

# MODERN METHODS OF DOCUMENTATION AND VISUALIZATION OF HISTORICAL MINES IN THE UNESCO MINING REGION IN THE ORE MOUNTAINS

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## ABSTRACT:

The article focuses on modern methods of mining activity documentation and visualization. The development of technologies that allow us to display 3D models are many in recent years, from web portals, augmented reality using smartphones or tablets to virtual reality glasses. These technologies give us a whole new way of looking at and viewing 3D models. In this study, we will use most of the available options to visualize mining activities in the UNESCO-protected Ore Mountains. Each of these technologies needs differently prepared data. Because each of these technologies have different limits, we need to find these limits and modify the 3D models. The ZEB Revo laser scanner was used for data acquisition, which uses SLAM technology and is much more suitable for such areas than conventional terrestrial scanners, with which the work is lengthy and not nearly as efficient, and not the least of which eliminates the time-consuming post-scan work of merging scans. Especially when using scanning for mining, where there is not quite enough to go around, manually splicing scans is a nightmare, and automatic post-production merging is also often problematic.

## 1. INTRODUCTION

### 1.1 Documentation methods

In the past, most documentation work in historic underground irregular spaces or caves was carried out using simple methods such as the miner's compass and tape, or sometimes just by plotting. Professional underground mapping work has used complex surveying techniques using gyrotheodolites. Nowadays, thanks to modern instruments, we can document an area of huge size with calculation accuracy down to centimetres, sometimes even millimetres, as well as the amount of rock extracted and more. Modern technologies such as laser scanners thus allow us to map and extract data from hard-to-reach areas such as mines where other technologies are not ideal, either because of the confined spaces or the light conditions that exist in the mine (Lee et al, 2019, Makkonen et al, 2015, White, 2016).

But the problem of modern times is the size and content of the data; recently we have been able to record millions of points on laser scanners, but an equally important activity is to be able to process this data afterwards. Processing the amount of data that we currently receive from the equipment is a key capability. Optimising the data for further subsequent visualisations is another extension of the process. We have gone from problematic measurement being most of the work time in the past to the other side of the process now, where taking the data is currently the quickest and easiest part. Postprocessing then takes most of the time (Jaakkola, 2008, Wang et al, 2019).

This paper focuses on the mentioned data processing and optimization and the use of the models created for visualizations using modern technologies such as web portals, virtual and augmented reality.

### 1.2 New technologies

Attempts at modern documentation of historical mining areas have been made at the Czech Technical University in Prague since 2003. However, the laser scanners of that time were

unsuitable for this type of work due to their size, weight, and power consumption. For example, the practical use of the Callidus laser scanner, which was purchased in 2003 at the Faculty of Civil Engineering, was not successful in the historical underground. Photogrammetric methods were also possible; the historical analogue methods of light profiles were used for a long time as the only practically usable methods for documenting underground dark spaces (fig.1).



**Figure 1.** Laser scanner Callidus (2003, left) and historical photogrammetric method using light profiles (1970s, right)

Modern automated photogrammetric technologies began to develop in the form of SfM (structure from motion) and MVS (multi-view stereo) only in the late 1990s and started to take a strong rise after 2005 (Haala, Alshwabkeh, 2006, Hůlková et al., 2016, Remondino, 2011, Thompson et al, 2013).

### 1.3 Case project

One of the most important areas of historical mineral mining is the Ore Mountains in the Northwest of the Czech Republic. The Jáchymov region has been rich in historical mining activity since the beginning of the 16th century, when rich silver deposits were discovered here and coins called tolars were minted (Jáchymov, in German Joachimsthal - hence the abbreviation thaler and later Czech tolar; from tolar the name for the dollar was also derived).

Later, tin was mined here and in the 20th century uranium ore was mined. But that is a different history, mainly connected with the Cold War and the communist regime.

Nowadays, several well-preserved tin mines can be found in the Jáchymov region, some of which have recently been opened to the public, and the entire German-Czech region with its historic mining industry was inscribed as a UNESCO World Heritage Site in 2019. Since the opening of the historic mines was mainly carried out by the civic associations with the support of local communities, precise professional documentation was not carried out and practically does not exist according to the survey (fig.2). The Mauritius Mine near Abertamy was the first mine to be opened in 2014. The tin mine prospered from the early sixteenth to the end of the seventeenth century and the original shallow pits and mine adits were turned into a huge underground mine with a large underground chamber. Mining was definitely stopped here in 1944.

A few kilometres from the important mountain resort and border crossing of the Czech Republic with Germany, Boží Dar, lies the locality of Zlatý Kopec - Kaff, with the Johannes Mine, which was in operation from the 16th century until the late 19th century. Tin, iron, copper, and later zinc ores were mined here. The mine was opened to the public in 2015 and is the largest mine in the area in terms of its size and spatial diversity (fig.3).

There is also the Kohltreuther Mine near the Johannes Mine, but it is not open to the public.



Figure 2. Area location in the Czech Republic



Figure 3. Johannes Mine main dome

## 2. METHODOLOGY

### 2.1 Photogrammetry

The first used type of documentation was classical close-range photogrammetry. A part of the historic Kohltreuther tin mine near the village of Zlatý Kopec was documented in 2014. The historic mine areas are very irregular in shape and contain many narrow passages and additional small spaces. Another problem is the complete darkness. Therefore, it is necessary to use flash equipment or to supply the spaces with an electric current to adequately illuminate the space for photographing. An electric current generator with halogen lights was used, and finally at least a small part was photographed. Unfortunately, photogrammetric technology has proven to be unsuitable for this type of documentation. Poor lighting and narrow spaces are not suitable (fig.4).



Figure 4. Photogrammetric documentation

The use of a panoramic camera together with lighting would give significantly better results. However, this is only possible in mines accessible to visitors and equipped with lighting. An example is the visualization of the Marie Auxiliary Mine on Mědník Hill nearby Měděnc village. It is possible to visit it on web.

(<https://my.matterport.com/show/?m=FYK3L5mdTBG>)

### 2.2 Laser scanning

Laser scanning technology provides better and more comprehensive possibilities. However, dark, and unlit areas are still a problem. If only the structure of underground spaces is documented, there is no problem, as laser scanning uses its own radiation source with an infrared laser (Urban, Jiříkovský, 2016). The Kohltreuther Mine was also scanned with a precision Surphaser laser scanner in 2014 along with an experiment on photogrammetric documentation (fig.5). This scanner has excellent accuracy, 0.6m at 10m, and produces a very dense and accurate point cloud. But as it turned out, he was not suitable for this type of work.



Figure 5. Laser scanner Surphaser 25HSX

In early 2015, a detailed documentation of the historic Mauritius Mine was carried out, which was at that time the only open mine for visitors in the Jáchymov region. A Faro Focus 3D 120 laser scanner was used, with a range of over 100m, a scanning speed of almost 1 million points per second and a relative accuracy of

1.6mm at 10m; the scanner has a built-in camera to colour the point cloud (fig.6).

In 2022, after the Covid pandemic, both types of lightweight and portable ZEB-REVO mobile mapping systems (ZEB REVO Go and ZEB REVO Horizon) were used for scanning underground areas. Another historical mine open to the public, the Johannes Mine, was selected. Both types of the instruments used have a relative accuracy of 1-3 cm at a measured distance of 10 m depending on the surface type.

ZEB-REVO Go has a speed of 43,000 points per second, stores reflection intensity information and has a range of 30 meters. ZEB-REVO horizon has a speed of 300,000 points per second, stores reflection intensity information and has a range of 100 meters (fig.7,8).



Figure 6. Laser scanner Faro Focus 120



Figure 7. Mobile laser scanner ZEB REVO Go



Figure 8. Mobile laser scanner ZEB REVO Horizon

### 2.3 Data processing and analysing

Data was processed differently. Photogrammetric data was processed as a set in Agisoft Photoscan. It succeeded in creating a spatial model of a small cut-out chamber, which was illuminated with halogen lights. However, documenting the entire mine in this way is beyond our standard capabilities. It is not possible to model the tight mined passages photogrammetrically.

Data from laser scanners Surphaser, Faro and ZEB-REVO was processed by the company's software.

The Surphaser scanner is still one of the most accurate scanners, however, the disadvantage is that the individual scans cannot be directly connected, the scanner does not have a camera, and the work in the underground is laborious, time consuming and unnecessarily precise. A total of 18 scans were taken in 6 hours of work, but in the end they could not all be joined due to insufficient overlays. This was only identified after the measurement, prediction and ideal scan position was not made possible by the software at that time. What was successful with this excellent and accurate scanner on the surface when monitoring e.g., deformations, was not fully successful when working in the underground.

Scanning with the Faro scanner was simple and practically consisted in repeating the scanning from sequential positions and transferring the spherical targets. However, due to the poor lighting, the images were not captured. Scanning in tight spaces was challenging and tedious. Special spherical signals were used for automated merging of scans, which were always forward in the scanning direction during the measurements to distances of about 5m and 10m. Here, the measurement was also time-consuming. 140 scans were taken, and the scanning took a whole day; some small and narrow parts could not be documented because of the size of the scanner with the tripod.

Scanning with the ZEB-REVO Go and ZEB-REVO Horizon mobile scanners was very simple and comfortable. It was practically just a walk through the accessible parts of the mine with the scanner on. For practical reasons and the scanning principle of starting and finishing measurements at the same place, the scanning was divided into several parts. Even narrow and low parts could be scanned. Problematic is of course the possible deformation of the resulting point cloud, which depends on the inertial measurement unit (IMU) and the operator's own movement or experience. Both types mobile scanners used do not have the possibility of control or display, so the result can only be seen after the measurement. The Geoslam Hub software works as post-processing and there is not much possibility to influence the result. The scan was spread over 4 separate measurements and took about 2 hours in total, typically 20 minutes each. Post-processing took approximately the same time. For the scan of the long narrow mine adit, it was necessary to change parameters during processing as the default settings resulted in visible point cloud deformation (table.1).

Technology	device	Object mine	measurment time	Processing time	accuracy	Suitability
Photogrammetry	Canon D20	Kohlreuter	2 hours / small part only	2 hours	2-5 mm	low
Laser scanning, stop and go	Surphaser 25HSX	Kohlreuter	6 hours	12 hours without success	1 mm	low
Laser scanning, stop and go	Faro Focus 3D	Mauritius	8 hours	6 hours	2 mm	average
Mobile scanning	ZEB REVO Go	Johannes	2 hours	2 hours	1-3 cm	high
Mobile scanning	ZEB REVO Horizon	Johannes	2 hours	2 hours	1-3 cm	high

Table 1. Time and precision analysis

### 2.4 Modern possibilities of visualization 3D models

The rapid development of hardware in recent years allows us to display 3D models and perform visualizations in high quality.

There are many modern options for visualizing 3D models, but currently virtual and augmented reality are the most used and popular. However, what must not be forgotten is the big development of web portals that are able to display high quality 3D models on a progressive loading basis as well. All these above-mentioned methods were used to visualize Mauritius and Johannes mines that were selected as the case study. Each of these technologies has its own specifics and 3D models that need to be properly processed and optimized individually. These are mainly working with texture (for mines this problem is eliminated because there is no texture), number of polygons in the case of mesh, number of points in the case of point cloud visualization (Förstner, Wrobel, 2016, Pavelka, jr., Raeva, 2019).

## 2.5 Data optimization and visualization

The following visualization options were selected for the case study. In the following chapters they are analyzed in more detail and their pros and cons are described.

**2.5.1 Augmented reality:** Augmented reality is currently experiencing tremendous development and can be found in a variety of industries from shoe retailers, where you can have selected shoes appear on your foot using your smartphone, to placing furniture around the room, to visualizing landmarks and various 3D models. This technology brings quite extensive capabilities to display models using devices that most users already own. We are talking about tablets and smartphones. So, the clear plus point of this technology is that the user does not need any sophisticated device to view 3D models and can use these devices for simple AR displays. For advanced augmented reality, special glasses are used, for example Microsoft HoloLens, but they are already quite expensive (3,200-6,000 USD based on equipment and use), and still have many limitations which are limiting for ordinary users: especially the field of view and the battery (fig.9). However, these glasses are slowly finding a place for professional use - automotive industry, architects, designers, etc.



Figure 9. HoloLens

**2.5.2 Virtual reality:** The use of virtual reality is widely used in several industries. However, it is still finding its footing: apart from gaming, working with virtual reality is still in the testing phase. It has huge potential for the future, the idea of a doctor operating remotely or in the automotive industry etc. Thanks to virtual reality, the user does not have to physically visit the object and can explore and analyze the object in the comfort of his home or office. The most common game engines used to create applications include the Unreal Engine and Unity. The advantage of this technology is definitely the total immersion in the VR world. The disadvantage is the higher purchase price, the glasses usually require a powerful workstation (fig.10).



Figure 10. VR equipment

Unreal Engine was chosen for our work. The engine can only render a limited number of polygons, so the data needs to be optimized for virtual reality. The first quality model that has millions of polygons, the so-called hi-poly model, needs to be reduced to a low-poly model. To preserve and transfer the quality of the hi-poly model to the low-poly model, different textures are used which are then assembled into materials in the game engines.

The textures record all the important information for the game engine and make rendering such a model noticeably easier. Mostly only the basic texture is known - diffuse texture which records RGB information, but there are textures like elevation texture, normal texture, occlusion texture etc. For objects like mines, working with texture is a bit different because there is usually no texture, so artificial material is added for visualizations.

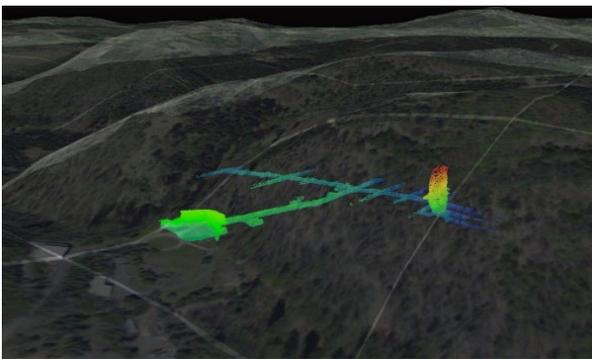
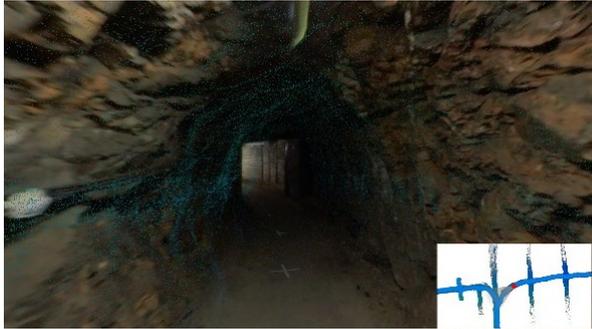
**2.5.3 Web portals:** Web portals are an ideal form of project presentation for customers and ordinary users, where they can connect to the portal/database at any time and view, analyze, change layers, measure in the model, etc. This is the easiest way to present the results to someone and guarantee them access to them without the need for a powerful workstation. The web portals are optimized for a web interface, so the only requirement is a fast internet connection for data download speed. The ease of use on the part of the user is undoubtedly a big plus of this method, however, it should be emphasized here that for the owner it costs a lot of money to develop and create such a sophisticated system, but for most companies involved in creating and working with 3D models, such a system is nowadays indispensable. Most portals use the LOD system for model visualization (level of detail, fig.11). Thanks to this system, the models are displayed smoothly, it is a gradual recording of the details that depends on the zoom level.



Figure 11. LODs example

Basically, it is about data optimization, when the user is farther away from the object, the details are not visible anyway and so these details are not rendered, while with a higher zoom level the details increase. Systems working this way are efficient and not so hardware consuming.

Each web portal uses administrator mode in which, after importing optimized data, the administrator sets basic default values for how the model should be displayed by default when someone loads it (fig.12).



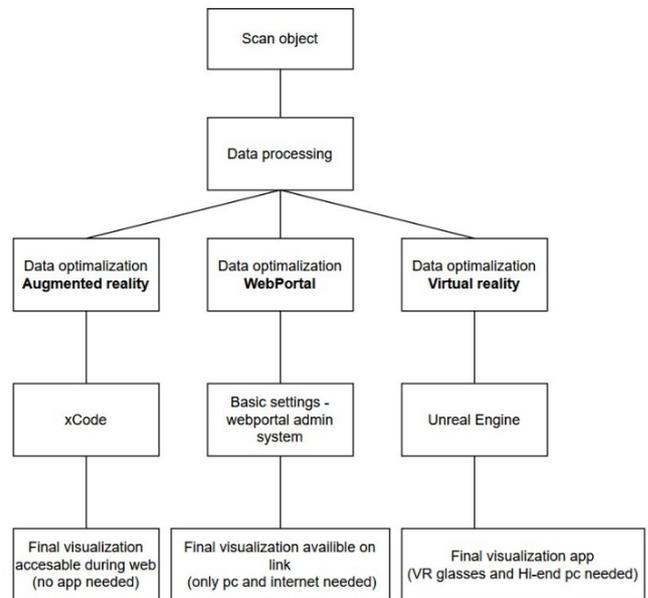
**Figure 12.** Web portal example (IntellMaps company); St. Joseph Mine (University Experimental Underground Centre, CTU in Prague, FCE)

### 3. DATA PROCESSING

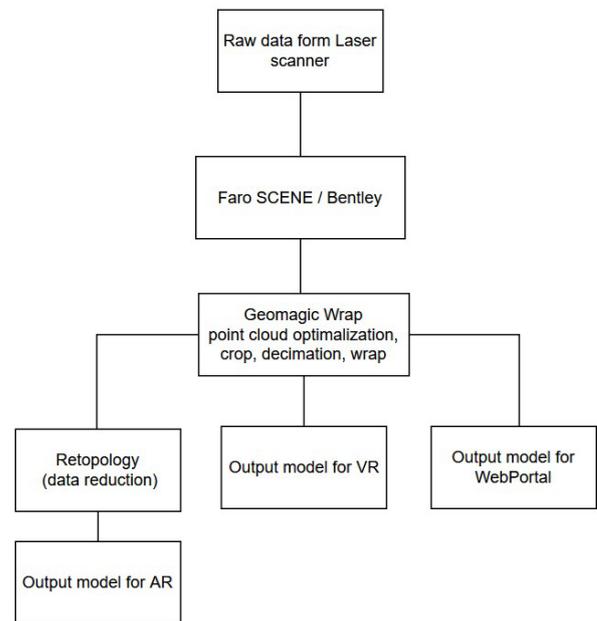
For main data processing Bentley (ZEB-REVO go), Faro Scene (Faro) and Geomagic Wrap software were used. Bentley and Faro SCENE were used for the first data processing. Geomagic Wrap was used for the second data processing as noise reduction, cropping minor sections, wrapping etc. Creating a web portal for viewing 3D models is a very challenging task, so for this purpose portal from G4D was used. The visualization process workflow diagram and the visualization process diagram are in (fig. 13-14).

The Johannes mine captured data had to be processed, and the processing was done in Bentley software. Here the cloud was exported. It was two large clouds, and the object was quite large and so the scan needed to be split into two units. These were then merged and cleaned of noise. The final point cloud had more than 20 million points. The final polygon model had over 10 million polygons (fig.15).

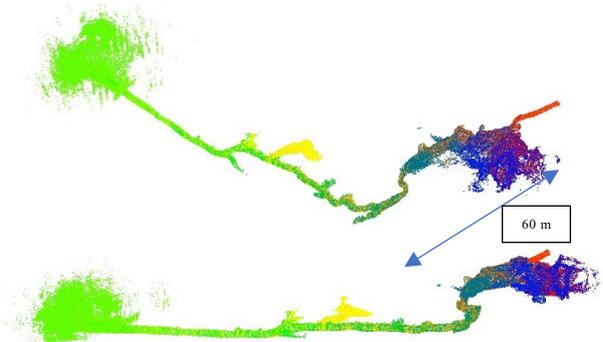
The Mauritius mine had over 3.4 million points, so we must take into consideration the different size and ruggedness of the two mines. All 140 scans were processed in Faro SCENE software. The meshed model for visualizations had over 6.1 million polygons (fig.16).



**Figure 13.** Workflow diagram of visualisation process



**Figure 14.** Data optimization workflow diagram



**Figure 15.** Scanned data after first processing – the Johannes mine. Top fig. – top view

### 3.1 Web portal

The web portal has been filled with modified models, with both point cloud models and meshed models exposed, in the case of both, as test models. This is the simplest way of data distribution for ordinary users.



Figure 16. Mauritius Mine – web portal with measurement possibility

The models are different, the differences can be observed mainly in the point clouds and in the structure (fig.16-19).



Figure 17. Johannes Mine - mesh model in web portal

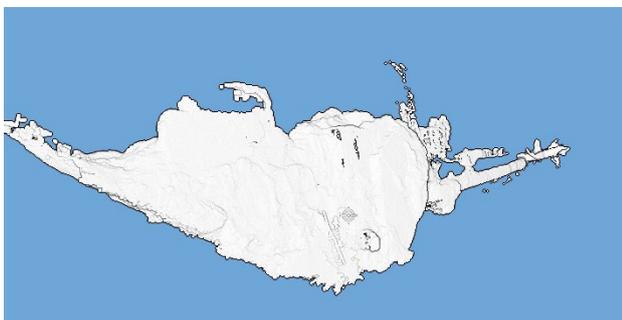


Figure 18. Mauritius Mine-the main dome

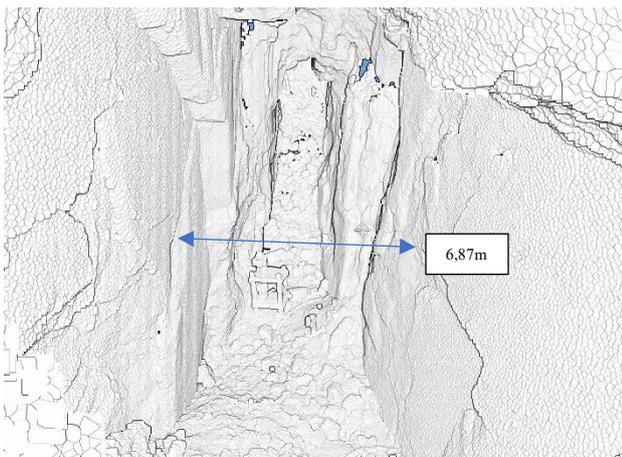


Figure 19. Mauritius Mine-the main dome, inside view

### 3.2 AR

The Xcode development environment was used for AR visualization. The AR models are thus only available for iOS devices (apple). Data optimization was performed in the Instant Meshes software, which took care of the object retopology. There was a significant reduction, for the Johannes mine the mesh was reduced on 8 % from original data (fig.20,21).

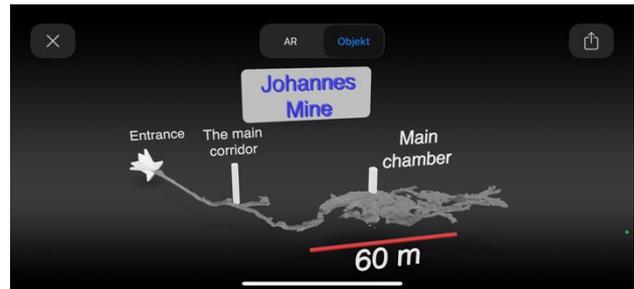


Figure 20. Johannes Mine, web portal

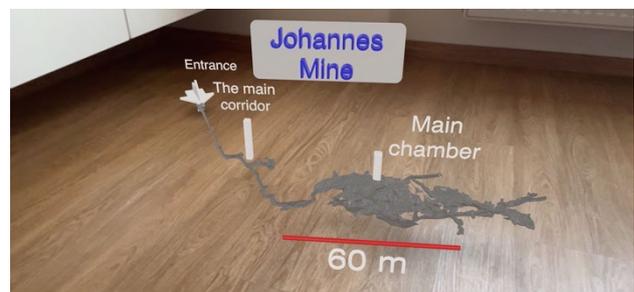


Figure 21. Johannes AR model

### 3.3 VR

Virtual reality allows us to have a unique experience/immersion that is unique and not disturbed by the environment as in the case of the other technologies mentioned. In this study, a part of the model - the main house - was modified for virtual reality. The towers, supports, railings and others were modelled. In the case of this model, a very faithful copy of reality was achieved. The VR application created in this study contains a total of two meshed models of the mentioned mines. After launching the application, the user gets to the main menu where he/she chooses which mine he/she wants to visit.

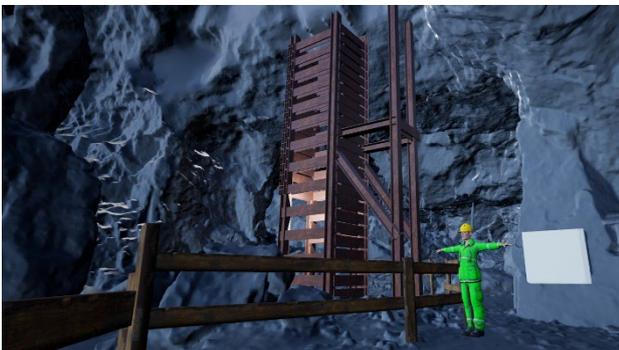
The Unreal engine, possibly combined with Blender, allows us to modify the models to achieve unique results and realistic visualizations (fig.22-24).



Figure 22. Original 3D model pro scanned data



**Figure 23.** Creation of tower (served to export the material) model in UnrealEngine



**Figure 24.** Final tower construction in UnrealEngine

#### 4. RESULTS AND DISCUSSION

As mentioned above, the Mauritius and Johannes mines were selected for this project. Each mine was scanned by a different instrument and technology. As already written in the paragraph 2.2, the Mauritius mine was scanned with a Faro terrestrial scanner, while the Johannes Mine was scanned with Zeb REVO laser scanner. Each scanner uses different technologies. With the Faro scanner, scanning stations are made and the subsequent merging is semi-automatic, sometimes purely manual, but the data is very accurate and dense. In contrast, Zeb REVO is a personal mobile handheld scanner that uses SLAM (Simultaneous Localization and Mapping) technology. This technology allows the operator to scan an object in its entirety, creating one large cloud, eliminating the work of connecting many parts. The problem, however, is the possibility that the cloud can be deformed and then the whole result is unusable. These scanners generally produce a relatively sparse point cloud, and the accuracy is in an order of magnitude worse than by

conventional static terrestrial scanners. However, with the irregular structures of a historic mine, we really don't need to be accurate to millimetres.

#### 5. CONCLUSION

Among the neglected cultural heritage are certainly the historical mining objects and sites. In this article, we focus on the documentation of historic mines in the Czech-Saxon area, which has been on the UNESCO World Heritage List since 2019. Although some historic mines are open to the public for tours, adequate 3D documentation of the objects is not usually available. Also, virtual tours are not yet common, which would allow interested people to visit the site from home. The goal here is clear: to make remote objects accessible to visitors, to enable visitors with mobility difficulties or claustrophobia to visit the site, and to attract new visitors to an interesting real, often adrenaline-filled tour. This will raise the level of knowledge about this interesting part of cultural heritage. In terms of research, it has been possible to document two historic mines in the Czech Republic on the Czech-German border and to use, compare and analyse current documentation possibilities and technologies. Here it turns out that among the best documentation methods are mobile mapping systems in the form of personal mobile laser scanners. Their accuracy is sufficient, and the speed of documentation is a great advantage. In general, it is problematic to take a good quality texture in dark underground spaces; this can be done, for example, in well-lit spaces using panoramic cameras, but the result is a kind of panoramic viewer, not a real 3D model. Another result is an analysis and example of the use of VR and AR technology for a virtual visit to the underground. In our project we have succeeded in transforming laser data from different devices into virtual reality using artificial texture. This process is not entirely simple and varies in parameters depending on the object type and documentation method.

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Johannes mine mesh model - <https://g4d.masterinter.net/demo-cvut-dul-mesh/>