel surface: (a) dip direction, (b) dip, (c) spacing, (d) roughness.

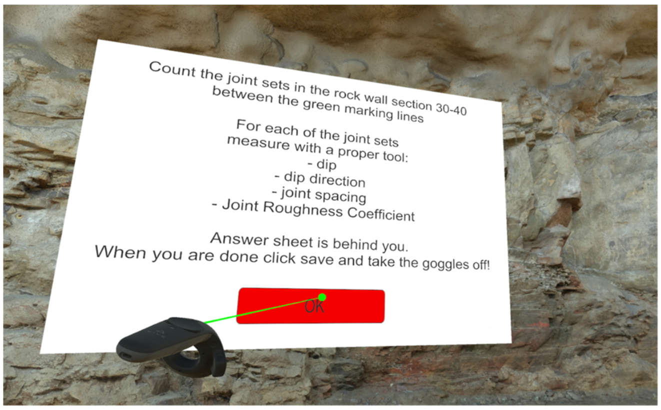

Fig. 5. The task is displayed for the user in VR.

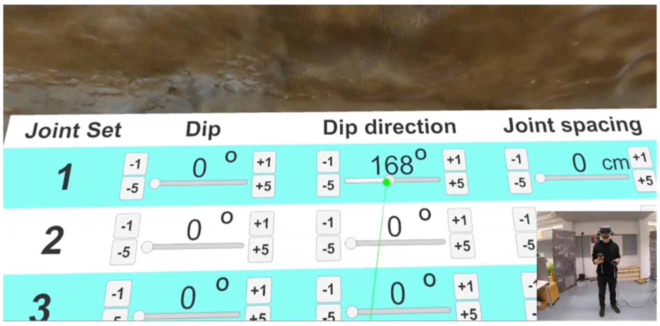

Fig. 6. Virtual answer sheet for the structural mapping exercise.

One key benefit of VR is that it enables an easy way to augment the virtual environment, which would not be possible in real-life. Therefore, we use this opportunity to test the visualization of spatial data on the tunnel surface. The Discontinuity Set Extractor (DSE) software developed by Riquelme et al. (2014) was used to process the tunnel wall point cloud acquired from the photogrammetric scanning, and to extract semi-automatically the discontinuity planes. The result was a 3D point cloud colored by joint set, which was implemented into the VUTE system in Unity (see the workflow in Fig. 7).

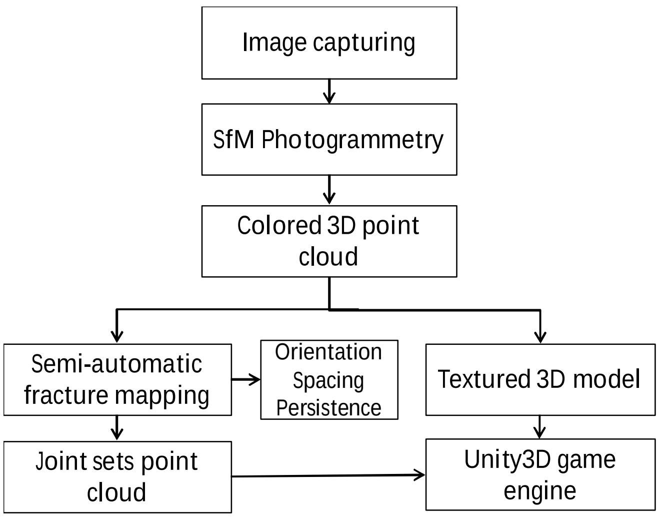

Fig. 7. Workflow of the photogrammetric digitization of the tunnel and joint sets extraction for the VUTE system.

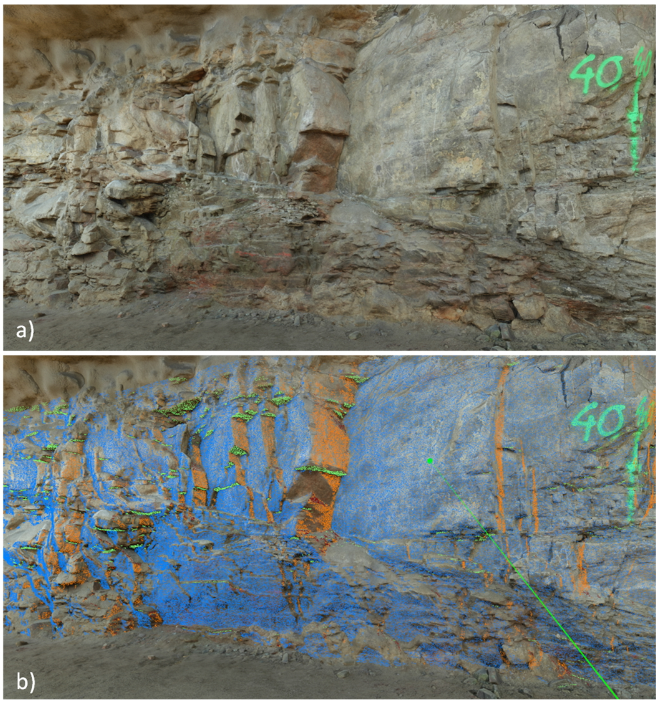

Fig. 8. Discontinuity sets extracted from the tunnel wall (a) and visualized on the virtual tunnel surface (b).

As a result, we can display the classified point cloud on the virtual tunnel surface (Fig. 8) to explain to the user which fracture planes belong to the same set.

3.2. Virtual learning feasibility test

To test the feasibility of using Virtual Reality as a training tool, a group of 20 students was split into groups A and B. Group A used VR first and then did the exercise in a real tunnel, and Group B vice versa. The measurements performed in VR were compared against real-life mapping performed by students and staff in the tunnel.

It was found that VR reduces scatter in measured learning outcomes (Fig. 9). Group A (VR first) had more consistent results than Group B when compared to Staff members. Also, active learning time was increased by +50%. The results demonstrated that students could identify the same three major joint sets with analogous orientations in both VR and tunnel mapping. The measurements made in the VR system were more systematic, and exercise completion time was reduced by 50% compared to manual compass measurements performed in the tunnel.

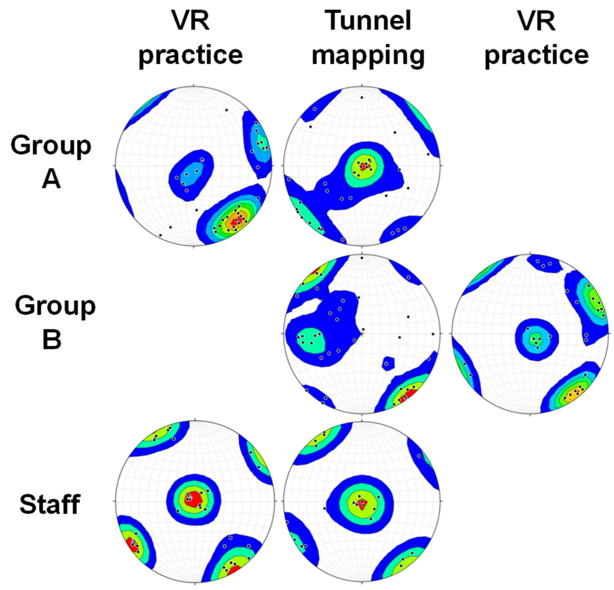

Fig. 9. Measured MIEDU learning outcomes of rock joint orientations (modified after Uotinen el al., 2020).

This work is one of the first steps towards investigating and realizing the full potential of VR technology in the education of future rock and mining engineers. The developed VR system has been proven to be a feasible enhancement of the regular way that rock mass mapping and characterization are taught at Aalto University. However, it must be stressed that VR is not intended to replace the practical exercises and field trips and should only be used to complement the regular teaching activities, for example as a priming session before the actual field exercise.

Subsequently, VR technology can provide a range of benefits to the mining industry. One of the most crucial aspects is related to the training of new personnel, where VR gives the possibility to replace the hazardous workplace with the safety of a virtual environment. With the use of 3D photogrammetric scanning, the previously inaccessible areas are available and fully safe explorable for the trainee. Realistic safety training could include a possible scenario in any part of underground excavations, repeatable as many times and as often as necessary without disrupting the everyday operations.

3.3. Rock mass classification (QVR)

The second exercise in VUTE that is currently being developed at Aalto University aims at the teaching of rock mass characterization using the Q-system developed by Barton et al. (1974) for classification of rock masses in underground openings and field mapping. The Q-system is often used in Scandinavia and is based on empirical data from many tunneling projects in Norway.

The Q-system is based on six parameters (see Fig. 10). In the virtual QVR exercise, the users are instructed to use the Q-system to classify the Q-value of a 10 m long rock wall section of the virtual tunnel. The objective is to divide the 10 m length into five equal windows and estimate each parameter five times per each window (Q-histogram method). The results are then entered into a virtual mapping protocol (see Fig. 11). The users can also access a virtual help sheet, in which the possible values for each parameter, as well as short explanatory notes, are described (see Fig. 12).

From the six parameters of the Q-system, the user can directly measure RQD (using a measuring stick), joint set number Jn (using the geological compass), and joint roughness number Jr (using a profilometer as demonstrated in Fig. 13). The joint alteration number and joint water reduction factor have to be estimated visually, which is possible thanks to the high-resolution textures of the 3D model. The Stress Reduction Factor SRF is calculated using a simple tool, where values are input using a slider, and the final value is displayed for the user.

Finally, the results are saved as a CSV file that can be imported into a sheet to compare the results against values estimated by experts. In the future, the mapping protocol will be upgraded to display the Q-histogram and the mean Q-value in real-time during inputting the values in the virtual mapping protocol.

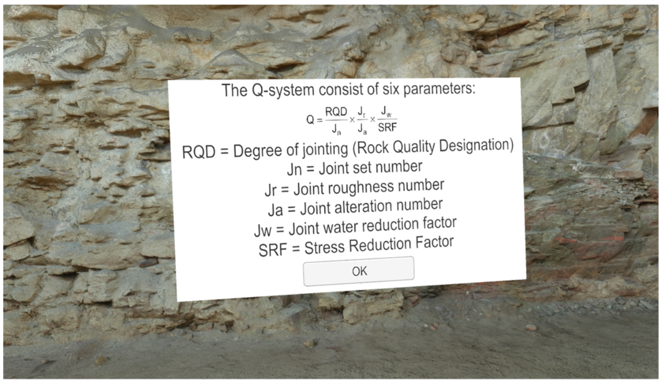

Fig. 10. Virtual Q-system classification exercise.

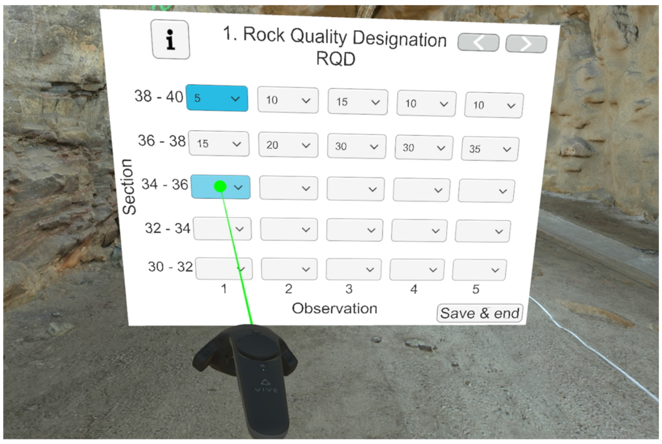

Fig. 11. Virtual mapping protocol.

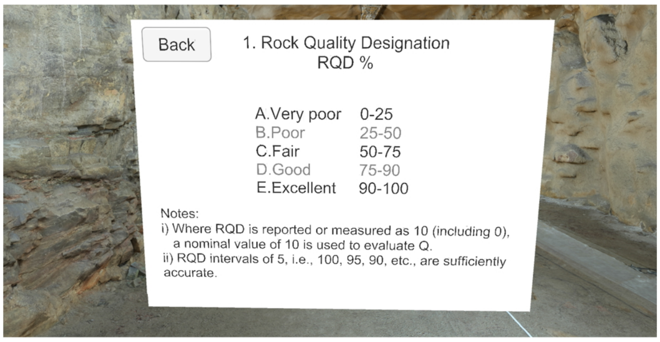

Fig. 12. An example of the help table in the QVR system.

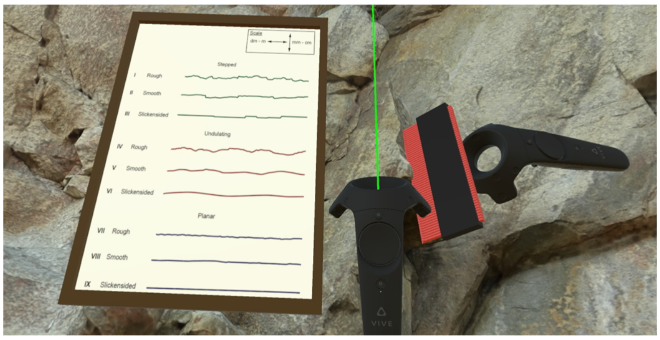

Fig. 13. QVR joint roughness profilometer and comparison chart.

4. VIRTUAL ROCK AND MINERAL COLLECTION (EDUROCK)

The second VR learning system was developed for teaching students how to identify rocks and minerals. The work was part of the Educational Virtual Rock Collection (EDUROCK) research project. The goal was to turn Aalto's rock and mineral sample collection into a digital online learning asset using SfM photogrammetry. The virtual collection is aimed to be used as teaching material for basic geology courses at Aalto University.

More than 100 samples were scanned using a custom-built photo studio with two DSLR cameras and a turntable (Fig. 14). In the typical workflow, the samples were placed on the turntable and scale bars were added to be later used for scaling of the samples (Fig. 15). Each sample was photographed in three rounds. First, 36 overlapping images were captured at 10° intervals of the turntable rotation. Then, the scale bars were removed and the sample was flipped by 90° and the second round of photos was taken. Finally, the sample was flipped again to capture the last round of photos. This helped to capture all surfaces of the sample, and at the same time, achieve overlap between the photos in three rounds. Next, the samples were processed in a photogrammetric software and 3D models were created. Digital 3D samples have photorealistic textures based on high-quality images and are scaled according to their real-life size. The detailed workflow is described in detail in the thesis by Merkel (2019).

Fig. 14. Photo studio built for the digitization of rock and mineral samples.

Fig. 15. Scale bars used in photogrammetry for scaling the scanned samples.

The virtual collection was uploaded to an online model repository Sketchfab and can be viewed or downloaded freely (Fig. 16). It is also implemented into an interactive learning platform developed in the Unity game engine for both PC-based and mobile VR headsets (Fig. 17). In the VR environment, students can inspect and interact with the digital samples (Fig. 18).

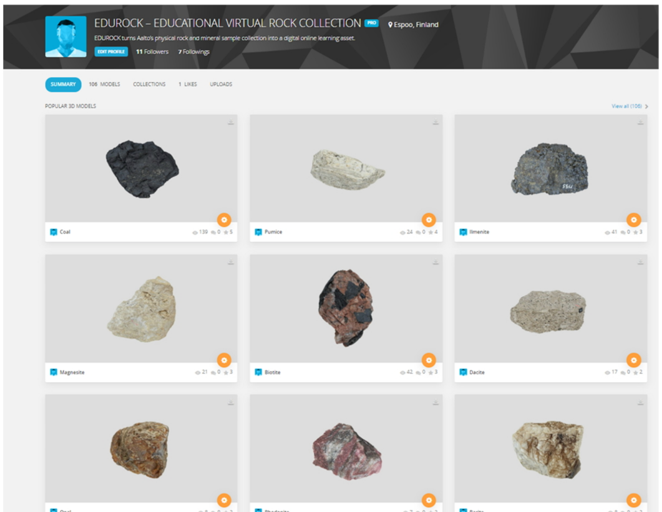

Fig. 16. On-line educational virtual rock collection. (https://sketchfab.com/EDUROCK_AALTO).

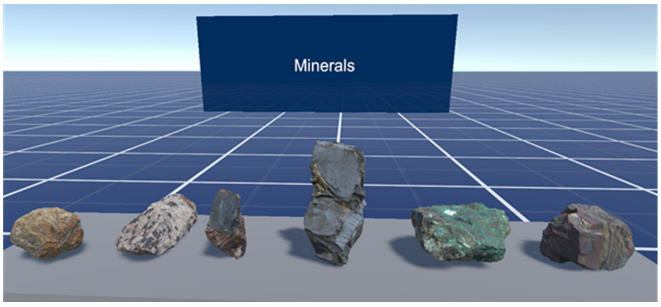

Fig. 17. Virtual mineral samples.

Fig. 18. EDUROCK virtual reality learning environment (see an example video of the VR system here: https://youtu.be/8mjEVKjdasY).

At this stage, the downside of the virtual collection is that the digital samples only contain the albedo textures exported from the photogrammetric software, so that the color of the sample is reproduced. However, some virtual samples lack luster, which is crucial for their identification. Therefore, the current development focuses on upgrading the samples using the Physically Based Rendering (PBR) materials, so that the glossy look is replicated for each sample.

5. CONCLUSION

The effect of applying of Virtual Reality (VR) for the mining and rock engineering education was investigated. Underground Research Laboratory of Aalto University was digitized using photogrammetry and made into an interactive VR rock quality mapping exercise. The exercises were 50 % faster to carry out and a significant reduction in scatter of the answers was observed compared to the group without VR training.

A subset of the Aalto rock mineral sample collection was digitized and made into an interactive VR rock and mineral identification exercise. A collection of 100 rock and mineral samples was published online for open access. Current efforts are aimed at Physically Based Rendering to provide more accurate luster for the samples.

ACKNOWLEDGMENT

We thank Jakub Jastrzębski and Jyrki Oraskari for their contribution to the development of the VR systems. This work was supported by Aalto University as part of the Aalto Online Learning educational development project and we kindly acknowledge the financial support for MIEDU and EDUROCK pilots.

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