Use of virtual reality for teaching geotechnics – application to the study of an abandoned underground mine

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ABSTRACT: This paper describes an innovative teaching activity based on the use of a 3D virtual model of a real abandoned underground mine exploited using the room-and-pillar method and located at a depth of several dozen meters. The model covers an area of about 1 hectare, composed of approximately 25 rooms and about 15 pillars made of in-situ rock or reconstructed (dry stones). The model consists of 80 measurement stations (3D scans and 360° photos). The educational activity is conducted in three stages. The first stage consists of visiting the site to learn how to use the model, get a first impression of the environment, and discover the mining techniques used. The second stage involves a guided analysis, where points of interest are indicated for students to analyze the fracturing of the pillars and roof (whether natural or mechanical in origin). The third stage involves a stability analysis, combining previous observations with some simple calculations, such as using the tributary area model to estimate the stress state of the pillars or the calculation of the roof reinforcement with bolts. A feedback session is also offered to highlight the strengths and weaknesses of the approach.

Keywords: Virtual model, Mine, Practical work

1 Introduction

The techniques associated with virtual reality have reached a level of maturity that allows fairly easy access to 3D models that can be used for training. Depending on the teaching situation (small group, large group, face-to-face or at home), we may favor visualization using virtual reality headsets or more simply on computer screens. 3D models can be composed of geometric objects simulating reality (BIM model for example), geometric objects resulting from a real capture of reality (3D scan or photogrammetry for example) or a combination of the two.

Several tools dedicated to learning geotechnics in the broad sense have been published. García-Vela et al. (2020), for example, present different tools allowing them to replace field trips that are difficult to organize (travel costs, student safety, availability of companies) with immersive experiences where students collect information from tunnels, mines and rock slopes in order to exploit them. Gürsoy & Buyuksagis (2024) present a virtual reality tool in underground mining education to enhance machinery comprehension. Janiszewski et al. (2020) present two virtual reality models dedicated to teaching to identify rocks and minerals or to carry out structural surveys and rock mass characterization. Afsharipour & Maghoul (2023) use virtual and augmented reality to teach soil mechanics concepts. The feedback provided generally conclude an added value for students and teachers. The feedback provided generally concludes that there is added value for students and teachers.

2 Presentation of the activity

The proposed activity involves studying the stability of an abandoned underground iron ore mine using a 3D model utilizing 360° photographs and laser scan measurements taken within the mine. The use of a virtual model appears to be an attractive solution for:

- avoiding the organizational constraints associated with a real-life visit (cost, travel time, student safety);
- reproducing a realistic situation for an engineer conducting a geotechnical assessment: collecting data, identifying geotechnical issues, and proposing and sizing solutions.

The mine consists of a fairly old operation (around 1850), made up of rooms, pillars and embankments. It corresponds to an intermediate period of exploitation between the first works whose geometry seems completely anarchic and the industrial period where exploitation follows a very geometric pattern. The use of explosive shots made it possible to achieve a certain regularity of work.

The educational activity takes the form of practical work carried out by groups of 4 to 5 M2 level students in an engineering course in Geosciences and Civil Engineering (Ecole Nationale Supérieure des Mines de Nancy, France). Prerequisites are academic knowledge in engineering geology and rock mechanics, but no complex calculations are expected. The educational sequence lasts 3 hours at the end of which the students have an additional time (about 2 weeks) to write a report in the form of an expert report according to a plan proposed by the teacher.

The available documents for the activity are the following:

- Site plans allowing the location of the sector studied and the approximate geometry of the works (Figure 1). The area studied has a surface of approximately 0.5 ha.
- The 3D model (Figure 2) composed of 80 360° photographs and millions of points (Laser scan).
- The results of a geological drilling carried out near the mine (drill C104).
- A document on reinforcement by bolting accompanied by pull-out tests supposedly carried out on the roof of the galleries.
- Two detailed base maps representing the studied area.
- Extracts from a work concerning “the history of the mines of Moyeuvre” (Spanier, 1914) in which information can be found concerning the evolution of mining techniques from 1832 to 1913, a description of the extracted deposit and information on the faults and joints existing nearby.

The plan of the article follows that of the practical work in which the following work is requested (Table 1). The time schedule indicated is that proposed by the teacher for the supervised activity. Students work alone (groups of 5) for 3 hours with regular discussions with the teacher. Personal work time at the end of the session is estimated at around 2 hours per student to achieve the final report. The actual time of personal work has not been asked.

Table 1. Proposed schedule for the students during the 3h sequence

Part 1 – 1 hour	Discovery of the model and familiarization with the documents Read the statement in full (10 minutes) Watch a 3D model presentation video (10 minutes) Consult the accompanying documents (20 minutes) Visit the mine (20 minutes) – identify pillars, embankments, collapsed areas, view associated annotations and photos
Part 2 – 1 hour	Analysis of the site, disorders and discontinuities Carry out a simplified lithostratigraphic profile Create a diagram of the roof discontinuities Create a figure to distinguish the embankments from the pillars Identify the extracting method Identify and comment on the different observable disorders
Part 3 – 1 hour	Geomechanical analysis Calculate the extraction ratio and the associated safety coefficients. Propose a roof bolting reinforcement (nature of bolts, length and number of bolts/m^2)

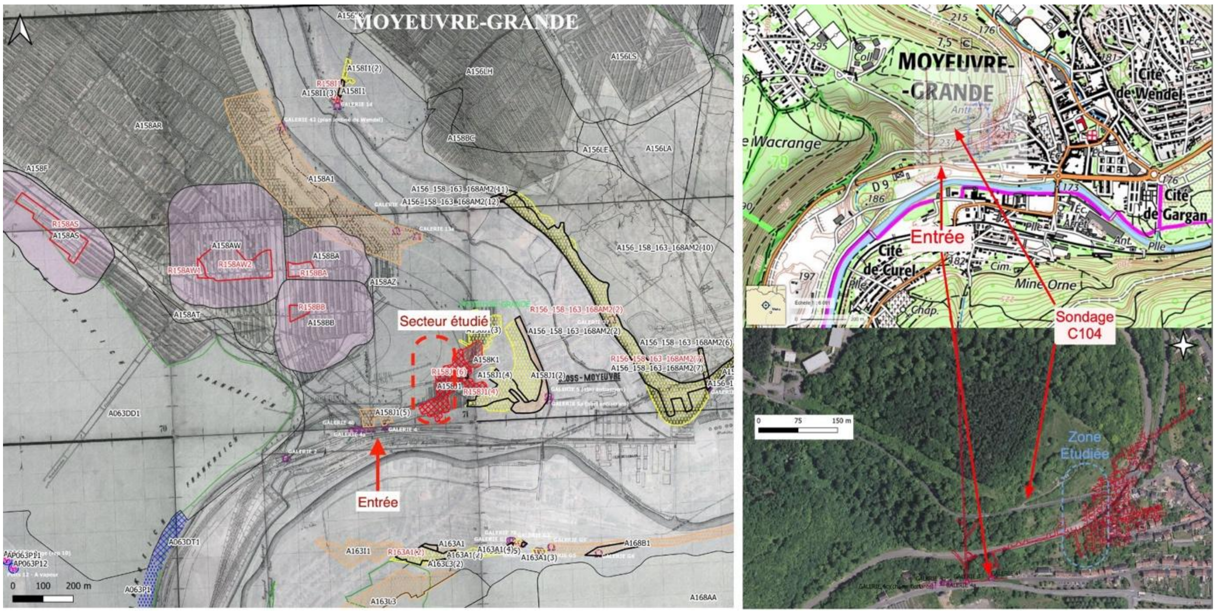

Figure 1. Location of the mining sector studied. Left) situation in relation to all the mining works located in the sector, Right-Up) Topographic map of the sector, Right-downC) aerial view of the sector.

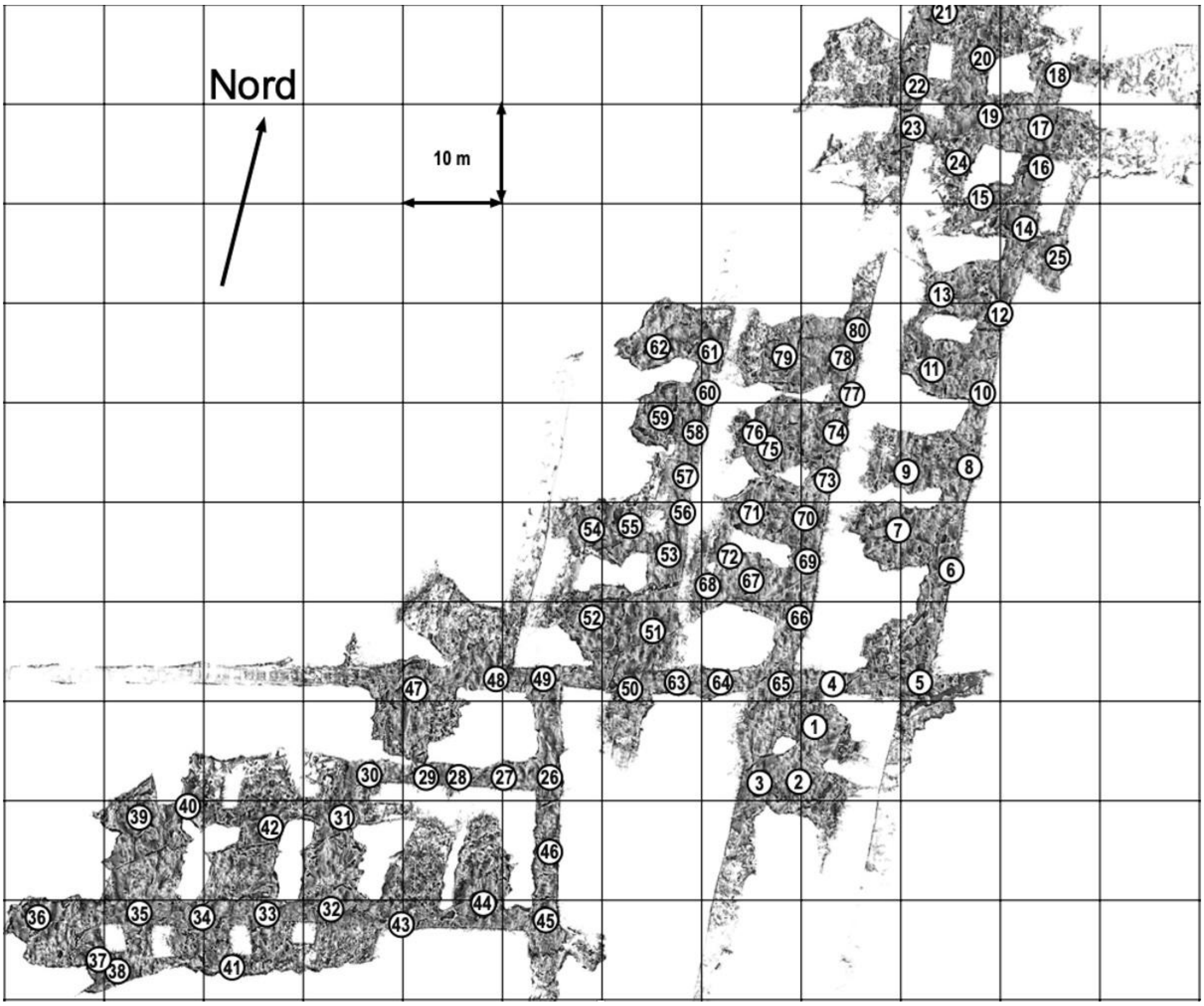

Figure 2. Map of the model produced from the 3D scan and location of the 80 stations where 360° photos are also accessible

3 Part 1 - Discovery of the model and familiarization with the documents

The model is accessible on the Web from any computer (Cintoo technology). The user has a view of the mine in the form of eighty 360° image (Figure 3) with a location on the map. Different visualization modes are possible: photographic image or colored point cloud. When the coloring is that of the photograph, the two renderings are almost identical. When the coloring is based on the reflectance of the walls, this provides access to a black and white image which has the advantage of making the underexposed areas of the photography visible (Figure 4). The 3D scan also makes it possible to carry out measurements in the mine and to visualize altitude iso values (Figure 5).

The model is also supplemented with annotations allowing access to comments and downloading higher definition photos in order to more clearly observe the discontinuities (Figure 7) and disorders (Figure 6) visible in the mine.

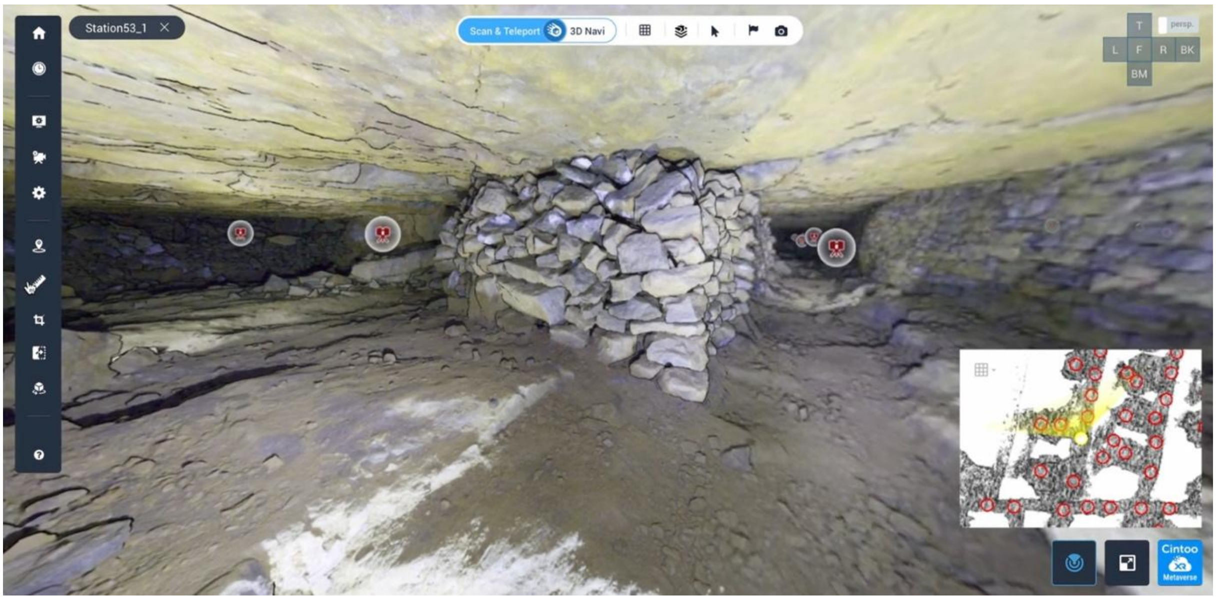

Figure 3. Example visual of 360° photos. The red icons on the image or on the map correspond to other places for viewing 360° photos. On the plan, a yellow angular sector allows you to know the orientation and angle of view.

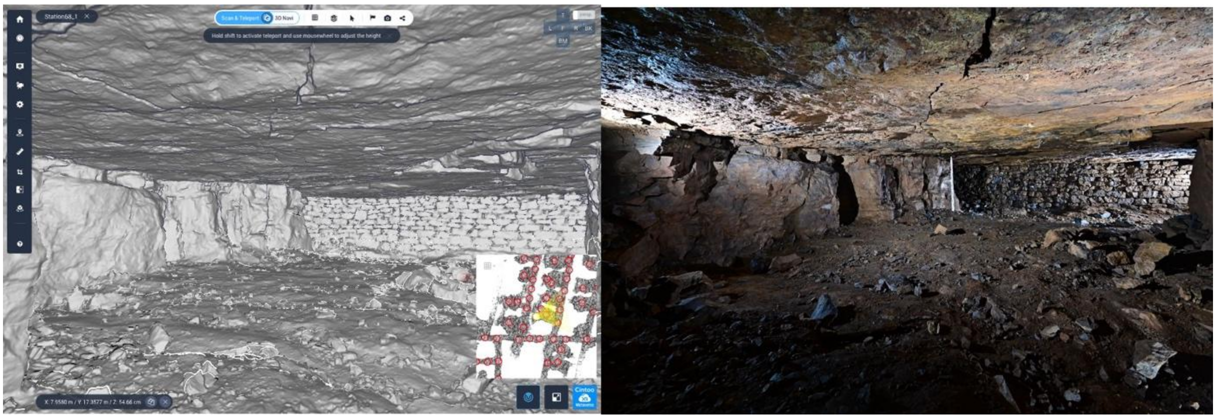

Figure 4. Example of a colored view (B/W) using wall reflectance, compared to a photograph from a similar viewing angle. The very visible discontinuity in the roof is also visible in the 360° photo. This same discontinuity is perfectly visible on the top view of the model.

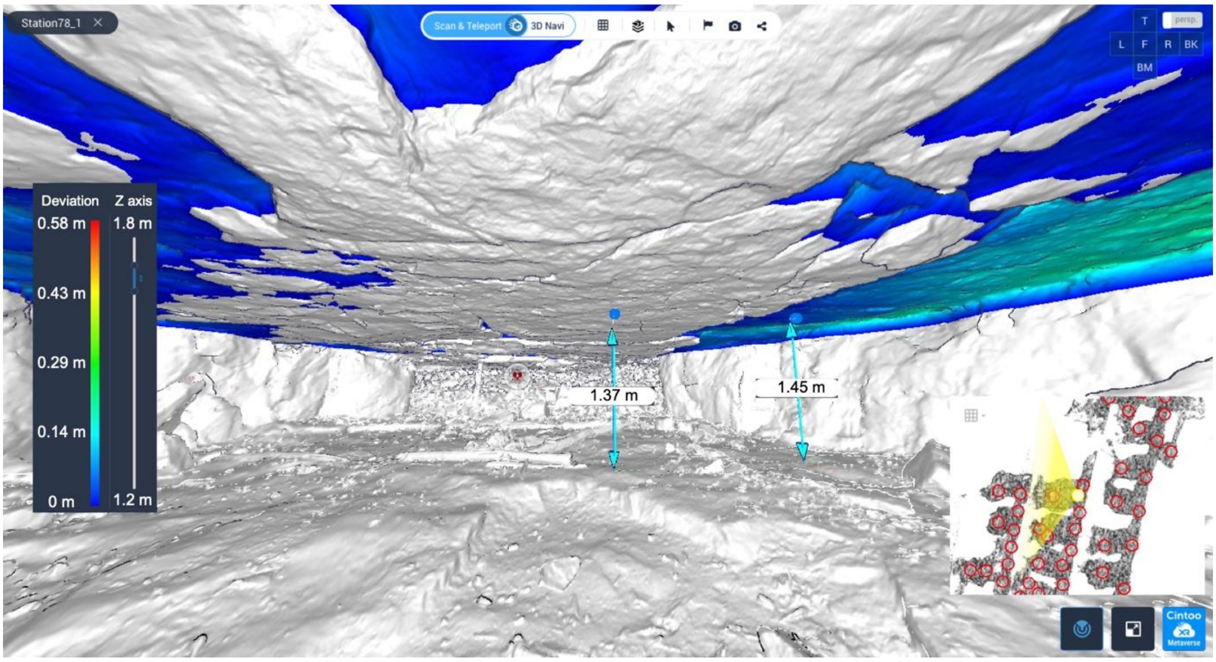

Figure 5. Example of iso-values of the altitude in a room. We observe that the roof in the center of the chamber is at a lower altitude than near the pillars, which suggests the existence of a sagging of the roof.

Figure 6. Example of photos accessible from the model and allowing visualization of disorders such as cracks in pillars (left) or in embankments (center) and roof instabilities (right)

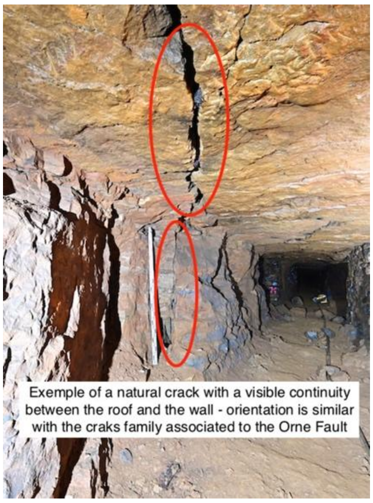

Figure 7. Example of photos accessible from the model and allowing a natural discontinuity to be visualized

4 Part 2 - Analysis of the site, disorders and discontinuities

The use of laser scanning provides access to a plan of the exploitation in black and white, where the solid areas are white (no measurements) and the exploited areas are filled with a texture that appears random at first glance. A more detailed observation allows to see in this texture some alignments that reveal the discontinuities located in the roof. The signature of these discontinuities is explained by the mask effect created by these discontinuities (Figure 8). Students are encouraged to observe this phenomenon and ensure through observations in the digital model that these alignments really correspond to discontinuities.

It is then possible to make a survey of these discontinuities from which the existence of 2 main families emerges, one oriented North, the other oriented N070 (Figure 9).

This observation can then be cross-referenced with archival documents (Figure 10) indicating the presence of two faults nearby, associated with a set of parallel discontinuities which strongly influenced the direction of the extraction works. Other discontinuities do not seem to belong to these two families (in green in Figure 9) and can be interpreted as discontinuities of mechanical origin associated with redistribution of stresses and ruptures of the roof of the galleries and chambers. Associated with the observation of locally collapsed areas, these different observations allow students to question the evolution of the mine and the risks of local instability (falling roof slabs).

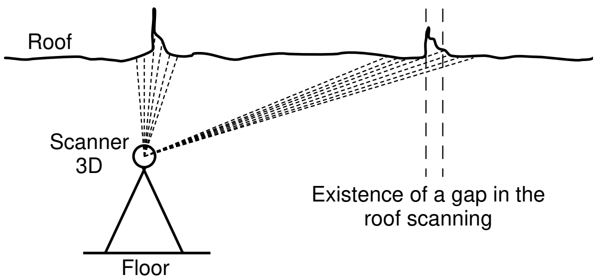

Figure 8: Explanation of the presence of voids in the 3D scan when discontinuities are not located directly above the scanner

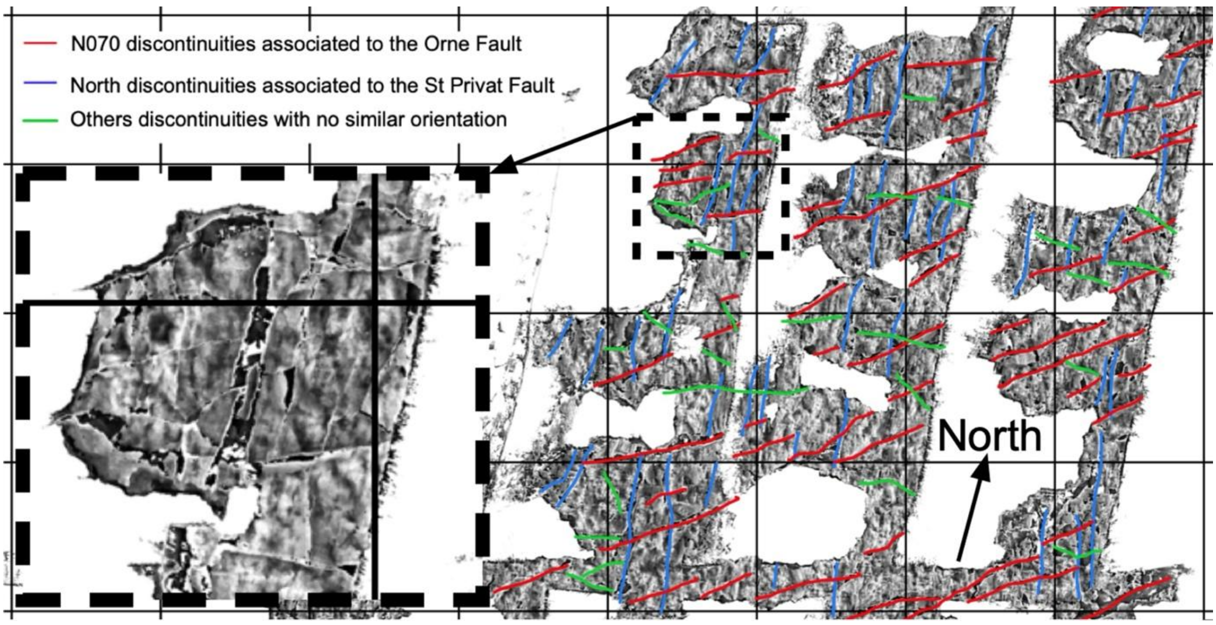

Figure 9. Visualization of the plan view obtained with 3D scan measurements and identification of discontinuities in the roof, where 3 families of discontinuity can be observed

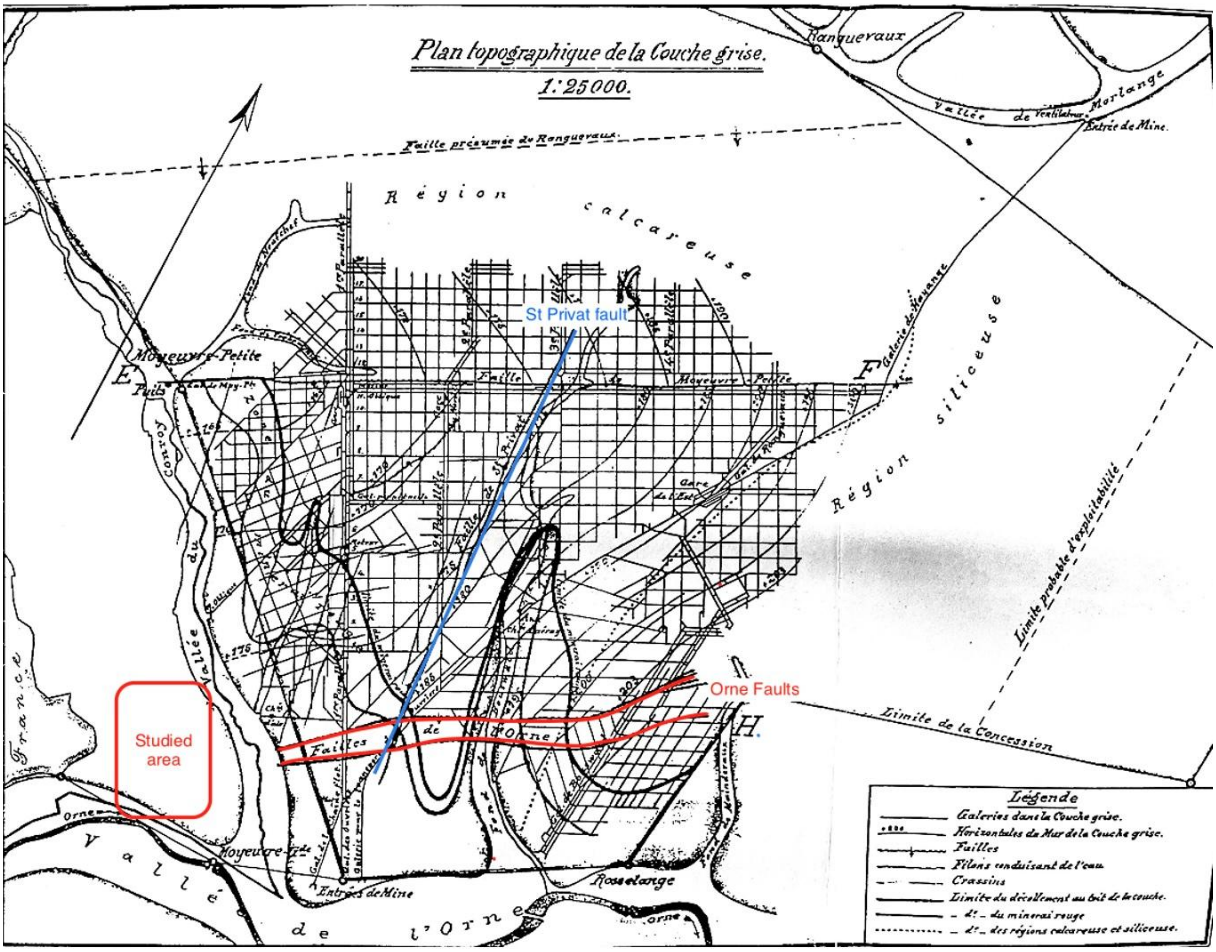

Figure 10. Historical document representing the surroundings of Moyeuvre-Grande with the location of fault zones whose orientations are consistent with those of the discontinuities observable in the virtual model (Spanier, 1914)

5 Part 3 - Geomechanical analysis

Students are led to question the long-term stability of the mine. For purely educational reasons, they are asked to propose reinforcement solutions for securing the mine, to avoid any consequence for the surface or underground.

The risk for the surface is essentially that of overall instability (rupture of the pillars due to overload) or a sinkhole (not studied by the students). The risk underground is essentially that of blocks falling from the roof.

To analyze the risk of overall instability, students must map the surfaces composed of in-place rock and those composed of embankments (Figure 11). The measurement of the exploited surfaces makes it possible to calculate the extraction ratio of the mine (exploited surface/total surface) with values around 50 to 60% when the embankments are considered equivalent to the rock in place (hypothesis 1) and 70 to 80% when the embankments are considered equivalent to exploited surfaces and therefore unsuitable to support the vertical loads in the long term (hypothesis 2). Considering the volumetric weight of the overburden around 25 kN/m^3 (safety hypothesis integrating the presence of iron in the overburder) and a depth varying from 20m in the South to 55m in the North (Figure 12), the average stress in the pillars is then variable from 1.25 to 2.8 MPa (hypothesis 1) or from 2.5 to 6.8 MPa (hypothesis 2). The long-term resistance of the pillars is also estimated at 7.5 MPa on the basis of inverse analyses carried out on examples of collapsed zones in the Lorraine iron basin (this data is given to the students). This analysis leads students to question the interpretation of a safety coefficient which then varies from 2.7 (hypothesis 1) to 1.1 (hypothesis 2). The observation of the degradation of the pillars and vertical cracking in the embankments encourages us to favor hypothesis 2 and therefore conclude in a stable situation, without excess security. Some reinforcements with masonry walls and pillars could be suggested for the most critical zones.

To analyze the risk of local instability, students are asked to propose a solution for reinforcement by bolting. Based on a set of pull-out tests carried out on bolts (Figure 13), students are required to calculate the bolt length and the required bolt density to secure the roof. The dimensions of the roof blocks delimited by discontinuities are of the order of 5 m2 and the thickness of the blocks on the ground can reach 50 cm. A bolting plan with a mesh size of around 2m would then lead to 0.25 bolts per m2. The load to be supported per bolt would then be approximately 50 kN, which implies an anchoring length of at least 60 cm and therefore bolts of at least 1.1m.

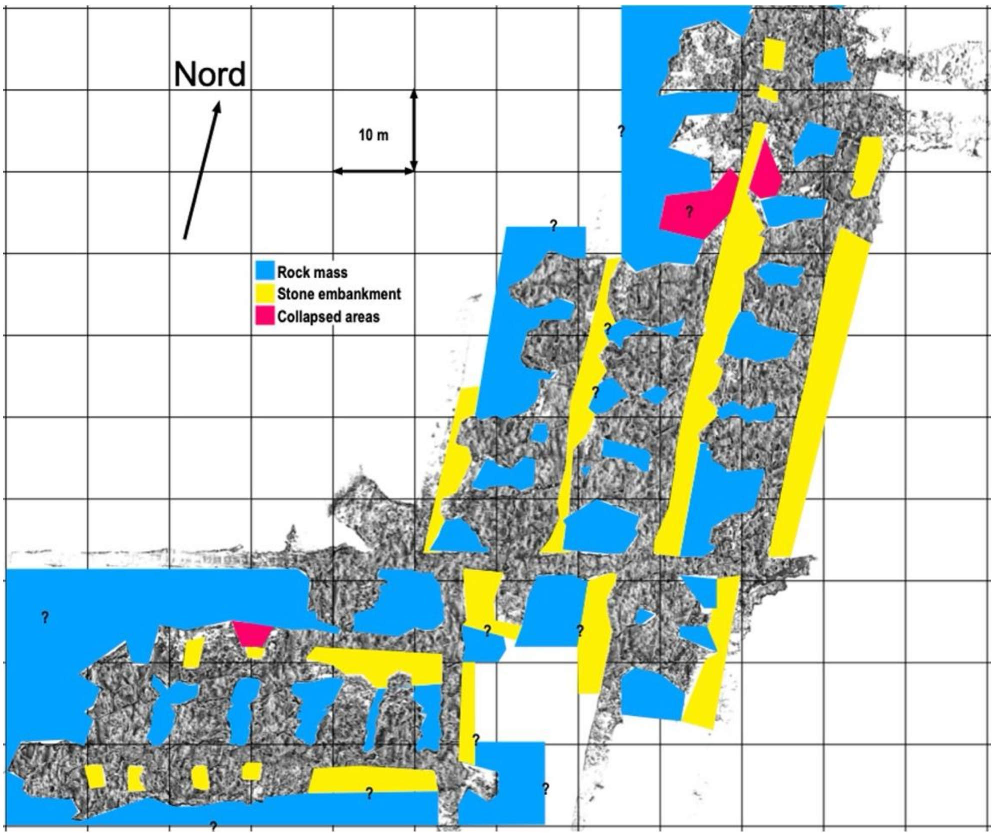

Figure 11. Identification of areas consisting of bedrock or fill

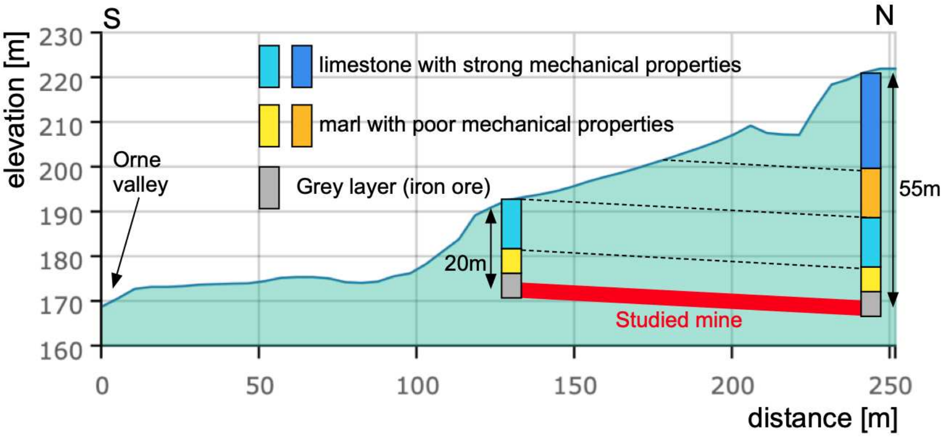

Figure 12. NS section directly above the studied area and schematic representation of the geology of the covering

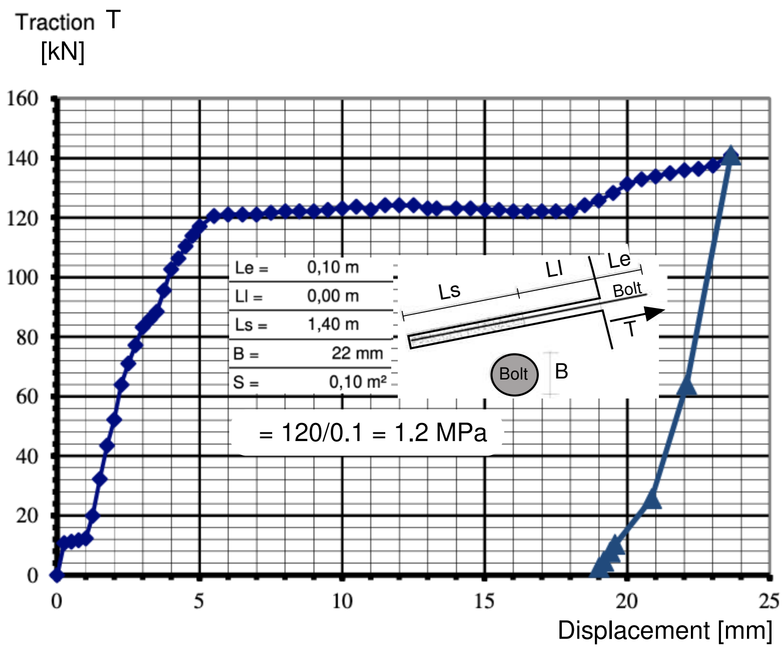

Figure 13. Example of a pull-out test carried out on a bolt

6 Students' feedback and recommendations

Examples of students' feedback are given next:

- "The concept is original, but it's still a very dense practical exercise. Nothing overwhelming, and the explanations are clear, but it's still a bit apprehensive at first."
- "The practical exercise is complex, therefore long, but very interesting."
- "Perhaps there are a few too many documents and information that we don't know how to use properly. As a result, we tend to focus on things that aren't necessarily very relevant."
- "I find there's a lot of information, and it's sometimes difficult to make connections between them."

First, it appears that the use of virtual reality is perceived as an original and rather stimulating approach. Since the tool is easy to use, getting started didn't seem to pose any difficulties, allowing the students to focus on the substance of the subject.

The scope of the work to be completed and the amount of documents available is clearly unsettling. However, this corresponds to a realistic professional situation when an engineer must conduct an expert assessment: gathering disparate information, analyzing the situation to identify issues, and delving deeper into topics identified as critical. Exposing students to this situation, although disconcerting, seems appropriate for developing this type of skill. However, the instructor must find the right balance between allowing too much autonomy, at the risk of overwhelming the students, and overly regulating the activity, at the risk of receiving only a simple copy of what was explained. Students can typically waste unnecessarily time calculating precise values of the extraction ratio, when a simple approximative evaluation already allows them to guide their thinking. The same goes for the depth of exploitation and the calculation of bolting.

Finally, it should be noted that this exercise allows students to demonstrate originality in the analysis of documents by providing arguments that the teacher had not necessarily identified or by using original computer tools (calculation of surfaces automatically from image processing, for example).

The development cost of the 3D model was about 10k€ that include 2 days of field recording with 1 engineer and one technician from a specialized company (IGECAV). The economic profitability of the 3D model may then be estimated to be about 10 years. The main interest is the complementarity of such an activity with more classical practical or academical works in class. It allows to develop skills that are required for geotechnical expertise, with some practical application geological and geotechnical concepts.

7 Conclusions

The tool created allows students to be placed in a geotechnical expertise situation combining a visit to a remote environment presenting risks and consultation of a set of technical documents.

The required work appears destabilizing to them at first glance due to the large quantity of information and the novelty of the problem. It then appears important to guide them in carrying out each step in order to arrive at a first approximative answer. Personal work after the session is required for precising some results and for writing the final report.

Acknowledgments

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References

Afsharipour, M., Maghoul, P. (2024). Towards education 4.0 in geotechnical engineering using a virtual reality/augmented reality visualization platform. Geotechnical and Geological Engineering, 42(4), 2657-2673.

García-Vela, M. T., Borja-Bernal, C. P., Jordá-Bordehore, L., Medinaceli-Torrez, R., Loaiza, S., Falquez, D. A. (2021). Teaching rock mechanics using Virtual Reality: laboratory practices and field trips during the confinement of the Coronavirus COVID-19 in Ecuador, Bolivia, and Spain. In IOP Conference Series: Earth and Environmental Science (Vol. 833, No. 1, p. 012172). IOP Publishing.

Gürsoy, M., & Buyuksagis, I. S. (2024). Virtual Reality in Underground Mining Education: Enhancing Machinery Comprehension. Mining, Metallurgy & Exploration, 41(6), 3073-3081.

Janiszewski, M., Uotinen, L., Merkel, J., Leveinen, J., Rinne, M. (2020). Virtual reality learning environments for rock engineering, geology and mining education. In ARMA US Rock Mechanics/Geomechanics Symposium (pp. ARMA-2020). ARMA.

Spanier J.P. (1914). Histoire des mines de Moyeuvre, document manuscrit.

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Prof. Olivier Deck is a full professor at the Nancy School of Mines, head of the Geosciences & Civil Engineering department. He carries out his research in the field of soil-structure interaction, reliability of structures and mechanical behavior of geotechnical structures. He is involved in teaching related to underground works such as mines, quarries and civil engineering tunnels with different use of 3D virtual applications.