



# BIM and TLS Point Cloud Integration for Information Management of Underground Coal Mines: A Case Study in Nui Beo Underground Coal Mining in Vietnam

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## ABSTRACT

Recently, digital mines (DM) have plays an increasingly important role in ensuring the safety, effective management and operation of mining activities. One of essential pillars for digital transformation in mining is Building Information Model (BIM), which is also one of the first steps to implement Digital Twin. Additionally, using BIM integrated with Terrestrial Laser Scanning (TLS) and adopting digital technology can provide powerful assistance in life cycle of mining. In this study, integrating BIM and TLS point clouds, which is the basic framework of DM, was applied to build 3D mining information model as well as assessing safety of Nui Beo underground coal mining in Vietnam. Industry Foundation Classes (IFC) standard is used to define the mining information model based on TLS point clouds providing geometric and attributive information of the structures. The 3D model was built for important structures of the mine, including the mine shaft, and tunnels based on TLS point cloud. Additionally, the safety assessment of rail tracks in the mine shaft was performed by comparing the TLS point cloud of rail tracks and their as-designed BIM models. The results showed that the integration of BIM and TLS is a practical solution for the information management and safety assessment of underground coal mines.

## 1. Introduction

In general, the life cycle of a mine includes five phases: exploration, mine design, construction, exploitation, and mine closure (Duncan and Abdul Rahman, 2015). Of those, two important stages that occupy most of the life cycle of a mine are construction and exploitation. These are also the main stages critical to the success of a mining project because they are the stages that produce products and bring revenue to the mine. In underground coal mining, mine construction is carried out obliquely in these two phases. During the exploitation phase, in order to access ore deposits or coal seams, new tunnels of all types, including transportation and ventilation tunnels are constructed. Therefore, the main works

in exploitation of an underground coal mining is the construction of tunnels and the auxiliary structures, which faces various safety challenges.

According to Li et al. (2021), mining data are collected from different fields, such as construction, mining, geology, electromechanical, transportation, and environment, with different formats. This leads to difficulties in creating and sharing data, which in turn creates independence in conducting data management for construction and mining operations. Consequently, the efficiency of data usage decreases, while management costs increase, and the work progress can slow down. Currently, 2-dimensional (2D) AutoCAD drawings are still mainly used in recording and documents for mining management. However, this kind of document makes

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it difficult to check errors, as well as to display attribute information, especially in the third dimension. As a result, it is inefficient in optimizing mine project operation processes (Li et al., 2021). Therefore, it is necessary to build a 3-dimensional (3D) information system to simulate 3D designs, build virtual reality, manage and share information for a mining project. With wide applicability in construction engineering, Building Information Modeling (BIM) provides new ideas and methods for mine information modeling and positively affects the mining industry (Li et al., 2021).

Incumbent industrial revolution 4.0, Digital Twin (DT) is increasing popular and can be hold the key to the mines of the future, wherein real-time data exchange and cognitive decision-making govern (Hazrathosseini and Afrapoli, 2023). A DT framework can be formed by integration of BIM, Internet of Things (IoT), and data mining (DM) techniques (Pan and Jiang, 2021). According to Deng et al. (2021) BIM can be changed to DT step by step as it assists simulation, integrates with IoT and couples with AI techniques for prediction. In other words, BIM is one of the first essential steps for implementing a successful DT. Therefore, to harnessing the power of DT solution, building digital infrastructure, in which BIM is one of the key pillars should be considered first.

Currently, total stations and 3D terrestrial laser scanning (TLS) are the two most popular ground measurement technologies in the construction field. While total stations are mainly used to measure single points of feature objects for generating 2D maps and drawings, TLS has been used effectively for the 3D data collection of the surface of complex objects, thereby allowing the construction of 3D models (Thomson and Boehm, 2015; Qin et al., 2021). This is thanks to TLS's ability to collect millions of 3D surface points in a short time with millimeter-level accuracy (Cao et al., 2021). In addition, the intensity data collected via the red, green, and blue wavelengths (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 integration of BIM and TLS has attracted attentions from researchers in architecture, engineering, and construction. In the literature, there are popular terms of this integration, such as Scan-to-BIM, and Scan-vs-BIM. While the former is about the applications to updating the state of buildings or structures, the latter includes progress monitoring and quality assessment. For example, Scan-to-BIM applications perform 2D or 3D reconstruction by processing the point cloud, extracting its main features, and modeling the BIM elements (Abreu et al., 2023). Meanwhile, Scan-vs-BIM applications determine the quality of a constructed structure by analyzing the error of the structure relative to the construction tolerances. More information about TLS and BIM integration can be seen in the review research of Koch et al. (2017) and Abreu et al. (2023).

In recent years, being emerged from the construction industry, BIM is now finding applications in wide range of project. However, its application in mining is still lagging far behind other sectors. Especially, in underground coal mining project, due to its complexity and diversity, the BIM development and utilization of is still rarely. Chen et al. (2022) applied BIM technology for digital

mine modeling of a coal mine in Guizhou province. This research established the mine geological model, mine field development positioning axis and mine main component model. Using parametric modelling concept, Salmi et al. (2024) generated BIM model automatically using a set of softwares including Autodesk Revit 2024, Dynamo for Revit, CloudCompare, Open3D, Jupyter, Python programming language and Fuzor. However, the generated models were not compared with the original data during the study. Additionally, large tunnel networks, drilled holes or shafts were also not modelled which could be due to the quite low development and utilization of underground space.

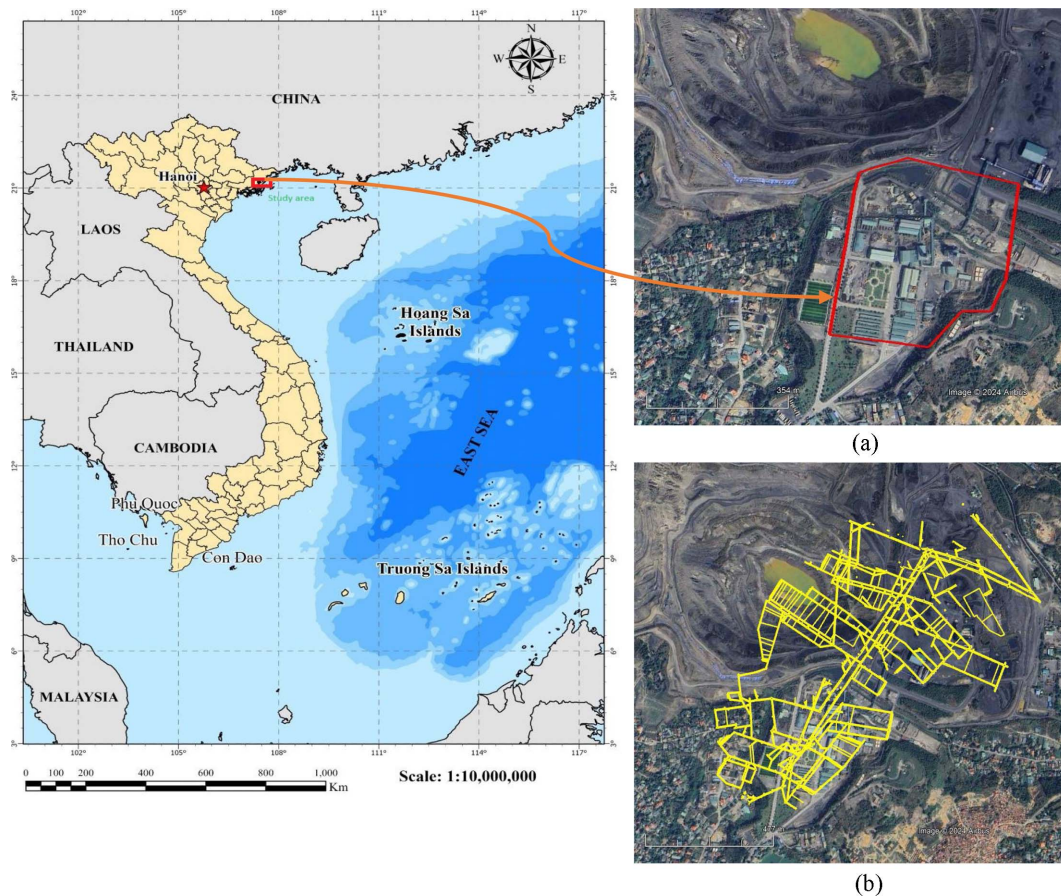
Although, adopting BIM can add value for mine data management and machine automation as well as improving the safety. However, activities and processes surrounding a mine takes place every day leading changes in built BIM; therefore, keeping such model up-to-date by intergrating rapid data observation is necessary. This study investigates the feature and adoption potential of BIM technology integrated with ground 3D laser scanning and other data sources for information management in underground coal mines. To accomplish this goal, the Scan-to-BIM method or creating BIM models from the TLS point cloud and the Scan-vs-BIM method or accuracy assessment of important as-built features are performed. For Scan-to-BIM, this article presents a process to create a BIM model from TLS scanning data of underground coal mines before exporting the model to the Industry Foundation Classes (IFC) standard for the management and data sharing. For Scan-vs-BIM, as-built BIM models are evaluated using the TLS data and used to assess the safety status of some important features, including rail tracks of the shaft and transportation tunnels.

## 2. Study Area and Data Collection

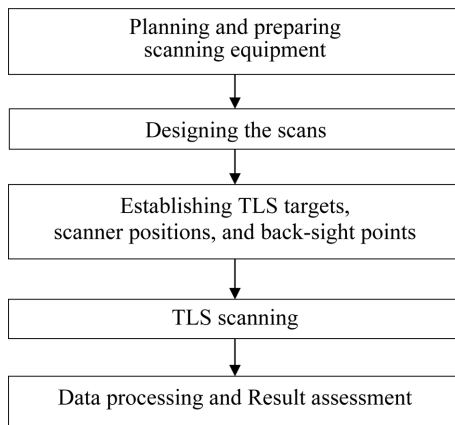
### 2.1 Study Area

In this study, the study area is selected in the mining infrastructure of Nui Beo Coal Joint Stock Company, Vietnam (see Fig. 1). Nui Beo is an underground coal mine with a surface plant infrastructure (SPI) of 12 hectares. It was built in 2012 at an altitude of +35 m, and access to coal beams by mine shafts and tunnels. On the SPI site, two steel mine shafts were built with a height of 50 m, equipped with a transport system. While an elevator or cage in the primary shaft is used for human transportation, the secondary one is used to transport construction materials, rocks, and coals.

At the time of this study, the two mine shafts were serving underground mining service from the seam to the -350 m level, with a design capacity of two million tons of coal per year. In addition to the two mine shafts, other ancillary structures were also built, such as plants and office buildings with brick walls and iron roofs, to ensure the production of the mine. The mine shafts have hoistrooms, headframes, and sheave wheels, which have complex structures (see Fig. 1(a)). The underground infrastructure of the mine includes 6.8 km of transportation, working, and ventilation tunnels (see Fig. 1(b)).



**Fig. 1.** Location of: (a) The Surface Plant Infrastructure (the red boundary), (b) The System of Tunnels (the yellow lines)



**Fig. 2.** Experimental Workflow

## 2.2 Data Collection

The workflow of scanning the coal mine's SPI is illustrated in Fig. 2. It includes five main steps: 1) planning and preparing equipment, 2) designing the TLS laser scanning station, 3) establishing TLS targets for registration, 4) TLS scanning and 5) data processing and result assessment. Three main survey equipment with the accuracy issued by the manufacturer used in this study are showed in Table 1. For centering mode scanners like total stations, each position of the scanner and control points for back-

**Table 1.** Survey Equipment

No	Name of survey equipment	Quantity	Accuracy
1	Topcon GLS 2000 scanner	01	Distance: $\pm 3.5$ mm Angle: $\pm 6''$
2	Faro Focus X130 scanner	01	Distance: up to $\pm 2$ mm
3	Leica FlexLine TS 09 total station	01	Distance: $\pm 1$ mm+1.5 ppm Angle: $\pm 3''$

sights can be measured. Planning is especially important because it shapes the entire content of the TLS scanning. Stemming from the project's requirements, appropriate equipment is selected and human resources are arranged for implementation based on the results of the field survey of the TLS scanning area. Scanning stations are designed to cover as many surfaces as possible based on the scanning area and the TLS scanner specifications, thereby reducing the number of scanning stations. It should also be noted to ensure the overlap of scanning data between stations to serve later scan co-registration.

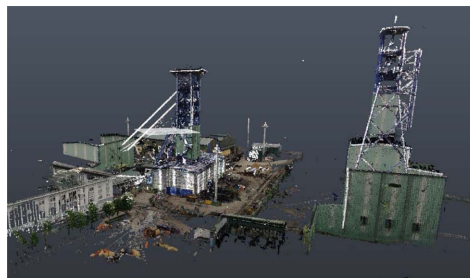
Ground control points (GCPs) and targets are subsequently established for each scan pairing. A minimum of three targets should be arranged so that two adjacent stations can be connected, avoiding locating on the same plane and in a position where the incident angle is too large for the laser. An electronic total station is suitable to determine the coordinates of these targets and GCPs



(Suyunov et al., 2023). Therefore, in this study, based on survey control points established by traversing with  $\text{RMSE} \leq \pm 8 \text{ mm}$ , coordinates of GCPs and checkerboards in arbitrary coordinate systems were measured using available functions of Leica FlexLine TS09 total station. For underground mines, mining drifts and shafts are two common methods to access seams from the surface. TLS scanning of these mines needs to be carried out from SPI through drifts or shafts, and finally to the different tunnels. At each location, there are different spatial and environmental structures, so it is necessary to set up the optimal scanning parameters. Data processing of the laser scans to obtain the point cloud is performed with professional software, which can be different between scanners. For example, scanning data collected by a FARO FOCUS X130 are processed using the SCENE software, while Topcon GLS 2000's scanning data are conducted using the Magnet College software. The final results are a point cloud (PC) and it can be exported to different formats, such as E57, LAS, and PTX.

Data collection is divided into three parts, including 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 scanner, while parts two and three were performed using a Topcon GLS 2000 scanner. In Part #1, there were seven and eight TLS stations employed to collect data inside and outside of the headframe. To ensure accurate co-registration, sphere and checkerboard targets were used. These targets were placed on the wall on the ground near the scan stations. The data collected by the FARO Focus X130 scanner were imported and processed by the SCENE software. The results were a PC with a number of 172,684,627 points (Fig. 3(a)) with reported co-registration error of 8 mm. PCs were exported to the E57 format and were ready for the next steps.

For scanning Part #2, the GLS 2000 scanner was used, it has function of centering and leveling like a total station, so it can be more useful for direct registration of point clouds. This scanner was employed to scan the shaft and it was placed on the top of the shaft elevator. In order to avoid large angles of incident signal that could create inaccurate results, each scanning station was set in every nine-meter vertical distance of the shaft when the shaft elevator moved up and down. As the space limitation on the top of the shaft, it could only scan half of the shaft at each scan station. Therefore, the whole shaft was scanned on the two ways of the shaft's up and down moving. There were a total of 86



(a)



(b)

Fig. 3. Result of TLS Scanning for Part#1: (a) Outside, (b) Inside of the Headframe

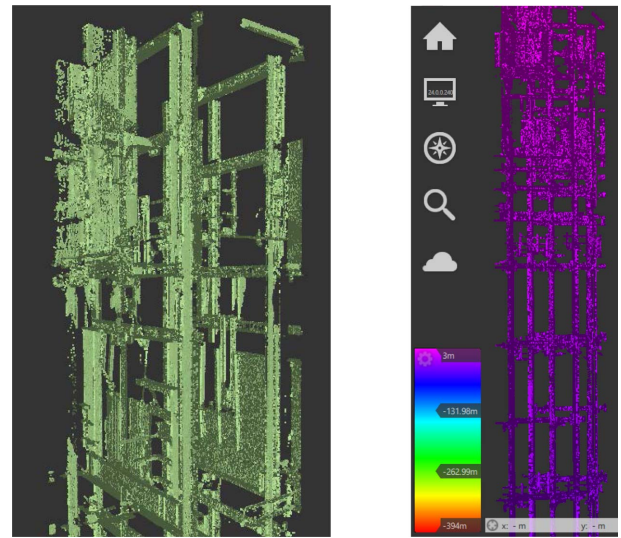
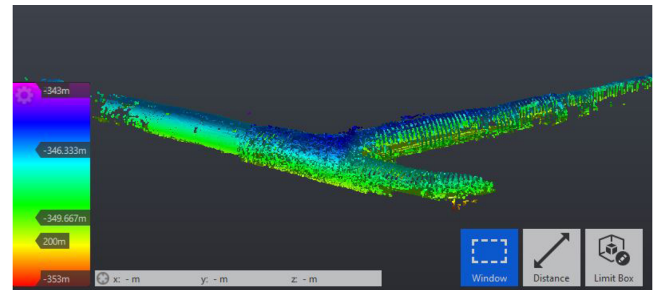
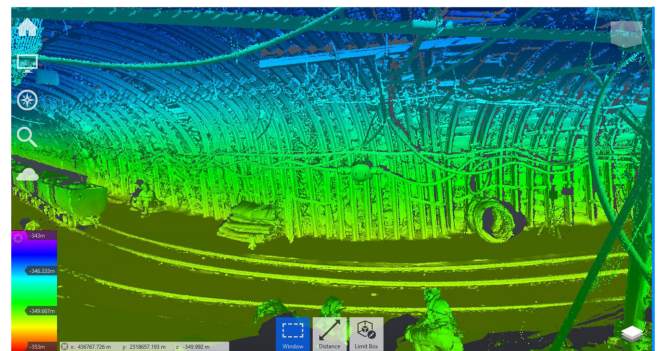


Fig. 4. Scanning Results of Part#2 (displayed in Autodesk RECAP Pro software)



(a)



(b)

Fig. 5. Scanning Results of Part#3 (displayed in Autodesk RECAP Pro software)

stations with almost 24 hours of scanning for this part. Scanned data was processed by Magnet College software and showed in Fig. 4. Similarly, scanning of Parts #3 (i.e., tunnels) was also conducted by GLS 2000 scanner. The control points established before scanning in each tunnel were used to position each scan station by resection. The processed results are point clouds for the inside of the tunnels as can be seen Fig. 5. PCs were also exported to the E57 format.

### 3. Methodology

#### 3.1 Industry Foundation Classes Standard of BIM

In a mining project, there is always a combination of many different fields such as construction, mining, geology, surveying, 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, the IFC and open format standards are used for BIM model management for mining projects. The IFC standard 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, including the domain layer, the interoperability layer, the core layer, and the resource layer. However, although many entities and their attributes are developed by IFC to describe objects, services, and visual information, they cannot satisfactorily describe mine working project. In this study, the mine working information model with IFC extension proposed by Li et al. (2021) was employed (Fig. 6).

#### 3.2 BIM Generation Based on TLS Point Clouds – Scan-to-BIM

Scan to BIM method is the recent result of the progression of design tools and reality capture technologies. This method illustrated

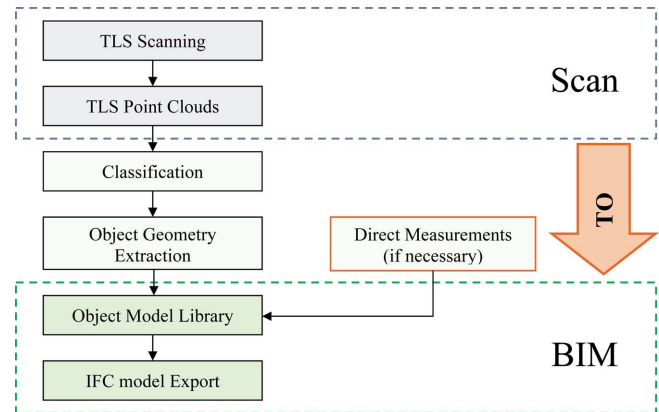


Fig. 7. Flowchart of BIM Generation from TLS Point Clouds

in Fig. 7 includes three phases. It starts with the scanning of objects which are built BIM models. In this phase, the TLS technology is employed to collect data. In the next phase, TLS raw data is processed with two main steps, including scan registration and data filtering or cleaning. The outcome of this phase is to provide data in the form of point clouds. In the last phase, BIM modeling is conducted using the post-processed point clouds using available tools of Autodesk REVIT software.

In experiment, the scanning process consists of many scan stations. Therefore, the co-registration of these scans is performed to obtain accurate point cloud of the scanned objects. The Iterative Closest Point (ICP) method (Zhang et al., 2022) is used to register the point cloud of the different scans. Then, the Statistical Outliers Removal (SOR) available in CloudCompare software is applied to remove noise. The noise filtered point clouds are classified into different objects before their geometrical information is extracted. For the procedure of classification, the Cloth Simulation Filter (CSF) plugin (Zhang et al., 2016) is applied to separate the point cloud into ground and non-ground parts. The non-ground

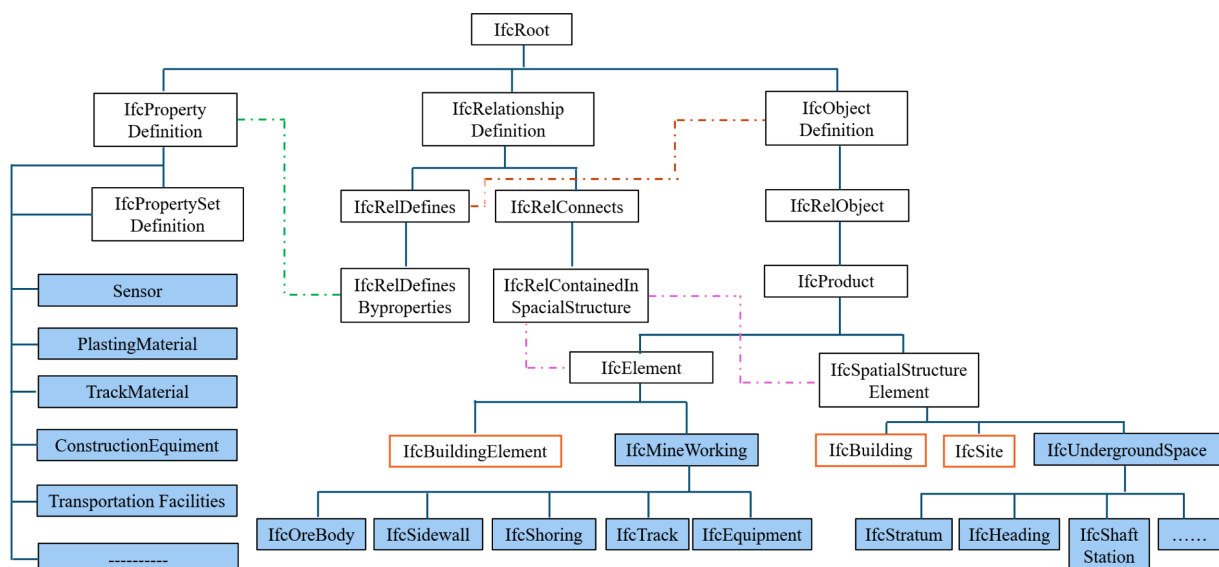

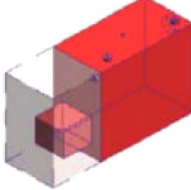





Fig. 6. IFC Extension for the Mine Working Information Model

**Table 2.** Description of BIM LODs (Source: BIM Forum <https://bimforum.org/>)

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

parts consist of man-made objects, therefore, they are used in the next step for the extraction of the object geometry, which are the model parameters needed for their BIM modeling. For complex structures, due to the similarity of material and laser return intensity, manual classification is performed. Next step, the BIM model is generated from the geometric information of objects manually extracted base on 3D edge detection. After this step, if there is a lack of objects' important dimensions, direct measurement can be performed by laser meter-based method. 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.

### 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) (Trimble, 2013). Table 2 provides some descriptive information about each LOD.

### 3.4 Model Evaluation

To evaluate the model, the Hausdorff 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, some specific geometric dimensions of the BIM models which are generated based on TLS point cloud are compared to the truth dimensions. For the truth dimensions between shaft rails or guides, the distances were measured twice by a laser meter at every 9-meter vertical distance along the shaft, the average value of the double measurements was used to compared with the corresponding dimension extracted from as-built BIM. This was performed after each scanning of the shaft. These distances are used to evaluate the accuracy of the 3D model of the shaft rails using the following equation:

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

$$RMSE = \sqrt{\frac{\sum \Delta D_i^2}{n}}, \quad (2)$$

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

### 3.5 Safety Assessment of Rail Tracks in the Mine Shaft – Scan-versus-BIM

Rail tracks are essential features built in mine shafts and tunnels as they are used for both human and stuff transportations in underground mines. In mine shafts, these are rail tracks of cages or elevators, while in tunnels, they are one part of the electrical rail-based transportation system. For safety reasons, rail tracks are required to periodically monitor and ensure that they are under normal conditions. The monitoring of rail tracks is to identify any rail irregularities, which are geometrical deviations of the rail cross-sections from an ideal track geometry (Urda et



al., 2021). In this study, the rail tracks of the mine shafts were scanned by TLS and compared to the as designed- BIM models to identify any rail irregularities. The comparison is shown through a cloud-to-cloud (C2C) distance map.

#### 4. Results and Discussions

Objects that were scanned by TLS include Part #1 (headframes), Part #2 (mine shafts), and Part #3 (tunnels). The model generation was manually performed using AUTODESK REVIT 2023 (AutoDesk, 2022) through three steps: 1) importing the point cloud into REVIT; 2) building the library of REVIT families and BIM objects; 3) drawing models using Drawing and Editing

Tools available in REVIT. As this process is to visually superimpose parametric objects onto their corresponding locations in the scanned point cloud, it can obtain highly accurate models. However, the spatial limitation 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 some objects mainly formed by columns and beams of the shaft on the ground and in the headframe. These objects are transformed to BIM by using manual command and



Fig. 8. Columns and Beams in the Headframe of the Mine Shaft

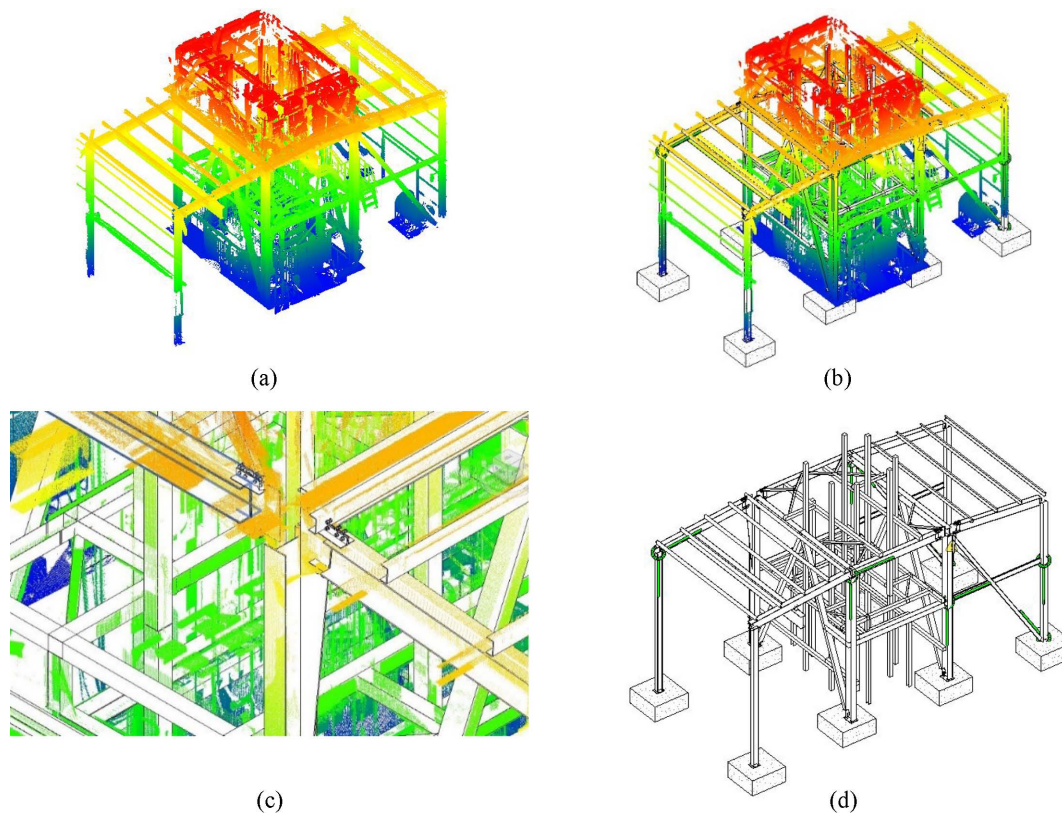


Fig. 9. Generation of As-Built BIM Models for Objects in Part #1: (a) Point Cloud Extracted for Beams, (b, c, and d) BIM Models Built From the Extracted Point Clouds



**Fig. 10.** Laser Scanning Beams Inside the Mine Shaft

library available in REVIT. REVIT offers a library of REVIT families such as beams and columns made according to the industry standard, they are standardized in materials, shapes, and dimensions, such as steel I-, C-, U-, and L-beams as can be seen in Fig. 9. In addition, REVIT allows users to edit the properties of beams. In this part, I-beams are the most common, and their dimensions, such as flange width, thickness, and web thickness are various.

#### 4.2 BIM Modeling Objects in Part #2

Mine shafts are the main objects to be modeled in Part #2. The mine shaft is a special object with a vertical dimension that is well developed, at 385 m in this study. The component of the mine shaft includes the shaft wall, which is concrete forming the perimeter of the shaft. In addition, there are beams at every 9-meter vertical distance along the shaft, while four shaft rails run along the shaft. The thickness of shaft walls cannot be measured by any surveying method; therefore, the design information was used. Other structures were scanned two times, the first one when the elevator moved down and another one when it moved up, with the scanner placed on the top of the cage (Fig. 10). At each time, the data for half of the mine shaft

**Table 3.** Summary Information about the 3D Model

Objects	Distance (m)
Shaft	450
Transport tunnels	3,500
Working tunnels	500
Ventilation tunnels	2,800

were collected. This is because of space limitations on the top of the cage. This data collection can provide enough points for extracting the dimensions of objects and then reconstructing their models. In this part, IFCWall, IFCBeam, and IFCCable are the most common (Fig. 11).

#### 4.3 BIM modeling objects in Part #3

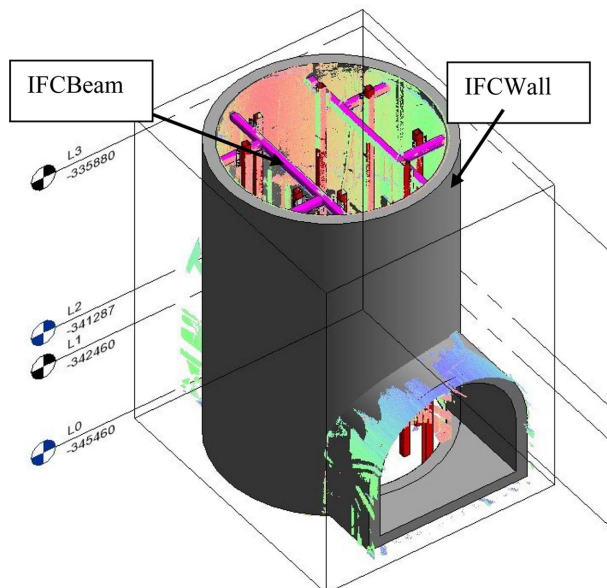
In Part #3, about 6.8 km in length of various tunnels were modeled. They are transportation (3.5 km), working (0.5 km), and ventilation tunnels (2.8 km) (Table 3). In transportation tunnels, steel U-beams are employed, and some of their dimensions, such as flange width, web, and flange thickness could not be extracted from point clouds, so they were measured directly from beams in the storage place of the mine (Fig. 12).

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

Table 3 provides some statistics of the main objects in the underground mine which were modeled. Figs. 13, 14, and 15 illustrate the details of transportation tunnel models. It is obvious that underground mines have objects with one well-developed dimension, such as tunnels and shafts. While tunnels are more likely to well developed on horizontal dimensions, shafts are well developed along the vertical dimension (see Fig. 16). While transportation and ventilation tunnels often exist for a long time, working tunnels normally last for short periods as they are where coal is extracted. Some working tunnels are intended to collapse or fill with waste rocks. It can be also seen that as-built BIM model of a long wall mining machine was well generated as illustrated in red rectangle in Fig. 15.

#### 4.4 Model Accuracy Assessment

In order to measure the distance between shaft rail tracks along the shaft, a steel rope with a weight was hung in the shaft from



**Fig. 11.** Generation of BIM Models for the Mine Shaft in Part 2





Fig. 12. U-Beams in Tunnels and the Measurement of Their Dimension Using a Tape

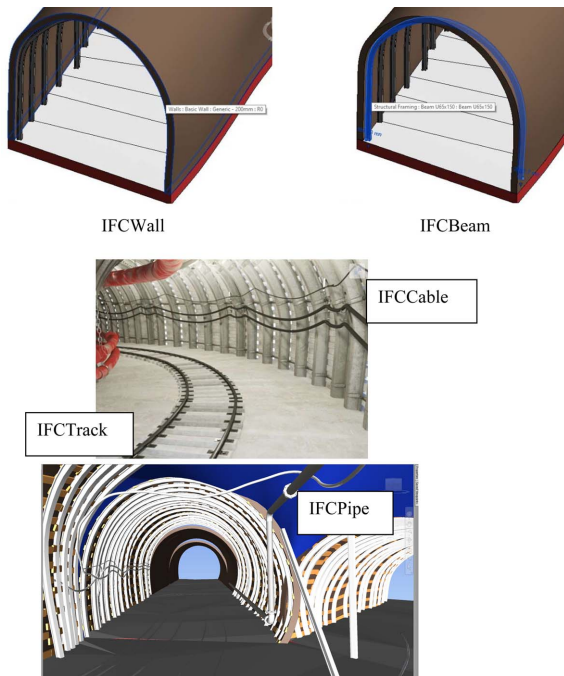


Fig. 13. IFC of Entities in Tunnels

the ground. Its weight was put into the sump of the shaft to reduce the oscillation of the rope due to wind and water. The distance between the steel rope and each track was measured twice by a laser meter then take the average value (Fig. 17). This distance was also measured from one to another track. The error of each measurement was calculated by the subtraction of the two distances. The RMSE of this measurement was  $\pm 3$  mm. These distances were used to compare with those measured from as-built BIM models (Fig. 18). The result is shown in Table 4 with the RMSE of  $\pm 8$  mm. This accuracy proved that TLS and BIM can 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.

For the accuracy assessment of tunnels' BIM models, Cloud-to-Cloud (C2C) distances was calculated between the original point clouds of TLS and those generated from the as-built BIM (illustrated in Fig. 19). The result was C2C map shown in Fig. 20.

From the C2C distance map, it can be seen that the difference between the BIM models and TLS point cloud ranges from -1.46 m to 1.45 m, but the large proportion of points ranges from -0.1 m

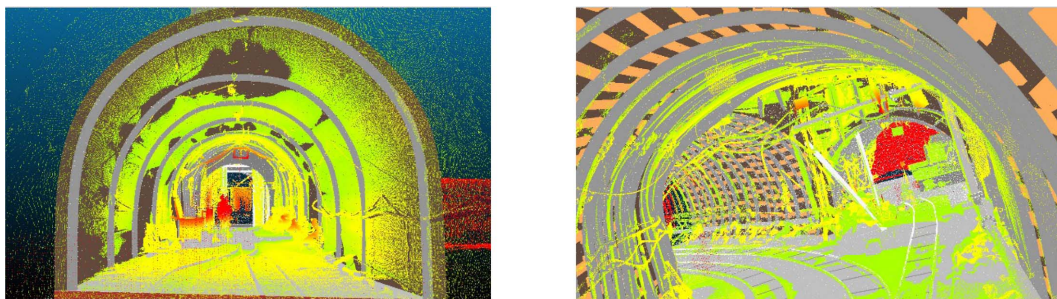


Fig. 14. As-Built BIM and TLS Integration for Transportation Tunnels



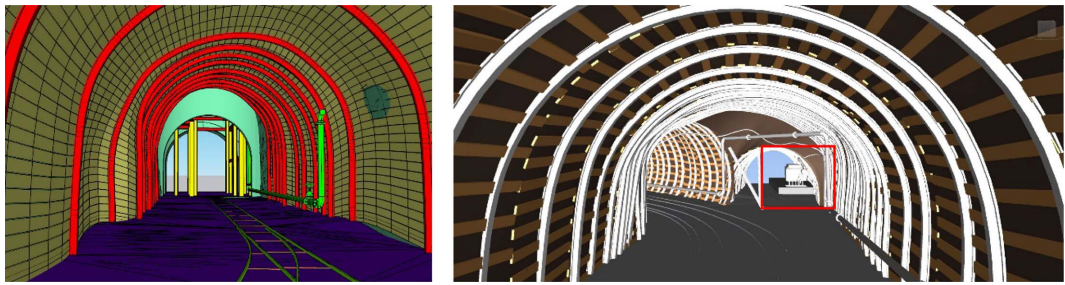


Fig. 15. As-Built BIM Models of Transportation Tunnels

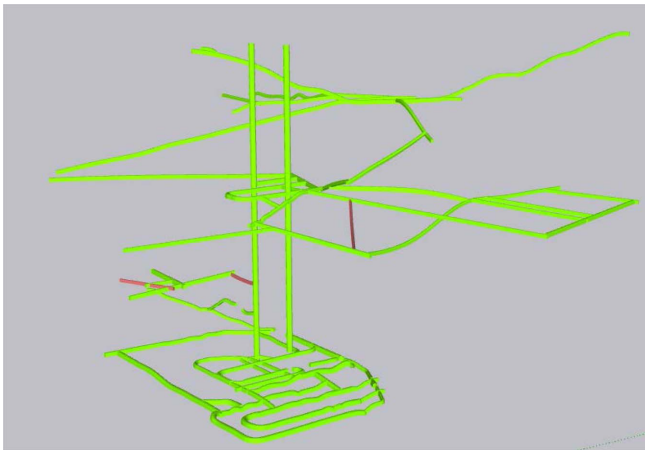


Fig. 16. Overview of 3D Models of Nui Beo Mine Shafts and Tunnels

Table 4. Accuracy Assessment of the Mine Shaft Model

No	Distances (mm)		$\Delta D$ (mm)
	Laser Meter	3D model	
1	3745	3742	-3
2	3749	3750	1
3	3754	3758	4
...	...	...	...
43	3740	3737	-3
RMSE			$\pm 8$

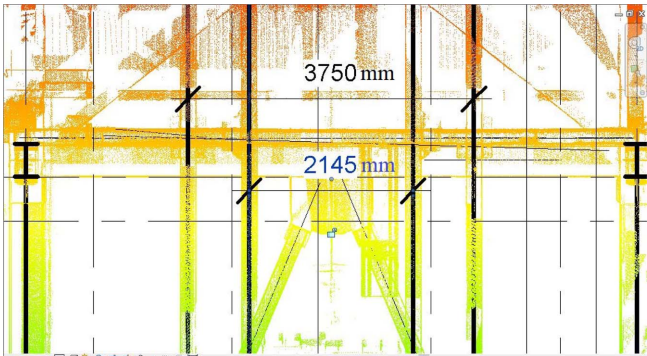


Fig. 18. Distance between Shaft Rails Measured in Millimeters From As-built BIM

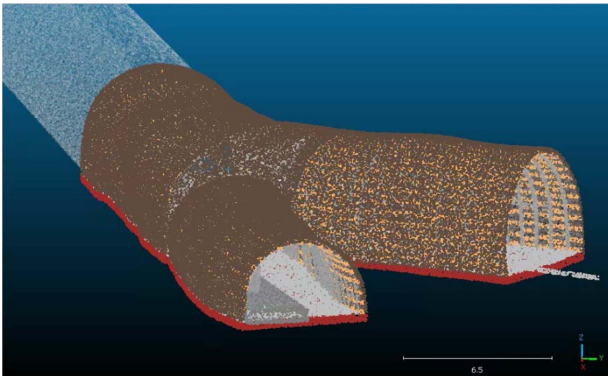


Fig. 19. Point Cloud of Tunnels Created from the 3D Models for Comparison With the Original TLS Point Cloud

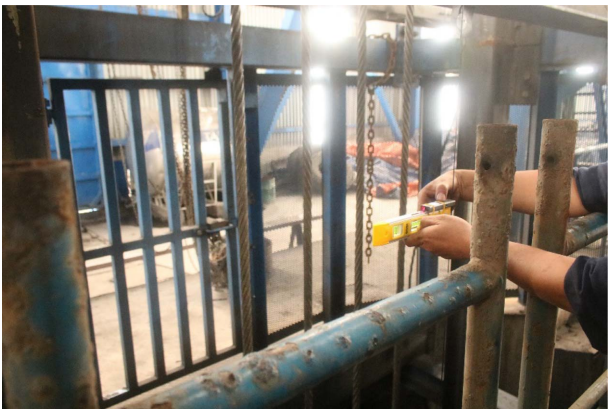


Fig. 17. Measuring the Distance between Two Shaft Rail Tracks or Guides for Accuracy Assessment

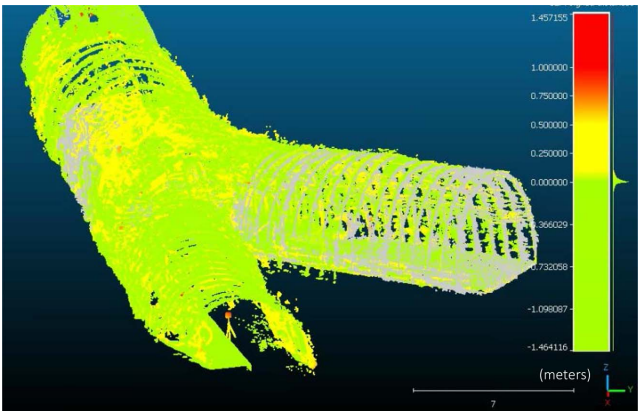
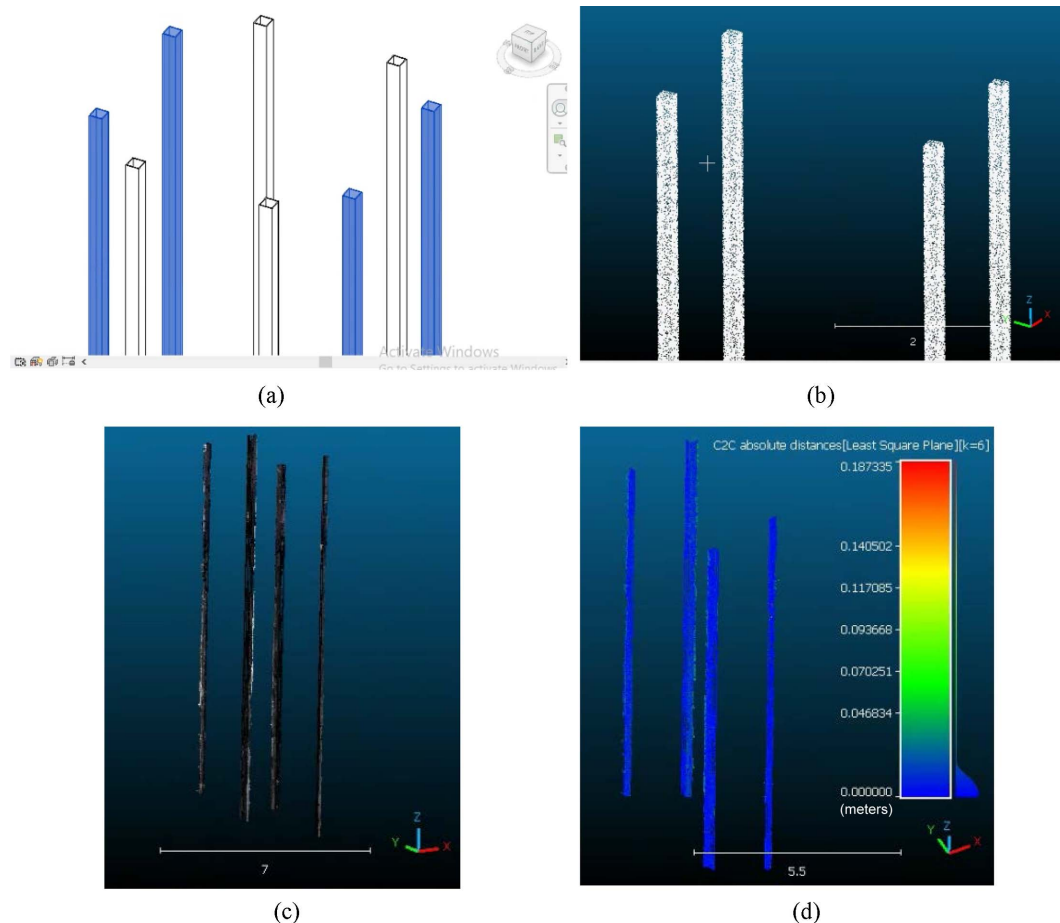


Fig. 20. C2C distance Map of the Tunnels



**Fig. 21.** Safety Assessment of Rail Tracks: (a) As-Designed BIM Models of Rail Tracks, (b) As-Designed Point Cloud, (c) TLS Point Cloud, (d) C2C Distance Map

to 0.1 m. There were some large errors because not all scanned features were modeled.

#### 4.5 Safety Assessment of Rail Tracks

Figure 21 illustrates the process of identifying rail irregularities of rail tracks along about 10 m depth of the mine shaft. After exporting the as-designed BIM models of rail tracks to the object format, these models were used to create a point cloud of 500,000 points (Figs. 21(a) and 21(b)). This point cloud was used as the reference for its comparison with the TLS point cloud of the rail tracks (Fig. 21(c)). The result of comparing the TLS point cloud of rail tracks and their as-designed models is illustrated in the C2C map (Fig. 21(d)). The result shows that there was a difference of 7.9 mm between the built rail tracks and their design, while there was no isolated track defect. However, this meets Vietnam's standards for underground mining construction; therefore, there is no need to implement a safety solution.

### 5. Conclusions

This study has performed the integration of BIM and TLS for an underground coal mine. A BIM and TLS integration workflow for underground mines was proposed and applied in the Nui Beo

underground coal mine, which has mine shafts for access to deep coal seams. The results showed that while TLS technology can provide dense and accurate point clouds of mining objects from the ground (hoistroom and headframe) to the underground (shafts and tunnels), BIM with the 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 a better representation of mine working information model.

In this study, TLS point clouds were utilized for two purposes, including reconstructing 3D models of objects and safety 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, in this case the design drawing or direct measurement can be used to provide missing information. For example, the design drawing of mine shafts provides the thickness of mine shaft walls which cannot be obtained from their TLS point clouds, since the LiDAR returns cannot come from the back facades. Similarly, for some primary transportation tunnels, the thickness of their concrete walls can be also derived from their designs.

The accuracy of the as-built BIM models was assessed using in situ measurements and the Cloud-to-Cloud distance method.










The results showed that the BIM models were built with an RMSE of 8 mm. However, due to complexity of underground objects as well as limitation of underground space, some 3D modelling procedures were performed manually. This is time consuming and therefore need to be solved in future study. In addition to as-built BIM generation, the safety 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. Although, this proved that 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. The development of BIM to DT need to be considered to heading new era of safety, sustainability, and profitability in mining industry.

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