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APPLICATION OF VIRTUAL AND AUGMENTED REALITY IN FLIPPED CLASSROOM – TEACHING AND TRAINING IN UNDERGROUND ENGINEERING: MUSEUM MINES AND EXPERIMENTAL LABORATORIES

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Purpose: this article explores how virtual reality can be used as a medium for teaching and training especially in the mining industry. It focuses on the topic of using virtual reality (VR) to facilitate collecting data from mine galleries. The issue is of significant importance considering the necessity of access to the mine by non – authorized people (students supplementing theoretical knowledge with field practice, potential employees, trainees). The proposed method of using the VR in such situations could be considered a geotechnical simulator. The selection criteria were mainly based on safety, accessibility and underground conditions.
Methodology: since 2019, a flipped classroom learning method based on virtual field trips has been developed. Different platforms were used to create virtual scenarios (Kahoot, Edpuzzle Cospaces), some with 360 panoramic images, others with 3D image repositories. In both cases, the images were accompanied by clues in which the students would find information and from which they would answer the class's questions – as if they were visiting a real mine.
Result: this type of virtual tour is fully aligned with the face–to–face hybrid teaching or blended learning that seems to be the near future of global education and an invaluable tool to be used in the mining industry. The collection of data from mines of other raw materials: with different extraction and deposit technology, should form the basis for the development of virtual teaching methods used in training future engineers or improving the skills and qualifications of the active miners.
Originality: the virtual tours were first designed during the COVID–19 pandemic lockdown. Since then, the layout and content of the virtual scenarios have been significantly improved. These types of scenarios and virtual tours proved to be very well received by students, pleased that even though they could not always visit certain places themselves, they could partially participate in the measurements and exercises.

Keywords: mining, virtual reality, engineering, teaching, training, virtual classrooms.

1. Introduction

1.1. Background

The concept of virtual reality (VR) is not a new topic. As early as the 1960s, researchers were attempting to formulate the idea itself and the first commercial VR tools appeared in the late 1980s (Cipresso et al., 2018). In 1965, Shuterland compared virtual reality to a window through which the user perceives the virtual world as if it looked and sounded real and in which one can act realistically (Sutherland, 1965). Since then, many other definitions of VR have emerged, usually explained in terms of the area in which the technology was used. Thus: Fuchs and Bishop in 1992 defined VR as real – time interactive graphics with 3D models, combined with display technology that gives the users the opportunity to immerse themselves in the world of the model and manipulate it directly (Fuchs et al., 1992). A year later, Gigante described virtual reality as the illusion of participating in a synthetic environment rather than external observation of such an environment (Gigante, 1993), while Crus – Neira, the same year, defined virtual reality as a specific environment: interactive, multisensory, three – dimensional and viewer – centered (Cruz-Neira, 1993). It can be noticed that these definitions, although different, emphasize three common features of VR systems: the number of senses stimulated, the perception of presence in the environment and the interaction with that environment (Slater, 2009).

As shown above, virtual reality is not a topic that has developed over the past few years. However, the COVID-19 pandemic has created space for VR technology to develop much faster. Physical distance, quarantine with a strong need for social interaction – all of this has led to an increase in the use of new communication techniques and virtual presence. The COVID-19 pandemic changed our lives irreversibly, nonetheless, it has greatly accelerated the use of remote solutions and new technologies in education, training and as a work tool adapted for many industries. Employees and students have been given a range of new opportunities to gain knowledge and experience without having to appear in person at a specific place and time, and without risking exposure to any real danger.

The pandemic time was very difficult on various levels. In the early stages, it was assumed that industries exposing many people to a contact in a relatively limited space posed the greatest threat to society. For instance, the occupational group particularly negatively perceived in this aspect, in Poland (Hildebrandt et al., 2021), were miners. They were considered to be a source of disease transmission due to the high density of people and their close contact in the workplace. Studies of aerosol dispersion in the mine workings have been carried out to confirm or refute this thesis (Hildebrandt et al., 2021). Therefore, the opportunity of accessing mines without the need of physical contact and the possible virological exposure could not be overestimated.

Many industries are using virtual reality technology to make their operations more efficient and safer. The mining industry is one of the most dangerous areas of employment, so the need for improved safety and access to training is significant (Stothard, 2007). In the mining sector, the technology is particularly valuable. Access to the underground part of the mine by non-authorized individuals is practically impossible for safety reasons and the continuous nature of the plant's operations. Training on simulators instead of expensive equipment, mapping mine galleries and presenting these plans to students and employees as well as virtual exercises of high-risk tasks (e.g. fire escape, VR blast wall (Virtual technology…, 2022) are the future of the mining.

A good example of the use of VR in the mining industry is the planting of explosives in a wall. When explosives are not placed in the right places without accurate measurements, the rocks can fracture uncontrollably. This creates a potentially dangerous situation, not only underground but also on the surface, and yet could be avoided by using VR techniques.

It should also be noted that virtual reality training has a definite advantage over traditional methods. Firstly, it effectively cuts the user off from the distracting environment, increasing concentration levels. Secondly, the trainee gets 'into character', perceiving the situation with all their senses. The course becomes a challenge, allowing the trainee to pay attention to details that they might not notice during standard training.

Additionally, training and educational implementation of the VR is simply more interesting for the apprentice. In the age of ubiquitous technology, computers or mobile phones the traditional methods using printed materials, slides and a speaker imparting knowledge seem unattractive and monotonous.

In summary, virtual reality significantly improves the way future employees might be trained, especially in occupations that require working under hazardous conditions. As demonstrated above, the potential for the mining industry is enormous: from training future engineers to improving the skills and qualifications of the active miners.

1.2. Objectives

There are many publications on safety in mining, training programs for current employees and potential employees. Miners are constantly exposed to a range of hazards that may cause serious injury or death. These hazards include: fire, underground explosions, toxic gases, geotechnical hazards and the ones associated with working in close proximity to mining machinery. In addition to the external factors mentioned above, there is also the possibility of human error caused by stress, inadequate training, or inexperience. This is where proper teaching and training are invaluable and VR is a perfect medium for carrying out these processes.

The mining industry is trying to make the most of the opportunities that the new technology offers. At the beginning of the 21st century Schofield pointed out in his research that virtual reality simulation offers the potential to improve safety – related training in mining.

He highlighted that the ability to remember safety information from a three – dimensional world is significantly greater than the ability to absorb information from traditional media (Schofield et al., 2001).

There is no doubt that, looking forward these 20 years, VR offers the opportunity to develop both perceptual – motor skills and cognitive skills, such as problem solving, decision making and hazard perception, without exposing trainees to unacceptable risks.

To date, much attention has been given to enhancing the skills and knowledge of people employed in the mining industry. In this paper, the main focus is put on the possibility of using VR for the learning process.

In teaching practice, the authors have carried out classes in operating mines to train new engineers that were meant to join the mine personnel. It is utterly difficult to find suitable areas for mapping not to interrupt daily activity in the active mines. Therefore, the conducted works (in Peru-Rinconada and Ecuador-Ponce Enriquez) result in the most realistic scenario performed so far in operating mines. In tunnels however, it has not been possible to carry out training in active workings; it was organized in abandoned ones. Nonetheless, accessing abandoned workings still creates some obstacles as students' safety is a great concern for their Universities. Fig.1 demonstrates a training conducted in active mines in Peru.

Figure 1. Training in active mines in Peru (2013-2015).

Mining is a broad field of study. When considering the training of future engineers, for example, it is important that the knowledge imparted covers all the main branches of mining. Such an assumption is difficult to implement in small and medium–sized resource–poor countries, where there are no opportunities for practical apprenticeships. VR technology offers such potential.

The mapping of exemplary coal, ore and salt mines would provide an opportunity for a no-cost and holistic study and explanation of the phenomena occurring during mineral exploitation (e.g. rock mass movement, occurrence of water and gases) and the establishment of rules for the rational and safe extraction of many types of aggregates.

2. Materials and methods

2.1. From the mining museums (show mines) and underground experimental laboratories to virtual reality

In a research process, trying to guarantee both the mapping requirements in realistic conditions and a safe location, it was noticed that visitable or tourist mines could be the ideal place to train underground geotechnical analysis since it is possible to introduce numerous students in secure conditions there. The environment is realistic and yet it lacks inconveniences caused by dispersed dust, poor visibility and circulating machinery of a real tunnel or mine. In the museum mines it is easier to reach the workings, and therefore, it is possible to reach the destination faster. Spacious areas can be searched for explanations. Before entering, a briefing in the access lobby can be given, a benefit that operating mines cannot provide. There is also a possibility to use classrooms and Wi–Fi connection in the facility to complement the practical sessions.

At the beginning of the research in the presented area there was a project launched that consisted of virtualizing the previously mentioned environments and also the real mines and tunnels that could be entered at the time. To virtualize these environments, students did not have to enter into the real mining environments. It was a small group of people, taking data while "scanning" the workings. For an hour or two, it was possible to choose a real face where the work would not be disturbed by the visit.

Fortunately, the work was done in advance because, in March 2020, the COVID-19 pandemic confined the world. These virtual mappings turned from being complementary into the only way of accessing real environments that the students had been using for months. The overall assessment of this virtual teaching material was very positive (García-Vela et al., 2020; Jordá Bordehore et al., 2020; Garcia-Vela et al., 2021).

2.2. Mines sites selected for the research

Until 2020, the work was mainly carried out in abandoned mines and tunnels, obtaining different virtual scenarios, and mapping didactic places. For this stage of the project, particular mines would be were sought, in which work could be carried out at ease, virtualizing with the best quality and taking detailed geomechanical data focused exclusively on teaching. Three mines were selected for this task, two in Spain and one in Poland. The chosen mines had to fulfil several requirements: meet the safety conditions (difficult to find in the abandoned mines), relatively easy access, and a certain comfort to take much data and virtualize the environment. The latter is not met by operating mines and tunnels, as there is little time to take data. The images are also of a bad quality due to the suspended dust. Therefore, the chosen locations are tourist mines and laboratories – experimental tunnels.

2.2.1. Study site #1: Experimental Mine 'Barbara'

One of the most important research facilities at the Central Mining Institute (Poland) is the testing ground of the Experimental Mine Barbara. "The EM 'Barbara' in Mikołów used to operate as an ordinary coal mine but after the WW II it become the only research and scientific post in Poland with an experimental infrastructure for testing devices, equipment, materials and procedures in real–scale underground conditions" (https://undergroundlabs..., 2023). The underground infrastructure enables numerous types of innovative research and projects, especially orientated on effectiveness and safety in mining as well as on environmental protection. The network of underground experimental galleries is a world class test stand for a real–scale testing. The mine includes a 53 meters deep shaft with two levels: 30 m and 46 m of different tunnels and galleries where tests can be carried out. The system of experimental headings includes several mining excavations with modern measurement systems installed and their dedicated sensors to check parameters of tested phenomena. A net of underground installed cameras provide real–time visualisation from the surface that guarantee a complex monitoring of the experiments. There is also a modern ventilation system of the workings that enables an adequate regulation of the airflow parameters according to what is best for the purposes of tests. The mining infrastructure and the external office and facilities are ideal for mining and laboratory practices, tests, and training.

The Experimental Mine 'Barbara' was excellent for the research and experimentation: to obtain in–situ geomechanical data, see different reinforcements and virtualize the galleries by taking 360° photos and photogrammetry with the Structure From Motion technique. Different areas of the mine, not very far from the main shaft, were chosen for their characteristics: mainly aimed at being able to analyse the live rock and obtain its properties. In addition, the places to be mapped had to be of good photo quality so that later the students in the images could virtually determine what the teacher had obtained in the field. A team of professional miners was available to facilitate investigation to work efficiently in the mine.

2.2.2. Mine School Saint Barbara Foundation (El Bierzo county, León Spain)

The Bierzo "School Mine" is located in former anthracite exploitation in El Bierzo, Spain, with a great coal mining tradition. The school mine is a part of the Santa Bárbara Foundation and one of its main objectives is the professional training of technical personnel – supervisors and mining machinery operators. An interesting extensive mining part was perfect for taking structural data in stable unsupported galleries and stopes. Next to the mining part, modern tunnels were developed (the New Austrian Tunnelling method) with different excavation techniques: blasting, roadheaders, etc. Research projects are carried out in this area. The tunnel faces are adequately supported and accessible for a longer period of time than the conventional workings, making it easy to introduce them into a virtual database. With good lighting and the absence of dust and noise, taking geomechanical data also makes it easy to take many adequate measurements for the students' notebooks.

2.2.3. Escucha mining museum and show mine (Utrillas county, Spain)

Figure 2. Mines visited for this project: a) 360 panorama in lignite galleries, Utrillas Spain, b) rock mass characterization in Experimental Mine ‘Barbara’ (Mikołów, Poland) c) fracture and RMR-Q index determination in advancing front in a tunnel, Mine School El Bierzo (Spain).

The Escucha mine museum is one of the few tourist mines in Spain where you can see a coal excavation face. It is located in a lignite mining region in the central–eastern part of Spain. The mine is of great educational interest at all levels, from the general public and high school students to university students. Different methods of support, metal arches, wooden frames, both in galleries and in mineral advances, can be seen. A ramp and a cable train enable access to the mine, which is also provided with a modern emergency gallery outlet. The view of the visited mines can be seen in Fig. 3.

2.3. The current state of virtual mines research- reasons for the post-pandemic application

The pandemic period lead to a significant increase in the use of VR tools. Data collection through these virtual applications is still taught in collaboration with many countries such as Bolivia, Peru, or Ecuador that continue to have important pandemic restrictions and teaching is almost entirely conducted online. It is believed that even when the restrictions have disappeared, this type of activity and material would be very valuable.

The virtual environments could be used as a kind of practical geotechnical simulators. It was decided therefore, to go one step further and virtualize very different mines and tunnels, looking for particularly didactic environments. With all the experience gained and with clearer objectives, two types of virtual environments were chosen: 3D images with comments and 360 inversive environments. These scenarios are utterly useful for educational purposes in some of the countries, where training centres are located far away or are very expensive. In addition, with the rise in fuel prices and the travel difficulties as well as competitive relocation environments, hybrid online teaching might be considered not as the matter of the future but of the present.

2.4. 3D images and online repositories

The first type of results after conducting the research is the digital repository. It was started with a project of 3D rock samples (Riquelme et al, 2019). The objective is to virtualize rocky outcrops and slopes through photogrammetry. The structure from motion technique is used to photograph a slope and convert it into a 3D element or a point cloud (Jordá Bordehore et al., 2017). These 3D blocks are later uploaded into a digital repository (in this case, Sketchfab).

This digital platform is very user–friendly, it is free of charge, and it also allows you to put a series of pop-up menus with keys and data on the slope that the students must take (a graphic scale is included in the image). Together with other purely observational data, the students carry out their calculations on the stability of the slope. The difficulty that appeared while using it, was that in the underground mines, without proper technique and lighting of the tunnel or mine, the software could not recognize the overlapping images. Tests in several mines and tunnels have been carried out and among the tests performed there were some performed during a one-week campaign in the Experimental Mine ‘Barbara’ in Mikołów and the ‘Guido’ Mine in Zabrze (Poland). The results of both are quite satisfactory.

2.5. Immersive virtual environments: 360 degrees images

To make the experience of taking data in outcrops or mines more realistic, it was necessary to have the students participate in the experience by going through various scenes where they collected different information and data, requiring a system that allows to move from one scene to another with ease. Compromise between realism, little time to prepare the scenes and to load

data as well as page opening speed (not to bore the student) was desired. The questions and templates in a teaching application were put to fill in outside the virtual environment. This way, the work is more realistic: students have a virtual screen, and they take data on a tablet or notebook. It is also the closest to the field trip situations because, in the actual tunnel, you do not have drop–down menus to fill in. Figure 3 below presents a methodological flowchart.

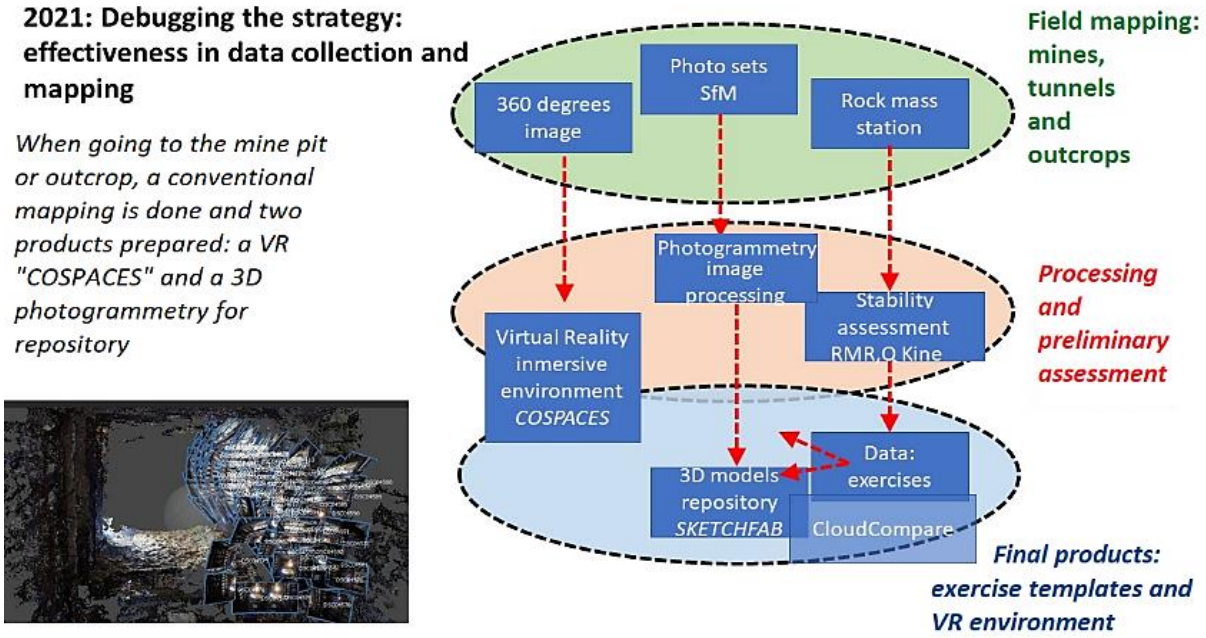

Figure 3. Methodological flowchart indicating procedures from field mapping to calculus and pedagogical material preparation.

3. Results and discussion (Quality indicators)

The aim of developing virtual scenarios, where students can access data and observations, was to make it available to as many people as possible. The most viewed virtual applications on the Internet (Kahoot, Edpuzzle, Cospaces) seem to be oriented towards secondary education students. Therefore, the authors' intention was to create a user–friendly but at the same time serious and professional tool. This innovative idea was successfully developed and introduced. The results have been used in classes at the University of Madrid, but also scholars worldwide included the created didactic material in their courses. As shown in table 1, the first of the scenarios was developed in tunnels and created shortly before the start of the pandemic confinement (March-May 2020), later more elements were added using commercial software and online applications such as Cospaces and Sketchfab (https://sketchfab.com/ljbordehore). Even in the post–pandemic times these virtual scenarios continue to be useful, since the hybrid model of teaching is becoming increasingly popular at universities and teaching centers. The scenarios are included as a part of classes on tunnels, mining, and rock mechanics in Ecuador, Peru, Bolivia, Spain (Master of CEDEX, Almadén, UPM, etc.).

Table 1 below indicates some of the scenarios and the number of accesses received since their creation by the end of 2020. It is important to note, that most visits are from the Spanish – speaking countries (Spain, Latin America), since it was first developed by the Polytechnic University of Madrid. Therefore, some scenarios are currently being translated into English to grant access to even bigger group of users.

Table 1.
Summary of the Cospaces virtual scenarios and visits to date

Virtual scenario link	Content	Languages	Total visits since 6/10/2022
https://edu.cospaces.io/TLS-TUT	Tunnelling and rock mass classifications for mining	Spanish and English	7418
https://edu.cospaces.io/NGF-LYM	Introduction to rock mechancs	Spanish	1613
https://edu.cospaces.io/KTU-APD	Rock slope stability	Spanish	3727
https://edu.cospaces.io/EPD-NHY	Laboratory testing	Spanish	1881
https://edu.cospaces.io/JNF-TVC	Mining: underground and open pit geotechnics	Spanish	953

Figure 4 demonstrates the virtual tour through mines and tunnels. The scenes allow students to find information and to solve different exercises. The degree of difficulty and reality depends on the scene and has a focus depending on the class involved.

Figure 4. Online technical tour at the 'Barbara' mine from the virtual university lobby and classroom where students can choose different scenarios depending on the topics and level of course.

Surveys have been carried out (Fig. 5) to determine how the scenarios were received by the users and how they could be improved. Sixty–six responses were received throughout 2020-2022. The vast majority find the system simple and intuitive (83.3% over 8/10 points). As for the avatars used, they were considered by 68.2% of responders to be amusing and give freshness to the exercises, while the rest of the responders indicated that they needed some improvement. 92.4% of the responders think it is appropriate to use this platform for home jobs commissioned or self-employment.

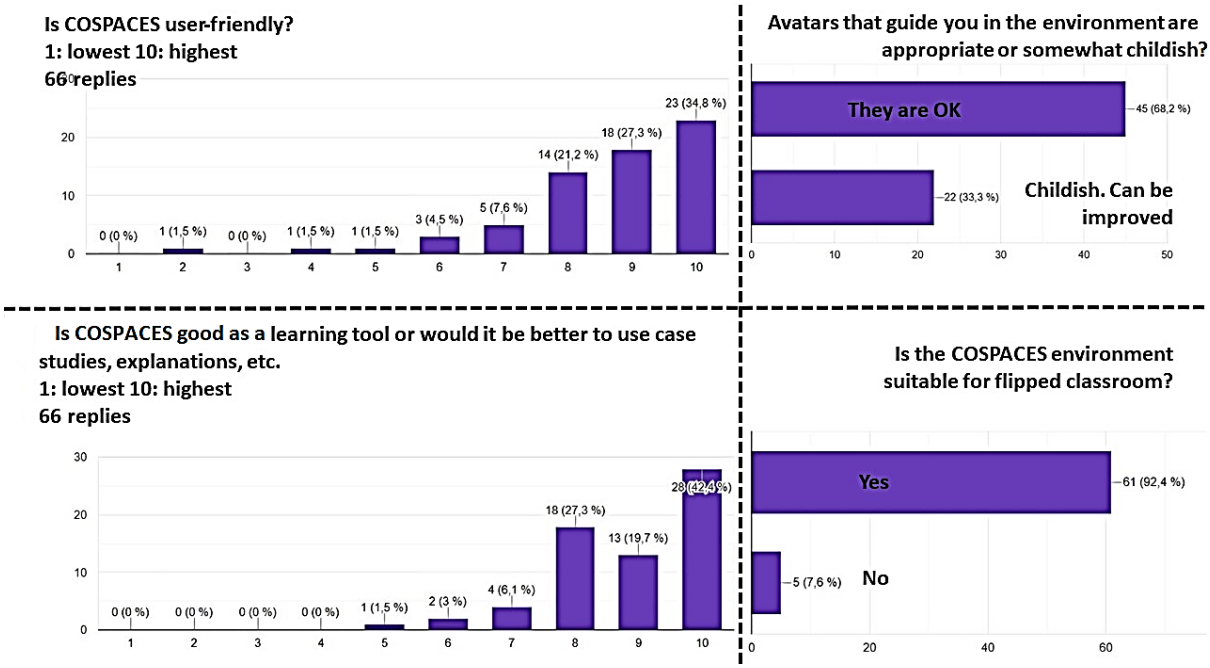

Figure 5. Evaluation of the Virtual Reality platform in training.

Throughout the two years of developing the inverted classroom with virtual reality, it has been noticed that the VR is a perfect addition for classical teaching methods. Even though it cannot replace field data collection, it can serve as an introduction or simulation before going into a real tunnel or mine. During the pandemic and the strictest confinements, it was observed that virtual reality became essential and, in various areas, the only access to the outside world. Even today, in many countries, face-to-face classes have not yet been resumed, and postgraduate classes even less so. Therefore, created virtual scenarios are very popular in Peru, Bolivia, and Ecuador, where what it more, great distances and logistical difficulties make virtual and online teaching extremely popular. The future of post-COVID education and training will probably be a hybrid face-to-face classes and online ones. Virtual and augmented reality seems to be a perfect link between the two. Nonetheless, the VR potential of prepared scenarios could be used not only for educational purposed but also to make the engineering world more accessible and more entertaining.

The results of the mapping carried out at EM ‘Barbara’ confirm the possibility of a virtual presentation of the most relevant issues of coal mining, as one of the branches of the mining industry. The presentation of how the deposit is located, the use of underground workings and their infrastructure in the form of emerging questions during the virtual tour enables the transfer

of practical knowledge to students and the testing of the skills acquired during theoretical classes.

4. Conclusions

This article explores how virtual reality can be used as a medium for teaching and training especially in the mining industry. The area of interest (mines, tunnels) is inaccessible to non-authorized people and therefore it creates barriers in both learning the job as well as preparing the potential employee. Virtual reality simulation offers the opportunity to develop perceptual knowledge, perceptual–motor skills and cognitive skills, such as problem-solving and decision-making in stressful situations, without exposing participants to unacceptable risks.

The virtual tours were first designed during the COVID-19 pandemic lockdown. Since then, the layout and content of the virtual scenarios have been significantly improved. These types of scenarios and virtual tours proved to be very well received by students, pleased that even though they could not always visit certain places themselves, they could partially participate in the measurements and exercises. This type of virtual tour is fully aligned with the face-to-face hybrid teaching or blended learning that seems to be the near future of global education and an invaluable tool to be used in the mining industry.

The collection of data from mines of other raw materials: with different extraction and deposit technology, should form the basis for the development of virtual teaching methods used in training future engineers or improving the skills and qualifications of the active miners.

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