Virtual learning environments for rock engineering education and training - a guideline for development, examples, and lessons learned

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ABSTRACT: This paper presents the research and educational development activity at Aalto University in creating virtual learning environments for rock engineering education. Virtual learning environments are increasingly recognized as tools to improve engineering education, but their creation requires specialized knowledge of 3D scanning, computer graphics, and game development. The paper discusses a method for creating 3D models of real environments using photogrammetry, along with hardware and software options. The models are then integrated into virtual learning systems built using game engines. Two case examples focusing on digitizing sites for virtual rock mass mapping are presented, and the outcomes and lessons learned are discussed. The paper concludes that accurate and photorealistic virtual learning environments can be developed to enhance rock engineering education and training. This has implications for the future development of virtual learning environments in engineering education and highlights the potential for using extended reality technology to communicate complex spatial data.

Keywords: virtual reality, engineering education, photogrammetry, virtual learning environment.

1 INTRODUCTION

Engineering education and training is undergoing a transformation due to the increasing demand for more innovative teaching methods and learning experiences. Virtual learning environments (VLEs) are becoming a popular solution as they offer students hands-on experiences in a controlled and safe setting (Paulomäki et al. 2022). The use of extended reality technology, such as Virtual Reality (VR) presents significant opportunities for the enhancement of engineering education through immersive visualizations and interactive experiences (Onsel et al. 2018). The use of extended reality technology allows, for example, virtual site visits to complement fieldwork and provide access to inaccessible sites (Godlewska et al. 2023). Despite the recent developments of VLEs for engineering education, their creation remains a challenge. Specialized knowledge in fields such as 3D scanning, photogrammetry, computer graphics, and game development is necessary.

The development of VLEs for rock engineering has been studied extensively at Aalto University in recent years (Jastrzebski, 2019; Janiszewski et al. 2020a; 2020b; 2021; 2023; Zhang, 2020. This article provides an overview of the research and educational development activities at Aalto University focused on the creation of virtual learning environments for rock engineering education. It presents a method for developing digital environments based on real locations digitized using a photogrammetry-based approach. This method provides a detailed 3D model of the digitized environment and can be applied to a range of spatial scales and applications. The article also outlines the basic workflow for incorporating the 3D models into virtual learning systems built using game engines and showcases two case studies of real sites digitized for a virtual rock mass mapping system. The main outcomes and lessons learned from these case studies are discussed, and the conclusion summarizes the key findings and provides recommendations for future work in this field.

2 GUIDELINE FOR PHOTOGRAMMETRY-BASED DIGITIZATION OF REAL SITES INTO VIRTUAL LEARNING ENVIRONMENTS

The key element of the VLE is an immersive 3D model of a real environment digitized using photogrammetry. Photogrammetry allows us to reconstruct a textured 3D model of the environment from a set of overlapping images captured from various angles. The photogrammetric method for high-accuracy digitization was researched extensively at Aalto University in recent years (Uotinen et al. 2019). The efforts were focused on developing low-cost methods that could compete with expensive laser scanning techniques while keeping the image acquisition time low.

2.1 Define learning objectives and select a site

Before creating a virtual learning environment, it is essential to define clear learning objectives. For rock engineering, the objectives could include understanding rock formations, identifying geological features, and understanding geotechnical principles. These objectives will guide the scope of the project and determine design choices.

To create an accurate and immersive virtual environment, real sites can be scanned using photogrammetry techniques. The first step in the photogrammetric acquisition process is to select a suitable site for data acquisition. The site should be representative of the geological features that are being studied. The site's accessibility, quality of rock formations, and permission to access the site should be considered when selecting a location to scan.

2.2 Scan the site

Once the site has been selected, the equipment for data acquisition needs to be set up. This can include cameras, tripods, and other equipment needed for capturing images. The initial step in the digitization procedure involves the acquisition of a series of overlapping images (at least 70% overlap) of the rock formation from different angles through the selected hardware. Each hardware option provides a way to digitize objects and environments at various scales so that accurate geometry and realistic visual appearance are represented as a textured 3D model.

The models for virtual rock engineering exercises must be at least scaled and orientated properly so that the measurements approximate real life. This is achieved using scale bars and control points (Janiszewski et al. 2022). The model can also be georeferenced using ground control points with known coordinates if available.

A range of hardware and software options were developed and tested for digitization at Aalto University and are discussed here, including, a smartphone, DSLR cameras, 360-degree cameras, a multi-camera rig, a rotary table studio, and a professional terrestrial laser scanner (TLS).

Small objects up to 1m in size are digitized using a custom-built photography studio with a rotary table and a high-resolution DSLR camera. The first use case of the studio was a virtual rock and mineral collection developed by Merkel (2019) and published in an online model repository (EDUROCK AALTO, 2019). The studio is used currently for the digitization of rock samples and fracture surfaces for hydromechanical tests (Torkan et al. 2022).

The simplest approach for digitizing sites, such as tunnel walls or drift, is to utilize the camera in the smartphone to capture the images, or to use an iPhone 12 Pro laser scanner for quick scans within the 1-5 m size and range, e.g., a tunnel face (Torkan et al. 2023).

For more demanding scans, the use of DSLR cameras and fixed focal length lenses provides high-quality images that can be used to produce 3D models of large areas, such as the virtual replica of the Aalto research tunnel (Janiszewski et al. 2020b).

For scanning large outdoor areas, for example, open pit mines, slopes or rock cuts, the better approach is to utilize UAVs for capturing the images, as demonstrated in Uotinen et al. 2021.

For cases where the time to capture the data is limited, we have also developed and tested an acquisition method with a 360 camera that allows for rapid capturing of multiple spherical images at the same time so that the entire geometry is digitized within minutes, e.g., tunnel section scanning presented in Janiszewski et al. 2022. Another rapid digitization method was developed for tunnel scanning where a low-cost multi-camera rig consisting of action cameras is used (Prittinen, 2021).

It must be noted that a combination of laser scanning and photogrammetry is also possible for efficient digitization of challenging and large environments. High-quality images are captured using DSLR cameras to provide detailed textures and laser scans are obtained with a professional TLS laser scanner to provide an accurate and rapid scan of site geometry. The raw data is then combined in photogrammetric software to obtain highly accurate and detailed 3D data of the environment.

2.3 Process the scans

Once the images have been captured, they need to be processed using photogrammetric software to create a 3D model of the rock formation. This involves identifying common points on each photograph and using triangulation to create a textured 3D mesh of the digitized environment.

Postprocessing is an important step in creating 3D models that are optimized for VR from photogrammetric data. A key postprocessing step is to optimize the mesh of the 3D model. This involves removing any unwanted elements or surfaces, such as holes or gaps, and reducing the number of polygons to make the model more efficient for VR. This can be achieved using software specifically designed for optimizing 3D models, such as Blender, or directly in the photogrammetric software.

2.4 Integrate the 3D environment into a virtual learning system

The 3D models are integrated into virtual learning systems built using game engines, providing students with an interactive and immersive virtual learning experience. The implementation of the 3D models into virtual learning systems includes few phases, e.g., importing the 3D model into the game engine, adding lighting and environmental effects, and integrating the model with educational content and interactive exercises. The two most popular game engines are Unity and Unreal.

Using the game engine's built-in tools, the virtual experiences can be designed to enhance the learning experience. Interactive elements, such as annotations, animations, and quizzes, can be added to make the environment engaging and effective. Lighting, weather effects, and ambient sound can also be incorporated to create a realistic environment.

2.5 Test and refine

Once the environment has been designed and developed, it should be tested and evaluated for its effectiveness in achieving the defined learning objectives. Testing can be done by using the environment and collecting feedback from learners, including observations of their interactions with the environment, feedback surveys, and other usability evaluations. This feedback can then be used to refine and improve the virtual environment, addressing any issues and making necessary changes to enhance the learning experience. By continuously testing and refining the virtual environment, learners will have a more engaging and effective learning experience, which will help to ensure that they meet their learning objectives.

3 CASE STUDIES

The practical applications of photogrammetry for developing virtual learning environments in rock engineering education are showcased through two case studies.

3.1 Rapid digitization method for virtual underground tunnel environment

The first case study focuses on developing a new 3D model of an underground tunnel for the Virtual Underground Training Environment (VUTE) created at Aalto University for virtual fracture mapping training (Janiszewski et al. 2020b). Initially, the VR system was built around one section of the Aalto test tunnel and was offering a safe and controlled environment to test and refine student skills before applying them in the field exercise in the test tunnel. The current effort is to expand the system by digitizing more locations with different rock mass conditions.

The rapid digitization method was utilized, and a 300 m long tunnel network was scanned using a multi-camera rig with four GoPro Hero 8 cameras (Figure 1a) recording a video of the environment. The total acquisition time amounted to 10 min. The video frames were then extracted and processed in Agisoft Metashape photogrammetric software. In total, 2877 frames were used and a 3D mesh with 39 million polygons and 10 textures of 8K resolution was produced. The preliminary results were very promising as demonstrated in an example of a tunnel scan in Figure 1. The mesh was then simplified to 1 million polygons and the high-resolution textures were reprojected so that it can be integrated into the VR learning system in the Unity game engine running on a PC.

Next, a more detailed scan will be done for an unsupported tunnel wall that will be used in the virtual mapping exercise. The two models will be seamlessly combined so that more details are distinguishable and measurable, such as smaller fractures or fracture roughness. An example of the combination of low- and high-resolution scanning is discussed in Janiszewski et al. 2022.

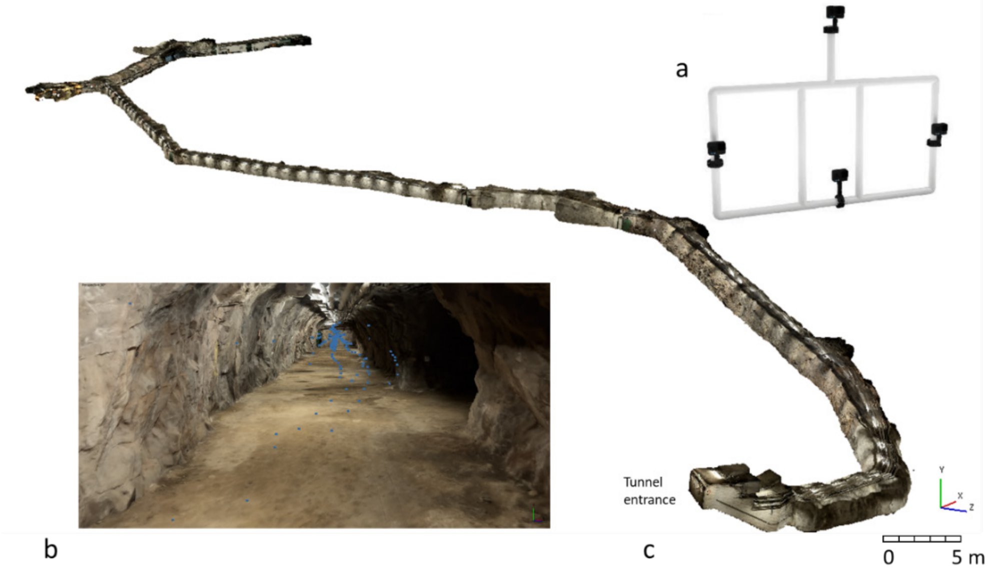

Figure 1. Tunnel network 3D model digitized using a camera rig composed of 4 action cameras (a); view from the inside of the 3D model (b), and perspective view of the entire 300m long tunnel model (c).

3.2 Gamified rock engineering teaching system for mobile VR

The second case study presents the digitization of a roadside rock cut for a gamified rock engineering teaching system for mobile VR headsets where the user is guided through basic concepts of fractures mapping. The gamified approach fosters student engagement and motivates active participation, leading to a more profound comprehension of the subject matter (Zhang, 2020; Janiszewski et al. 2023b).

A roadside rock cut with a clear jointing pattern was selected to be digitized into a virtual learning environment. Canon EOS 5DS R camera and Canon EF 14mm f/2.8 II USM lens were used to take 35 handheld pictures of the rock cut. To scale and orientate the model, an orientation board with 5 control points and known distances were used. The board was positioned in the scene so that all points are on a horizontal plane and one side is pointing towards the North (Figure 2b, c). This allows the correct fracture orientation mapping consistent with real life. The images were processed in Reality Capture photogrammetric software and a high-resolution model consisting of 114.1 million polygons and 4 textures of 8K resolution was reconstructed. The key postprocessing step here was to optimize the model so it can run on a standalone VR headset, such as Oculus Quest. The mesh was simplified step-wise (each step simplifies the number of polygons by 50%) to 11.4 thousand polygons. The textures (both the color and normal textures) were then reprojected from the high-res model to the low-resolution mesh, preserving the crisp visual quality required for VR (Figure 2a). The model was then imported into the gamified exercise and other interactive elements were added (Figure 2d).

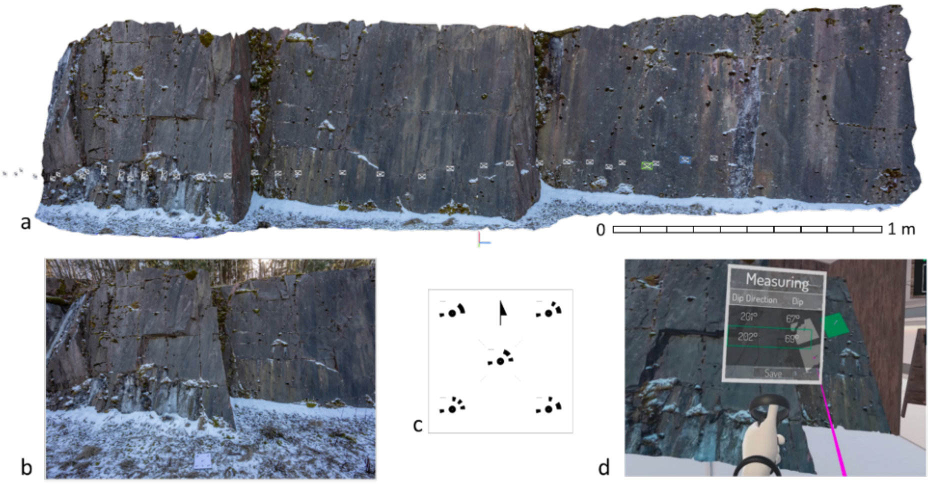

Figure 2. Roadside rock cut model (a) digitized using photogrammetry from overlapping images of the rock cut (b), and orientated using the orientation board (c); the model was implemented into a gamified rock engineering teaching system (d).

4 CONCLUSIONS

The utilization of virtual learning environments in engineering education and training has been gaining momentum in recent years, presenting significant potential for pedagogical advancement. This article highlights the potential of Virtual Learning Environments for rock engineering education and the work being done at Aalto University to make these environments a reality. By leveraging photogrammetry and game engine technology, the university is working to provide students with a more engaging and effective learning experience. A method for the creation of digitized environments, using a combination of hardware and software tools, was introduced.

The case studies presented in this paper demonstrate the effectiveness of photogrammetric methods for digitizing real sites into virtual learning environments. The underlying assumption is that practicing on real rock formations in VR is offering hands-on experience and promoting a deeper comprehension of rock engineering concepts. The results provide insights into the potential of virtual learning environments for rock engineering education and emphasize the significance of hands-on experience and interactive learning. Furthermore, research will be conducted to assess the impact of virtual learning environments on student learning outcomes and the improvement of understanding and application of rock engineering concepts.

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