EXPLORING THE POTENTIAL OF TERRESTRIAL LASER SCANNING FOR CULTURAL HERITAGE PRESERVATION: A STUDY AT BARONG CAVE IN WEST JAVA, INDONESIA

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ABSTRACT:

Barong cave, located in West Java, Indonesia, is one of the caves within the cultural heritage site of Pawon cave, which has the potential to have been a human settlement based on the artifacts found there. However, the site has faced challenges such as vandalism, lack of proper management and preservation efforts, and the negative impacts of limestone mining. Terrestrial Laser Scanner (TLS) have gained attention as a tool for cave measurement and documentation, but there is limited research on their use for cultural heritage preservation in Indonesian caves. This study focuses on documenting and creating a 3D model of Barong cave using TLS, with a specific exploration of the intensity values of point cloud data obtained from TLS near-infrared wave. Data acquisition was successfully carried out, resulting in detailed digital models of the cave. Although manual identification of vandalism using TLS was limited, our study demonstrated the potential of TLS as a tool for identifying vandalism in caves. Further research, including the development of augmented reality and virtual reality applications for museums and education, and automated identification of markings on 3D point cloud data using intensity values for cave art, requires further development.

1. INTRODUCTION

Barong cave, located in West Java, Indonesia, is one of the caves within the cultural heritage site of Pawon cave. The site is home to several ancient humans remains and other cultural artifacts, making it an important destination for researchers and visitors interested in the history and culture of the region. Research in the area started in 1999 by the Bandung Basin Research Group (KRCB). In 2000, the group found three pieces of stone tools in the small river of Ci Bukur, which is in front of Pawon cave (Brahmantyo, 2012). The stones suggest signs of prehistoric life in the area. Further research was conducted using magnetic measurement in one of the rooms of Pawon cave, which led to the discovery of low magnetic anomalies indicating potential burial or storage sites for archaeological objects. Excavations in the area revealed abundant findings, including human skeletal remains at a depth of 80 cm, and were conducted multiple times from 2003 to 2019. Excavations were also conducted in other caves in the region. The site includes several caves, including Barong Cave, which has the potential to have been a human settlement based on the artifacts found there (Yondri, 2019).

According to Yondri (2019) based on research conducted in Barong cave, it can be concluded that besides having ideal characteristics to be inhabited due to their easy-to-reach height and sufficient lighting, these caves are also suitable for human activities in the past as found in Pawon cave. Based on the excavation results in Barong cave, although no human skeleton was found, indications of their function as human settlement in the form of pottery fragments, obsidian flakes, and food remains in the form of bone fragments were also found. From this, it can be inferred that in the past, all the caves in those area were used as settlement by prehistoric humans.

Figure 1. Location of the Pawon cave cultural heritage site and Barong cave (1). Masigit cliff serves as a rock-climbing area and tourist destination (2). In the southern area of Pawon cave site, limestone mining activities are observed (3, 4, and 5). Image source: Google Earth, accessed on April 12, 2023.

However, the cave has faced several challenges in recent years, including vandalism, a lack of proper management and preservation efforts, and the negative impacts of limestone mining in the surrounding area (Haerani et al., 2019; Wulung et al., 2021). Therefore, data acquisition has been carried out to mapped Pawon cave using terrestrial laser scanner, unmanned aerial vehicle, and handheld scanner (Kartini et al., 2022a). Considering the importance of all the caves located in the cultural

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reserve area of Pawon cave, further documentation of other caves, including Barong cave, is necessary. The location of Pawon cave and Barong cave can be seen in Figure 1. In this study, we documented and created 3D model of Barong cave using TLS and attempted to explore more about the intensity value of point cloud data that obtained from TLS near-infrared.

2. RELATED WORKS

Research related to cave documentation has been commonly conducted. Traditionally, surveying instruments such as compasses, tapes, and clinometers have been used to measure and document the features of caves and other natural and cultural heritage sites (Büyüksalih et al., 2020; Giordan et al., 2021). Another cave measurement and documentation have been carried out using techniques such as total station survey and photogrammetry (Fritz et al., 2016). Tsakiri et al. (2007) both demonstrate the use of terrestrial laser scanning for the accurate and high-resolution 3D documentation of caves with complex structures and relief panels of prehistoric art.

In recent years, the use of terrestrial laser scanners has gained increasing attention as a tool for cave measurement and documentation (Marini et al., 2022; Šupinský et al., 2022). Terrestrial laser scanners are advanced scanning tools that use lasers to capture detailed three-dimensional point cloud data of the surrounding environment. Each point in the point cloud dataset is represented by a three-dimensional coordinate value (x, y, z) and an intensity value (i). The intensity value is influenced by various factors, such as the power of the laser used, the characteristics of the object being scanned, the reflection and transmission properties of the atmosphere, and the distance from the sensor to the target. One of the main advantages of terrestrial laser scanners is their ability to capture high-quality data quickly and efficiently, even in challenging environments such as caves.

As far as our knowledge goes, there seems to be a dearth of research on the use of TLS for the preservation of cultural heritage, particularly in caves in Indonesia. Brahmantara (2016), employed TLS to record the geometry of caves and the detailed rock art in the Karst Sangkulirang-Mangkalihat region. Oktaviana (2018), use portable 3D scanners to document various cave paintings in Maros-Pangkep and Sangkulirang-Mangkalihat. In 2022, we study the documentation of Belanda cave in West Java, the utilization of multi-sensor data for the acquisition of Pawon cave and its surrounding environment, and the use of low-cost 3D and handheld scanners in Barong cave, also located in West Java (Kartini et al., 2023; Kartini et al., 2022a; Kartini et al., 2022b). Given the scarcity of research on this topic in Indonesia, it is of utmost importance to pursue further studies in this area.

3. METHODOLOGY

The methodology employed in this study can be summarized into a workflow as depicted in Figure 2. It begins with data acquisition and processing, resulting in registered and modeled point cloud data. Further processing is conducted on the point cloud data acquired by using a TLS with near-infrared wave. According to Jalandoni et al. (2021), the intensity value of the NIR wave can reveal markings that are invisible to other wave types.

Data acquisition in Barong cave was conducted on September 2, 2021. In this study, we utilized the Leica BLK360 to acquire three-dimensional point cloud data in Barong cave. The Leica BLK360 is equipped with a high-quality imaging system and can capture detailed information about various types of environments. Based on Leica BLK360 Data Sheet, some of the short specifications include a field of view of 360-degree horizontal and 270-degree vertical scanning coverage, with a scanning range of 0.5 up to 45 meters, thus classified as a short-range laser scanner. In contrast to other types of TLS with a wavelength ranging around 1500 nm, the Leica BLK360 TLS utilizes a wavelength of 830 nm, classified as near-infrared. The device is operated through a cellular device that wirelessly connects to the TLS via a Wi-Fi connection.

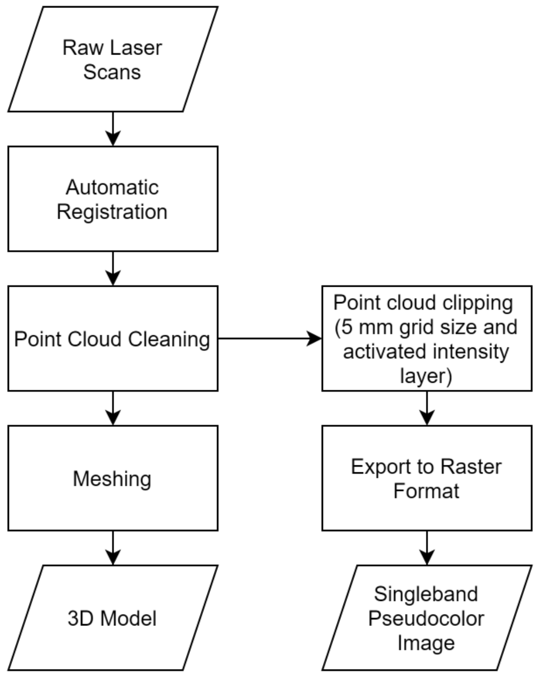


Figure 2. Data Processing Workflow

Data acquisition was focused on the entire surface of Barong cave with a total of 12 scanner positions. The device placement was done on stable and safe surfaces. During each change of scanner position, the amount of overlap between the scans was checked using a smartphone application integrated with the Leica BLK360. If the application was unable to bind the results of scanning in real-time between scanner positions, the scanning process needed to be repeated.

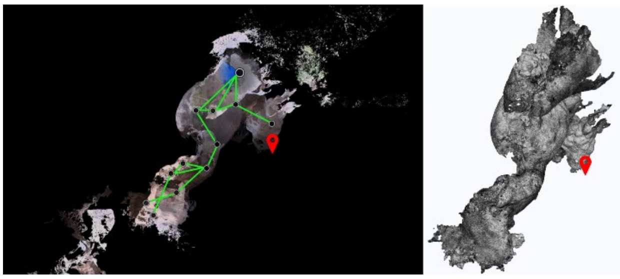
After data acquisition, we performed registration and filtering processes on the point cloud data obtained from the scanning process. Some parts of the overall scan result were not used, and a filtering process was conducted to remove those parts. This was followed by meshing, which aimed to reconstruct a solid 3D model from the registration process. Meshing was conducted by triangulating the point cloud data. To obtain the original colour of the cave surface, texturing process was conducted.

Further processing was conducted on the point cloud data. One of our goals in this study was to try to find any cave art in Barong Cave using the Jalandoni et al. (2021) methodology, which involves analysing the intensity values of the point cloud data. The data analysed was the surface area of the cave walls with numerous markings. We cropped the point cloud and rasterized it using a grid size of 5 mm. The 3D point cloud data was then rasterized, and the intensity range was adjusted. We classified the intensity value into 5 classes of singleband pseudocolor, and based on Jalandoni et al. (2021), intensity values under 0.14 have an indication that the color is based on carbon. However, we also observed that the color was not only black but also red. The red color also contains carbon even in small quantities (Ilmi et al., 2021).

4. RESULTS

4.1 3D Modelling of Barong Cave

The data acquisition in Barong cave was successfully carried out using a Leica BLK360 consisting of 12 standing points of equipment. The process of removing unnecessary objects for this research was done manually. There was a reduction in the number of point clouds by 61% from the initial number of point clouds, which was 129,871,851 points. From these points, a Triangulated Irregular Network (TIN) was formed to generate a three-dimensional object surface model. The results of each process can be seen in Figure 3.



(a) (b)

Figure 3. Implementation of Leica BLK360 scanning in Barong cave. (a) Scan positioning in Barong cave, showing 12 scanning points. (b) Barong cave after filtering and meshing process, with the red dot indicating the cave entrance of Barong cave.

Barong cave has a approximately 18.8×17.1 m based on the 3D model data. In order to access the entrance of Barong cave, located in the cliff area of Pawon cave, a brief hike is required. The mouth of Barong cave, with a size of 2.3 m, is situated at an elevated location that necessitates some physical effort to reach. In addition, Barong cave is relatively narrow, making the selection of scanning equipment one of the important considerations.

The use of bulky scanning equipment can pose challenges in terms of mobility, from the initial hike to navigating through narrow cave passages. As such, it is advisable to utilize scanning equipment that weighs less than 1 kg and can be easily stored in a backpack for cave exploration. Figure 4 provides an illustration of the terrain conditions leading to the entrance of Barong cave, highlighting the need for portable and lightweight scanning gear to facilitate data acquisition in such environments.

After reaching the mouth of the cave, we arrived at the main chamber which has an area of $\pm 35\ m^2$ (Figure 5). Given this size, it is very possible for the Pawon people to take shelter inside the main chamber of Barong cave. In this main chamber, there are many modern human vandalism. Judging from some of the vandalism that can be seen, modern humans have entered the Barong cave area since 1920.

Following the exploration of the main chamber, further advancement into the corridor area of Barong cave requires a short hike back along the designated path. Large rocks that form one of the water flow paths are the reason why this cave is called Barong cave by the local community (Figure 6a). If it has rained previously, these rocks become very slippery, so it is not recommended to continue the visit. Although generally, this cave is rarely visited due to the lack of adequate facilities to get to Barong cave and explore it.

(a) (b)

Figure 4. Terrain condition to the entrance of Barong cave. (a) Illustration of the terrain condition leading to the entrance of Barong cave. (b) Lightweight terrestrial laser scanner suitable for backpack use, used for the scanning process.

Figure 5. The main chamber of Barong cave in panoramic view.

This cave corridor has a length of $\pm 5.5\ m$. In this cave corridor, there is writing in Han script. We tried to find out the meaning of the writing. It was found that the writing was made by the Shuang Hua Football Club in October 1957 (Figure 7). The names of the players who participated in the club were listed in the writing. This shows that it has become a habit for humans to prove their existence, even in the form of vandalism.

Upon reaching the end of Barong cave, we encountered another mouth of the cave. Although this vantage point offered a view of Pawon cave, its elevated location rendered it unsuitable as an access point to Pawon cave. Detailed visualizations of certain sections of Barong cave, captured in 3D point cloud and 3D meshes, can be observed in Figure 8.

This data has the potential to support future research and preservation efforts in cultural heritage sites such as Pawon cave area. The three-dimensional point cloud data could be used to create accurate digital models of the cave, which could be utilized for virtual tourism or educational purposes. Videos of 3D models are available at this link: https://youtu.be/ZFBwI2u9kvA.

https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-821-2023

Figure 6. Geomorphic features of Barong cave. (a) Large rock formation acting as a water channel in Barong cave and the pathway leading to the inner passage. (b) Eroded cave floor due to water flow.

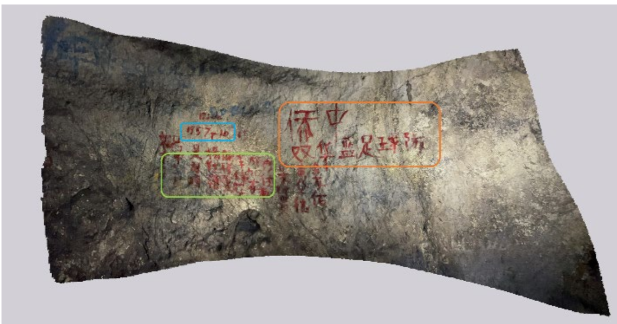


Figure 7. Photos of Han script inscriptions in Barong cave. Orange rectangle is the name of the football team, blue rectangle representing the date of writing or playing, and green rectangle showing the vertically written names of the team members.

4.2 Intensity Value

In this research, we attempted to find cave art in Barong cave. However, despite using this advanced scanning tool, we were only able to manually identify several of vandalism that were not visible to the naked eye. One possible explanation for the absence of cave paintings in Barong cave is the impact of climate change in the environment surrounding the cave. The presence of limestone mining in the area may have contributed to these environmental changes, which could have affected the preservation of any potential cave paintings (Huntley et al., 2021; Zerboni et al., 2022). In a review conducted by Ilmi et al. (2021), no cave paintings have been discovered on the island of Java to date.

The results obtained from the visualization of intensity values are in the form of raster images. Several visualizations of intensity values using near-infrared wavelength are shown in Figure 9, which compares the data using intensity images and RGB images. The RGB images generated from the photos are unable to clearly depict the cave features. This is due to the limited amount of light that penetrates the cave. In contrast, intensity images do not require ambient light for data acquisition, which makes them more suitable for cave imaging. Based on Figure 9, it can be observed that some graffiti is more clearly visible when using intensity images, highlighting the potential of intensity imaging for enhanced visualization of cave wall markings.

This research follows the methodology used by Jalandoni et al. (2021). However, the grid size used in the rasterization process in Cloud Compare is not elaborated in their study. Therefore, experiments were conducted with different grid sizes, such as 1 mm, 2.5 mm, and 5 mm (see Figure 10). From these experiments, it was found that a grid size of 5 mm is suitable for use in the color range division process in QGIS.

The processing results revealed that TLS with NIR wavelength can enhance faded markings. However, some results showed that if the markings are covered by thick pigments, the intensity images may not reveal what lies beneath those pigments (see Figure 9). Despite the extensive processing of intensity values, the original human-made cave markings from the intensity images could not be identified. Furthermore, according to Jalandoni et al. (2021), intensity values below 0.14 may indicate cave walls marked with carbon-based materials. However, not all black markings necessarily indicate carbon-based materials. In this study, red cave markings were also detected in the intensity value raster as carbon-based materials.

However, our study did demonstrate the potential of terrestrial laser scanners as a tool for identifying of vandalism. The intensity values and near-infrared wave allowed us to obtain detailed information about the current condition of the cave and manually identify of vandalism that were not visible.

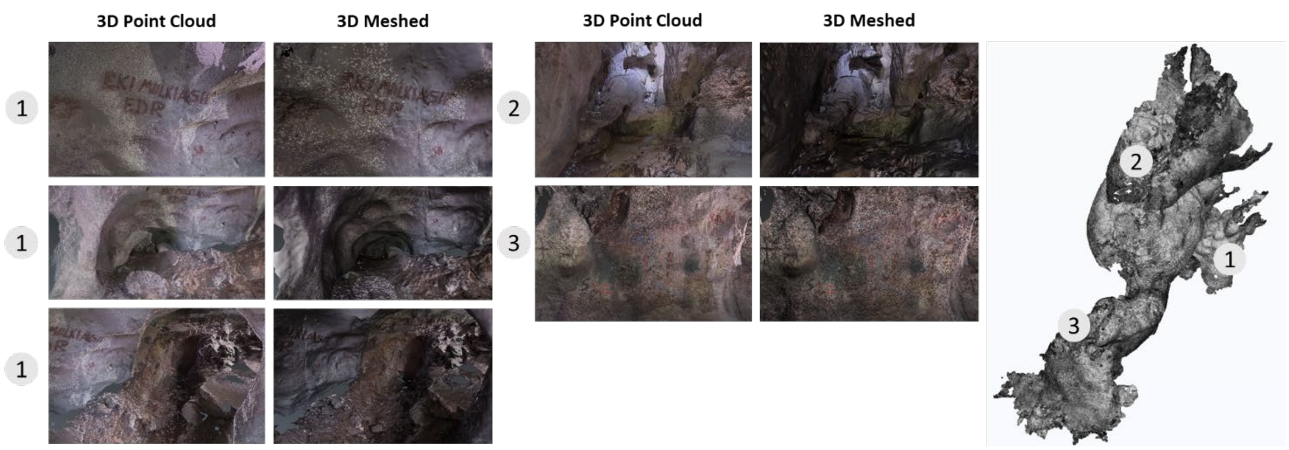


Figure 8. Example of 3D point cloud and 3D meshed inside Barong Cave. No. 1 represents the main chamber. No. 2 shows a large rock formation as seen from the main chamber. No. 3 captures several graffiti markings on the cave walls.

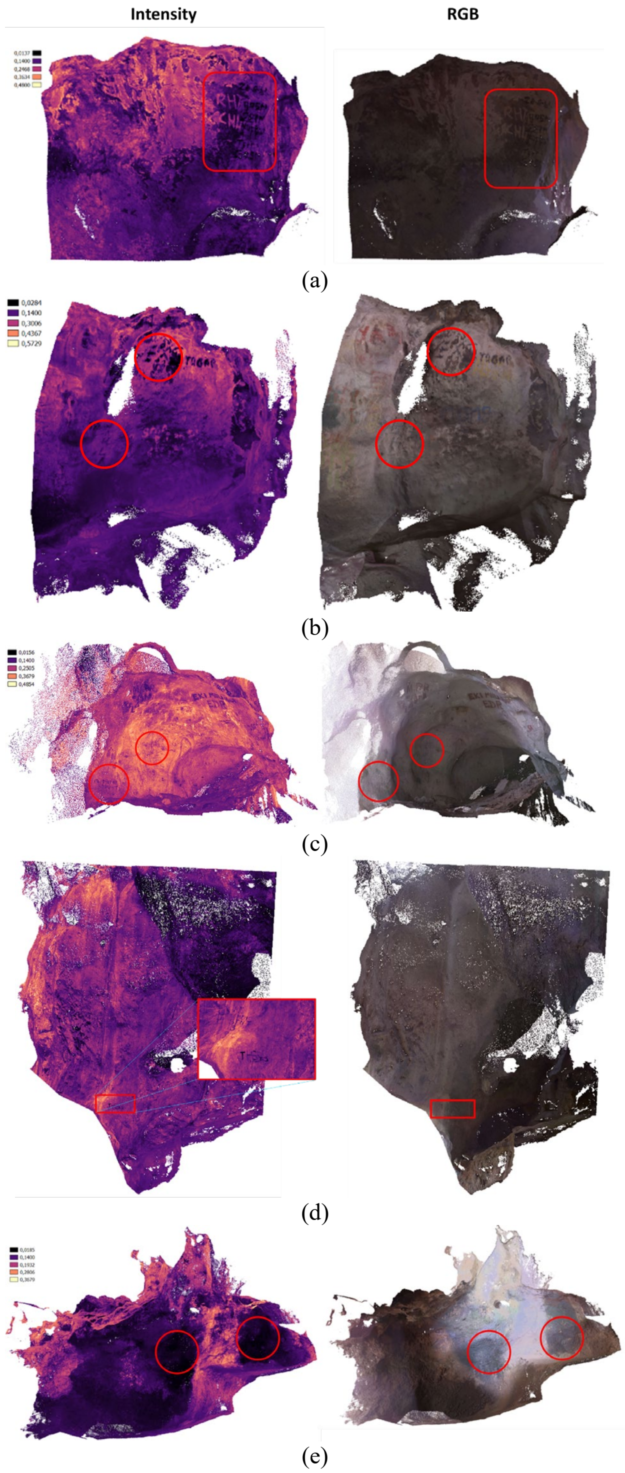


Figure 9. Vandalism identification from rasterized results. Left: Intensity images. Right: RGB images. (a-d) Red circles highlight faded markings visible in intensity images. (e) Thick layer of pigments covering cave wall surface.

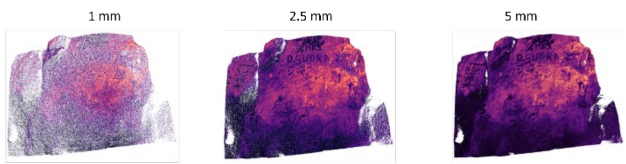


Figure 10. The Cloud Compare software uses grid sizes of 1mm, 2.5mm, and 5mm for the rasterization procedure.

5. CONCLUSIONS

In conclusion, our study demonstrated the potential of terrestrial laser scanners as a tool for cave measurement and documentation in cultural heritage sites such as Barong cave. The use of advanced technologies such as TLS short range with near infrared wavelength can support these efforts by providing detailed information about the current condition of the cave and identifying potential issues such as vandalism.

Based on the generated 3D model, the model effectively depicts the geomorphology of Barong Cave, including the rock formations and the eroded soil conditions inside the cave. Vandalism on the cave's surfaces can be captured using the 3D model. Faded markings and scratches are clearly visible using intensity images obtained from the TLS with near-infrared wavelength.

Further research, such as the development of augmented reality and virtual reality applications for museum and educational purposes, holds significant importance. Automated identification of markings on 3D point cloud data, particularly using intensity values, for identifying traces that may lead to cave art, also requires further development.

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