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Geospatial Integrated Technologies for Natural Hazards and Environmental Problems

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GEOSPATIAL INTEGRATED TECHNOLOGIES FOR NATURAL HAZARDS AND ENVIRONMENTAL PROBLEMS

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HA NOI - 2023**

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BUILDING A 3D INFORMATION MODEL FOR UNDERGROUND COAL MINES

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ABSTRACT

Recently, the digital mine, with a high ability to share mining information through the lifecycle of a mine, has played an increasingly important role in ensuring the safe and effective management and operation of mining activities. Build Information Model (BIM) has been widely used in the field of construction and is considered an advanced technology for construction management. In this study, a 3D information model for a mine is built using BIM. The Industry Foundation Classes (IFC) standard is used to define the mining information model. Point clouds collected by Terrestrial laser scanning (TLS) provide geometric and attributive information for building BIM models. This information model was applied to the NUI BEO underground coal mine. The information model was built for important structures of the mine, including the mine shaft and tunnels. The results show that BIM with the IFC standard can be built for the underground coal mine with a high level of detail and accuracy.

1. INTRODUCTION

The mining industry is one of the important sectors of an economy and plays a key role in the development of each country (Duncan & Abdul Rahman, 2015). As the demand for raw materials for the rapid development of the world economy is often at a high level, the role of the mining industry has been increasingly important. This becomes one of the main driving forces for the development of mining technologies. While the rapid development of mechanical and information communication technologies with heavy semi- or automatic equipment can improve the speed of activities in a mine, this also creates much higher requirements for collecting, storing and representing mining data, including geospatial data. This is because geospatial data is about the spatial information of mines, which is fast and continuously changing as the high productivity of advanced equipment, such as large-scale satellite bulk dozer push, semi-autonomous blast hole drilling, semi-autonomous tractor system (SATS) technology.

Recently, in the technical operation of mines, two-dimensional (2D) AutoCAD drawings are still mainly used. These are the main electronic documents for the management of a mining project. However, this kind of document makes it difficult to find errors and unable to display information, especially in the third dimension. It is noted that 2D drawings are considered traditional tools and have the disadvantage of inefficiency in optimizing mine project operations processes (Li et al., 2021). Therefore, it is necessary to build a 3D information system with functions such as design and display to simulate 3D designs, build virtual reality, computer graphics, construction operation process and finally, the construction and sharing of information for a mining project.

Building Information Modeling (BIM) is a technology for creating, managing and effectively using information about objects characteristic of construction projects throughout the project's life cycle from design, construction, operation and maintenance. Information in BIM includes geometric information and non-geometric information. BIM is widely used in construction such as bridge construction (Qin et al., 2021; Wei et al., 2021; Zou et al., 2016), building houses and heritage and culture structures (Karachaliou et al., 2019; Simeone et al., 2019), tunnels (Li et al., 2021; Zhanping et al., 2019), train line (Xu et al., 2014). With wide applicability in the field of construction engineering, BIM provides new ideas and methods for mine information modeling and positively affects the mining industry (Li et al., 2021).

In this study, BIM is used as the 3D information model for an underground coal mine that has mine shafts to access deep coal beams. For collecting geometric information and other attributes of underground coal mines, terrestrial laser scanning (TLS) is employed. TLS has been used effectively for the 3D data collection of the surface of complex objects, thereby allowing the construction of 3D models (Thomson & Boehm, 2015). This is thanks to TLS's ability to collect millions of 3D surface points of objects in a short time with mm-level accuracy (Cao Xuan Cuong et al., 2021). In addition, the intensity data collected via the RGB camera built into the TLS scanner enables the creation of detailed point cloud data and a highly realistic representation of the scanned object surface. The Scan-to-BIM method (Abreu et al., 2023; Koch et al., 2017) is used to reconstruct 3D models of objects. The accuracy of 3D models is assessed by two methods, comparing with the direct measurement and by comparing its surface mesh with its TLS point cloud.

2. STUDY AREA AND DATA COLLECTION

2.1 Study area

In this study, the study area selected is the mining infrastructure of Nui Beo Coal Joint Stock Company (Figure 1). This is an underground coal mine with an area of 12 hectares for the surface plant infrastructure (SPI), built in 2012 at an altitude of +35 m and access to coal beams by mine shafts and a variety of tunnels. On the site of SPI, two mine shafts are built with a steel structure with a height of 50 m, equipped with a transport system. While an elevator or cage in the primary shaft is used to transport people, the secondary one is used to transport construction materials and rock and coal in and out of tunnels. At the time of this study, the two mine shafts were serving underground mining service from the seam to -350 m, with a design capacity of two million tons of coal/year. In addition to the two mine shafts, to ensure the production of the mine, other ancillary structures were also built, such as plants and office buildings with brick walls and iron roofs. The mine shafts have hoistrooms, headframes and sheave wheels, which have complex structures (Figure 1-a). The underground infrastructure of the mine includes 6.8 km of tunnels for different purposes, such as transportation tunnels, working tunnels and ventilation tunnels (Figure 1b).

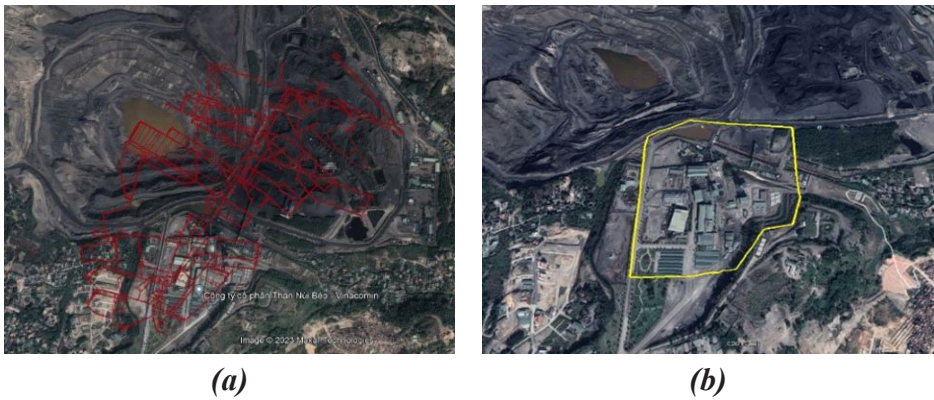


Figure 1. Location of (a) the surface plant infrastructure (the yellow boundary) and (b) the system of tunnels (the red lines).

2.2 Data collection

The procedure of scanning the coal mine’s SPI is illustrated in Figure 2. It includes five main steps, such as planning and preparing equipment, designing the TLS laser scanning station, establishing TLS targets for registration, performing TLS scanning and processing data and exporting TLS point clouds. For scanners that provide the centering mode like total stations, each position of the scanner and control points for back-sights can be measured.

Planning is especially important because it is the process that shapes the entire content of the TLS scan. Stemming from the project’s requirements, based on the results of the field survey of the TLS scanning area, select appropriate equipment and arrange human resources for implementation. In this study, the following equipment was used (see Table 1).

Table 1. Some comments on tables.

No	Name of survey equipment	Quantity
1	Topcon GLS 2000 scanner	01
2	Faro Focus X130 scanner	01
3	Leica FlexLine TS 09 total station	01
4	Topcon GLS 2000 scanner	01

Based on the characteristics of the TLS scanning area based on the specifications of the TLS scanner, design the scanning stations to cover as many surfaces as possible, thereby reducing the number of scanning stations. It should also be noted to ensure the overlap of scan data between stations to serve later scan registration.

Establish ground control points (GCPs) and targets for each scan pairing. This is for two purposes, including scan registration and transferring the point cloud coordinate system to the geodetic coordinate system. Therefore, at least 3 focal points should be arranged and measured using an electronic total station.

For processing TLS data, each laser scanner has its own software, e.g. Faro scanner with SCENE, whereas the Topcom GLS scanner with Magnet College. However, they have the same processing procedure, including processing for each single scan station before registering all stations and the resulting point clouds (PCs) can be exported to a variety of formats, such as E57, LAS and ptx.

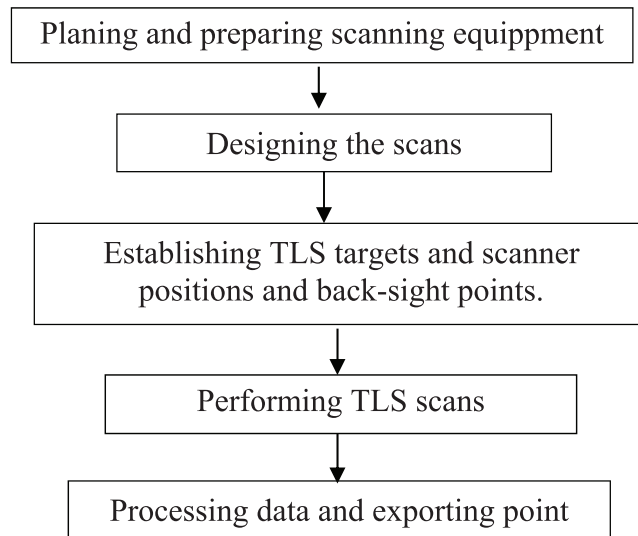


Figure 2. Collecting and processing data procedure.

The data collection is divided into three parts: (1) TLS scanning of the SPI, (2) TLS scanning of the secondary mine shaft and (3) TLS scanning of tunnels. Specifically, part one was performed using a Faro Focus X130, while parts two and three were performed using a Topcon GLS 2000. In part one, there were seven TLS stations to collect data inside the headframe and eight TLS stations collecting data outside the headframe. A number of checkerboards are measured in their coordinates based on survey control points using a Leica FlexLine TS09 total station. Their coordinates are in the VN2000 coordinate system. The GLS 2000 scanner has the function of centering and leveling like a total station, so it can be more useful for the direct registration of point clouds. This scanner was employed to scan the shaft and there were a total number of 86 stations with almost 24 hours of scanning. When scanning tunnels, each tunnel was scanned by the GLS 2000 scanner with its function of resection. The control points in each tunnel were used to position each scan station by resection, so its point cloud was directly measured in the VN 2000 coordinate system. The results were a PC with a number of 172,684,627 points (Figure 3a) with a registration error of 8 mm. PCs were exported to E57 format and ready for the next steps.

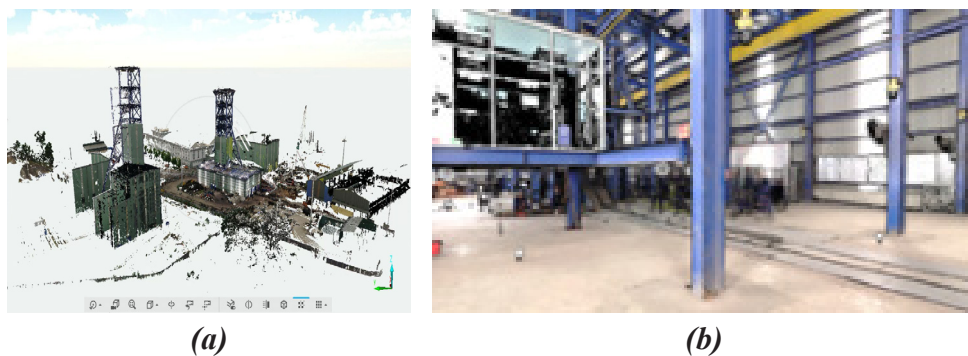


Figure 3. Result of TLS scanning for part 1: (a) Outside of the headframe; (b) inside of the headframe.

Scanning data of parts 2 and 3 is performed using Topcon's Magnet College software. The processing results are point clouds for the inside of the shaft (Figure 4) and tunnels (Figure 5). PCs are also exported to the E57 format.

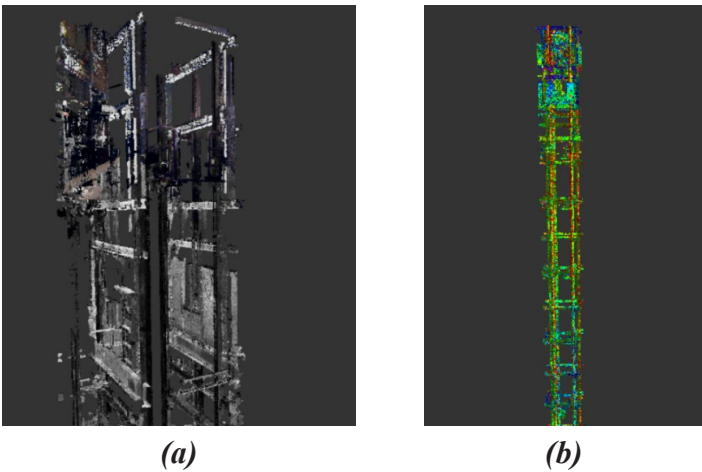


Figure 4. Scanning results of part 2 (displayed in Autodesk RECAP Pro software).

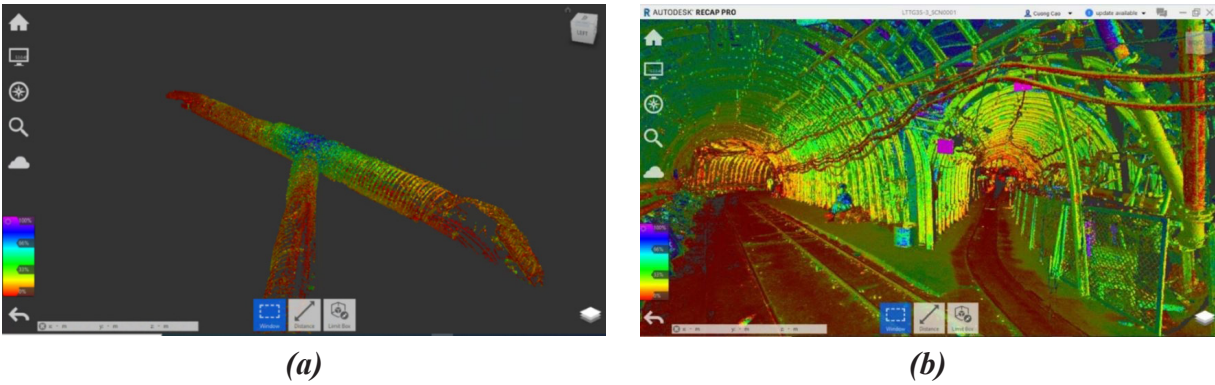


Figure 5. Scanning results of part 3 (displayed in Autodesk RECAP Pro software).

3. METHODOLOGY

3.1 Industry Foundation Classes (IFC) standard of BIM

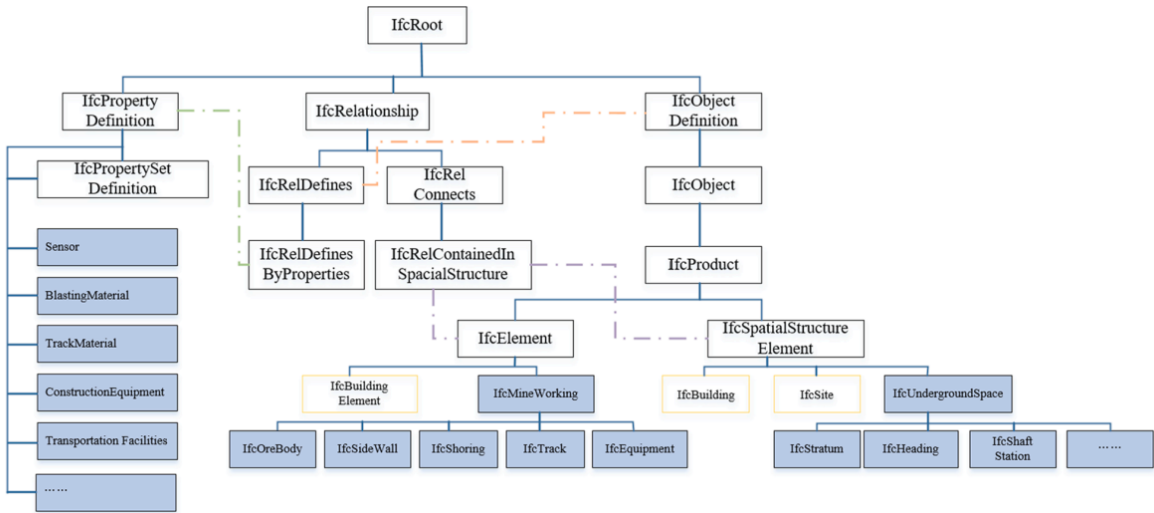


Figure 6. IFC extension for the mine working information model (Li et al., 2021).

In a mining project, there is always a combination of many different fields, such as construction, mining, geology, geodesy, electromechanical, environment and transportation. Therefore, data for BIM can come from a variety of sources and in different formats. To facilitate the exchange of data

between different sources, software, or formats for BIM model management for mining projects, the IFC (Industry Foundation Classes) standard, an open format standard, is used. The IFC uses the EXPRESS language to define the information. The IFC data format contains geometric data and other information, such as the relationship between the Model's elements. The structure of the IFC standard consists of four layers: The domain layer, the interoperability layer, the core layer and the resource layer. However, although many entities and their attribute were developed by IFC to describe objects, services and visual information, they cannot satisfactorily describe our working project. In this study, the mine working information model with IFC extension proposed by Li et al., (2021) was employed (Figure 6).

3.2 Method of BIM generation based on TLS point clouds - Scan-to-BIM

This is a common method for integrating BIM and TLS laser scanning technology. TLS technology provides raw data for BIM, which is point clouds. TLS point clouds, after noise filtering and classified into different objects before extracting their geometrical information. In other words, the model parameters of the objects are estimated. After this step, if there is a lack of objects' important dimensions, direct measurement of these objects can be performed, e.g., the tape or laser meter-based methods. Based on parametric models, a complete BIM model is created after data transformation. For complex objects, the modeling process needs to be done manually with specialized software to produce highly accurate and detailed results. For the objects in the mine, most of them have industrial structures such as beams, trusses and columns, so it is possible to automate the modeling process. However, in fact, there are always many differences between the as-designed and as-built objects due to construction and the impact of environmental factors over time, so to ensure accuracy, the semi-automatic method is suitable for projects in the mining field.

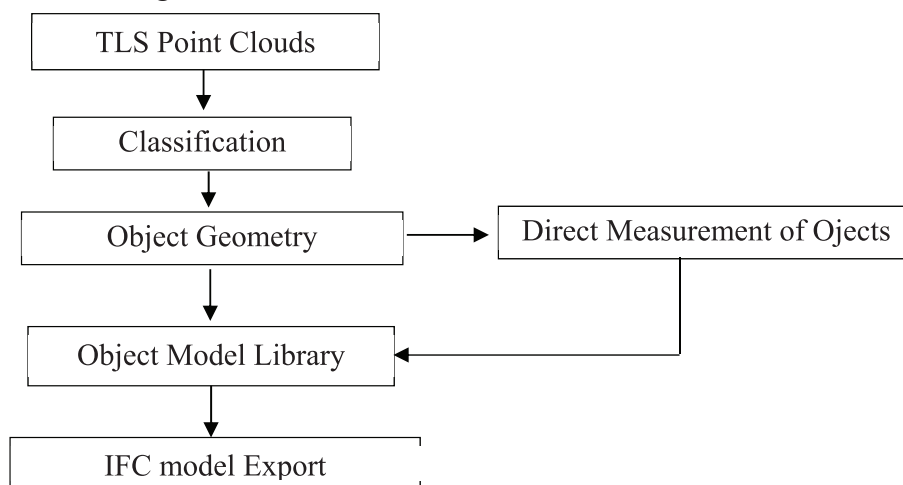
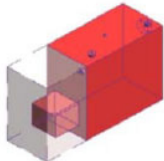


Figure 7. Flowchart of BIM generation from TLS point clouds.

3.3 Level of Details (LOD)

LOD is to determine the quality of models. In this study, a LOD proposed by Trimble (2013) was used. There are five LODs, including LOD 100 (Conceptual), LOD 200 (Approximate Geometry), LOD 300 (Precise Geometry), LOD 400 (Fabrication) and LOD 500 (As-built Model). Table 2 provides some descriptive information about each LOD.

Table 2. Description of BIM LOD (Source: BIM Forum).

LOD 100	LOD 200	LOD 300	LOD 400	LOD 500
Conceptual	Approximate geometry	Precise geometry	Fabrication	As-built
				
The Model Element may be graphically represented in the Model with a symbol or other generic representations but does not satisfy the requirements for LOD200. Information related to the Model Element (i.e., per square meter, etc.) can be derived from other Model Elements.	The Model Element is graphically represented in the Model as a generic system, object, or assembly with the approximate quantities, size, shape, location and orientation. Non-graphic information may also be attached to the Model Element.	The Model Element is graphically represented in the Model as a specific system, object, or assembly accurate in terms of quantity, size, shape, location and orientation. Non-graphic information may also be attached to the Model Element.	The Model Element is graphically represented in the Model as a specific system, object, or assembly that is accurate in terms of quantity, size, shape, location and orientation with detailing, fabrication, assembly and installation information. Non-graphic information may also be attached to the Model Element.	The Model Element is a field-verified representation accurate in terms of quantity, size, shape, location and orientation. Non-graphic information may also be attached to the Model Element.

3.4 Evaluation of Model Accuracy

To evaluate the models’ accuracy, Hausdorff’s distance from the original TLS point cloud to the Model is calculated based on the “cloud/mesh” distance calculator provided by Cloudcompare software. It is the distance between the TLS point cloud and the corresponding triangular surface of the exported 3D Model in OBJ format.

In addition, the geometric dimensions of the BIM models are compared to truth dimensions. For the ground truth dimension, the distance between shaft rails or guides was measured by a laser meter every 9-meter vertical distance along the shaft. This was performed after each scanning station of the shaft. These distances are used to evaluate the accuracy of the 3D Model of shaft rails using the following equation:

$$\Delta D_i = D_i - d_i; (i = 1, 2, \dots n) \tag{1}$$

$$RMSE = \sqrt{\frac{\sum \Delta D_i}{n}} \tag{2}$$

where D_i and d_i are distances between shaft rails measured in 3D models and by a laser meter, respectively, n is the number of measurements.

4. RESULTS AND DISCUSSIONS

Objects that were TLS scanned include Part 1 (headframes), Part 2 (mine shafts) and Part 3 (tunnels). The model generation was manually performed using AUTODESK REVIT 2023

through three steps: (1) Inserting the point cloud into REVIT; (2) Building the library of REVIT families and BIM objects; (3) Drawing models using Drawing and Editing Tools in REVIT. As this process is to visually superimpose parametric objects onto their corresponding locations in the scan point cloud, it can obtain highly accurate models. However, the limitation of space in tunnels and mine shafts is unavoidable, so some dimensions of objects cannot be collected or measured and their design information can be used. All objects were preprocessed and reconstructed in LOD 500. This LOD is as-built and requires the highest effort of drawing models.

4.1 BIM modeling objects in Part 1

Figure 8 shows the results of drawing BIM models of some objects of the shaft on the ground and in the headframe. This part is mainly formed by columns and beams (Figure 8). REVIT offers a library of REVIT families, such as beams and columns. As they are made according to the industry standard, they are standardized in materials, shapes and dimensions, such as steel I-, C-, U- and L-beams (Figure 9). In addition, REVIT allows users to edit the properties of beams. In this part, I-beams are the most common one and their dimensions, such as flange width, thickness and web thickness are various.



Figure 8. Columns and beams in the headframe of the mine shaft.

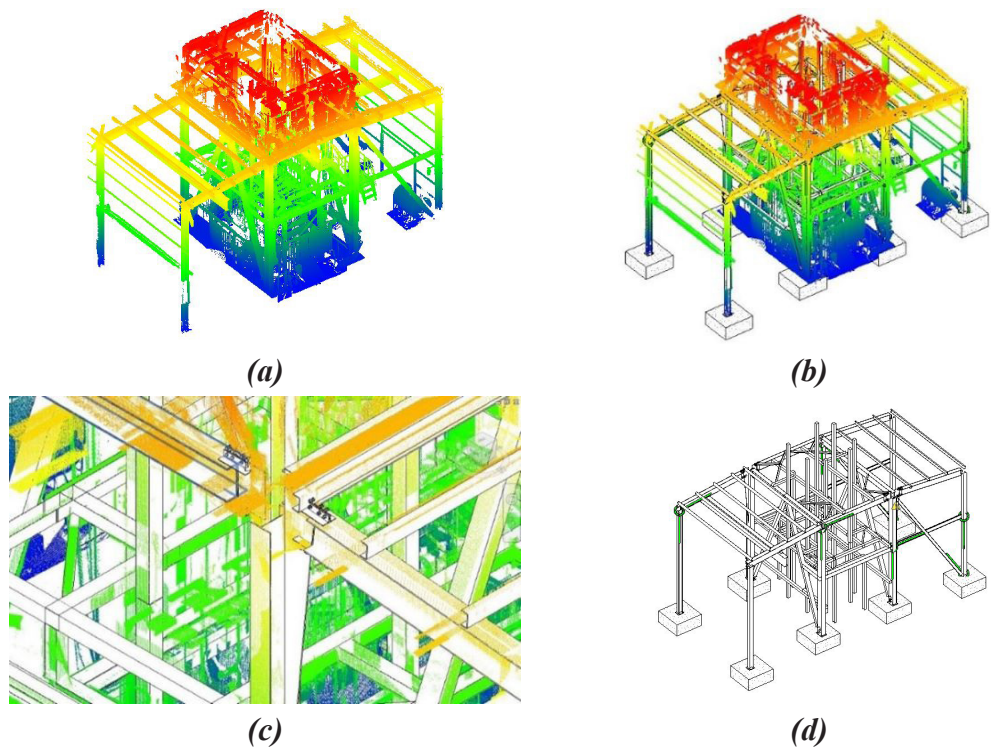


Figure 9. Generation of BIM models for objects in Part 1: (a) Point cloud extracted for beams, (b, c and d) BIM models of beams built from extracted point clouds.

4.2 BIM modelling objects in Part 2

In Part 2, the BIM model of mine shafts is built (Figure 10). The depth of the mine shaft is 385 m with some components, such as concrete walls, beams at every 9-meter depth and 4 shaft rail tracks running along the shaft. Some features cannot be measured, such as the thickness of shaft walls, then the design information was used. Figure 4 shows that the data collection provided enough points for extracting the dimensions of objects, which in turn were used to reconstruct their models. In this part, IFCWall, IFCBeam and IFCCable are the most commonly used (Figure 11).



Figure 10. Laser scanning beams inside the mine shaft.

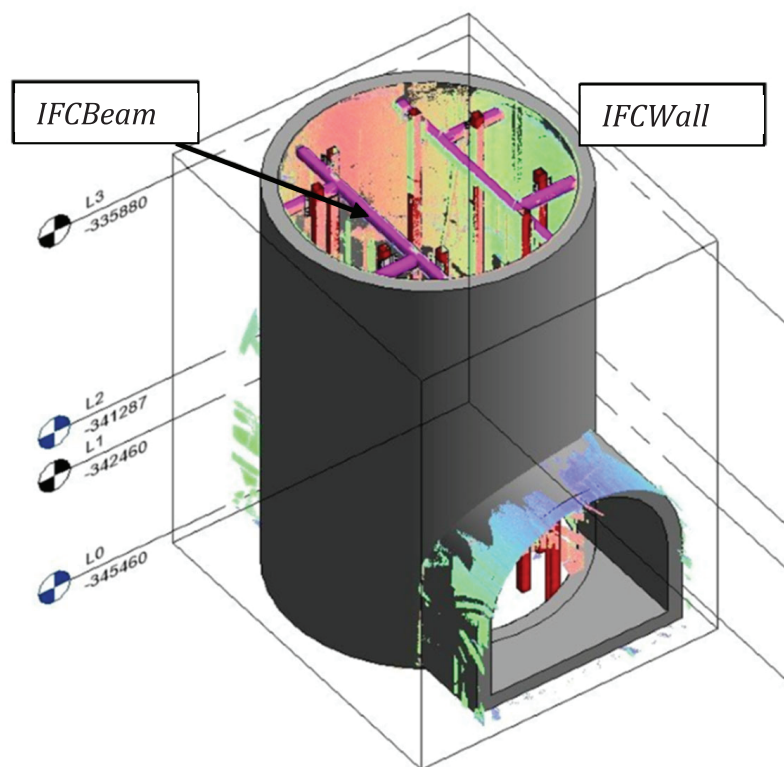


Figure 11. Generation of BIM models for the mine shaft in Part 2.

4.3 BIM modeling objects in Part 3

In Part 3, about 6.8 km length of various tunnels were modeled. They are transportation (3.5 km), working (0.5 km) and ventilation tunnels (2.8 km) (Table 3). In this part, some geometry information about beams can be obtained from point clouds, but some of their dimensions cannot be directly measured, such as flange width, web and flange thickness, so they were measured from beams in the storage place of the mine (Figure 12).



Figure 12. U-beams employed in tunnels and the measurement of their dimension using a tape.

In each tunnel, IFCBeam, IFCCable, IFCPipe and IFCTrack were used to model the tunnel (Figure 13).

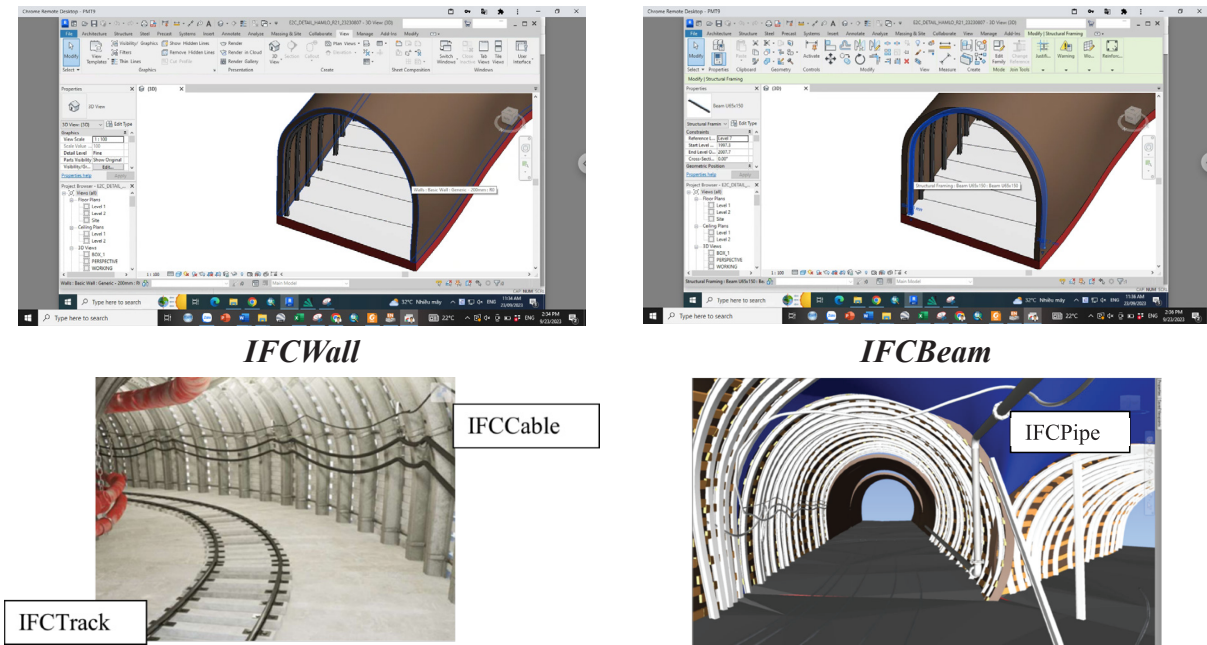


Figure 13. IFC of entities in tunnels.

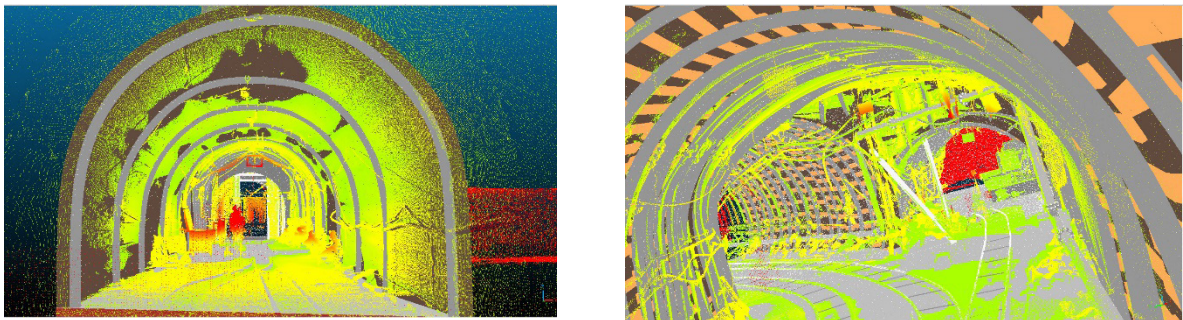


Figure 14. BIM and TLS integration for transportation tunnels.

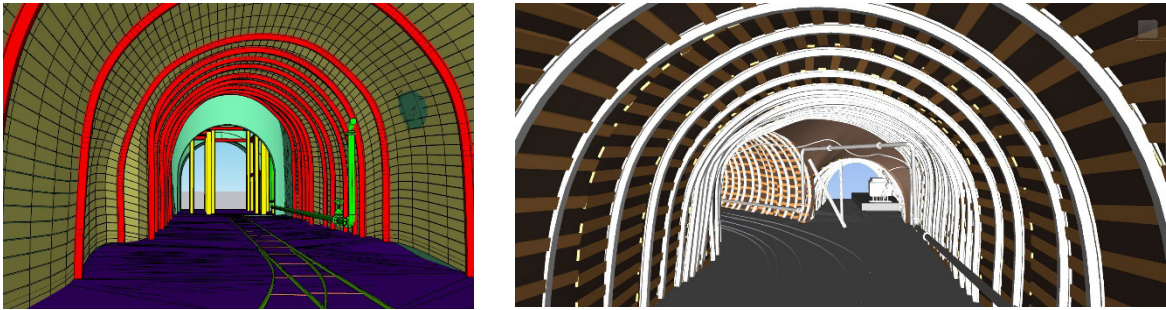


Figure 15. BIM models of transportation tunnels.

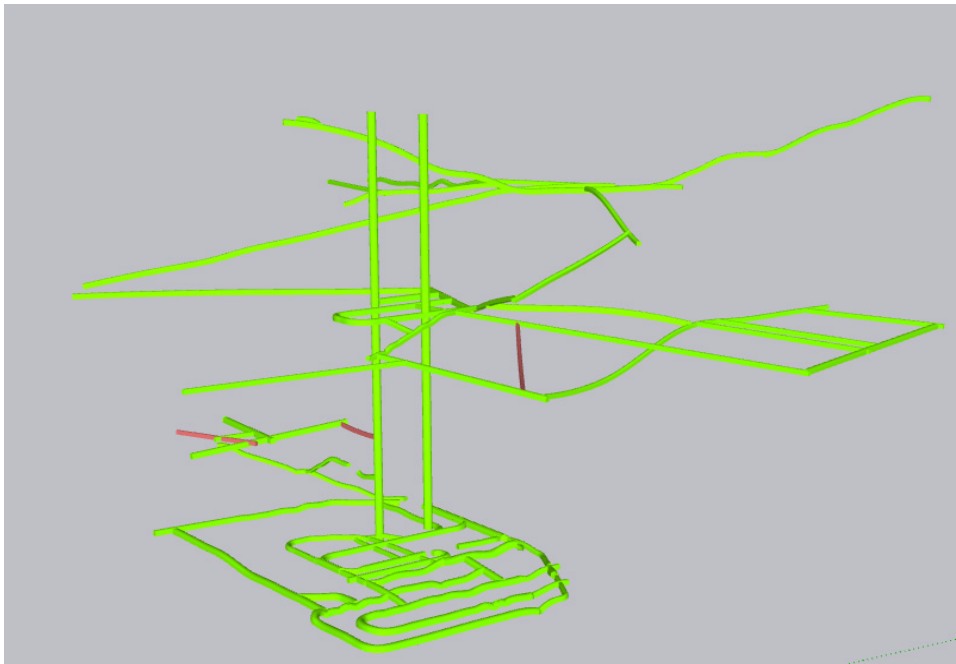


Figure 16. Overview of 3D models of Nui Beo mine shafts and tunnels.

Table 3. Summary information about the 3D model.

No	Objects	Distance (m)
1	Shaft	450
2	Transport tunnels	3,500
3	Working tunnels	500
4	Ventilation tunnels	2,800

Table 3 provides some statistics about the main objects in the underground mine which were modeled. There were 3,500 m of transport tunnels modeled for this project, followed by 2,800 m for ventilation tunnels and there were 500 m of working tunnels. Figure 16 illustrates an overview of the 3D Model of tunnels.

4.4 Model Accuracy Assessment

In order to measure the distance between shaft rail tracks along the shaft, a steel rope with a weight hung in the shaft from the ground. Its weight was put into the sump of the shaft to reduce the oscillation of the rope due to the effect of wind and water. The distance between the steel rope and each track was measured by a laser meter (Figure 17) and then the sum of the two distances is the distance between the two tracks. This distance was also measured from one track to another.

The error of each measurement was calculated by the subtraction of the two distances. The RMSE of this measurement was ± 3 mm. These distances were used to compare with those measured by BIM models (Figure 18). The result is shown in Table 4. The RMSE was ± 8 mm and this accuracy proved that TLS and BIM could be used to monitor the shaft rail tracks. This is important for the maintenance of shaft rail tracks and ensures the safety of the mine shaft’s transportation.



Figure 17. Measuring the distance between two shaft rail tracks or guides for accuracy assessment.

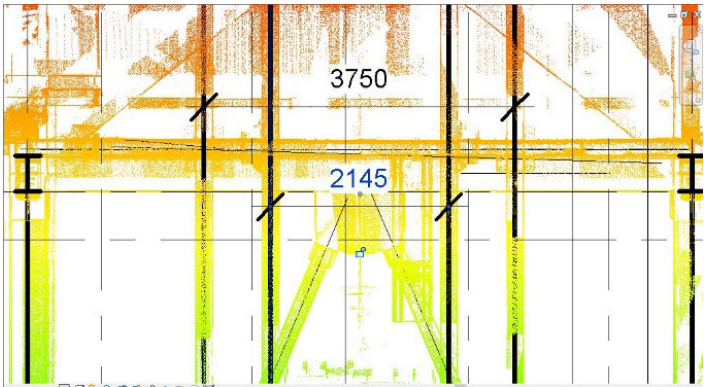


Figure 18. Distance between shaft rails measured from 3D models.

Table 4. Accuracy assessment of the mine shaft model.

Scan Stations	Distances (m)		ΔD (mm)
	Laser meter	3D model	
1	3,745	3,742	-3
2	3,749	3,750	1
3	3,754	3,758	4
...	...	...	...
43	3,740	3,737	-3
RMSE			8

For the accuracy assessment of tunnels’ BIM models, Figure 19 illustrates the point cloud, which was created from the BIM model and used to calculate Cloud-to-Cloud (C2C) distances between point clouds of TLS and BIM models (Figure 20).

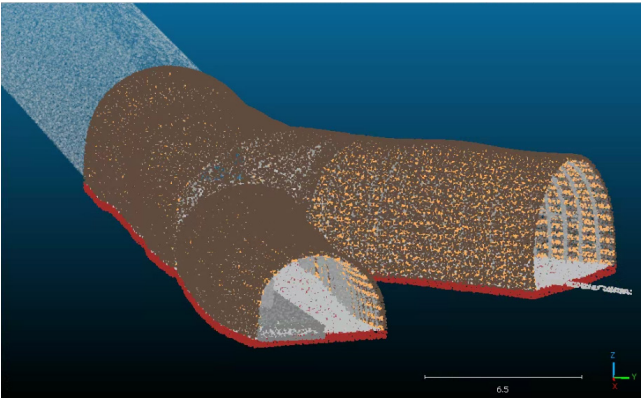


Figure 19. Point cloud of tunnels created from 3D models for comparison with their TLS point cloud.

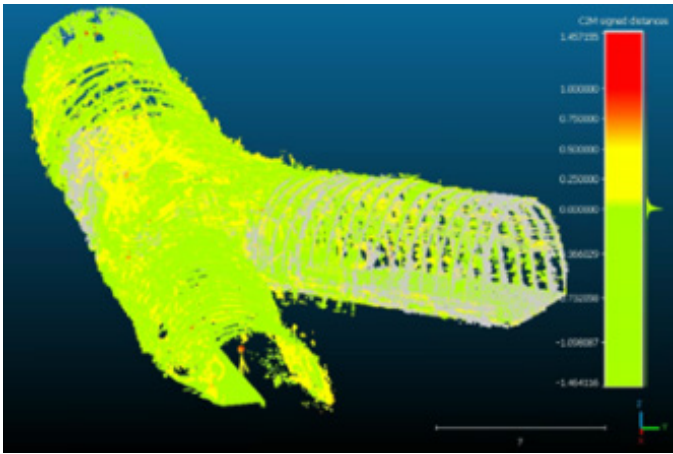


Figure 20. C2C distance map of tunnels.

5. CONCLUSIONS

In this study, we have built a 3D information model of an underground coal mine. The Scan to BIM method was applied in the Nui Beo underground coal mine, which has mine shafts for access to deep coal seams. The result shows that BIM with IFC standard is an effective solution in generating and managing 3D mine information. IFC mine working was extended and inherited from the original IFC standard for the better representation of mine working information model. There were IFCBeam, IFCWall, IFCCable, IFCTrack and IFCPipe, which were most commonly used in this study. TLS point clouds were utilized for two purposes, including reconstructing 3D models of objects and accuracy assessment. With dense and accurate point clouds, underground mining objects were reconstructed in LOD 500. However, as the unavoidable limitation of underground space leads to a lack of data for some objects, the design information was used to have important dimensions of these objects.

The accuracy of the BIM models was assessed using truth dimensions and the cloud-to-cloud distance method. While the former is based on a small number of distances measured using a laser meter and cannot show the modeling accuracy of a whole object, the latter employs point clouds to calculate C2C distances between the BIM model converted point clouds and TLS point clouds and can provide more comprehensive accuracy assessment. The result shows that BIM models were built with an RMSE of 8 mm. In addition, the safe assessment of rail tracks in the mine shaft can

be performed through the rail irregularity, which can be identified using the TLS point cloud of rail tracks and their as-designed BIM models. The comparison between TLS and as-designed BIM was performed by computing their C2C distances.

In conclusion, the integration between BIM and TLS with Scan-to-BIM and Scan-vs-BIM applications is a practical solution for the information management of underground coal mines.

6. ACKNOWLEDGMENTS

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