e-ISSN 2580 - 0752

BULLETIN OF
GEOLOGY
Fakultas Ilmu dan Teknologi Kebumian (FITB)
Institut Teknologi Bandung (ITB)

MULTI-SENSOR DATA ACQUISITION AT BUKIT PAWON (WEST JAVA) TO SUPPORT SUSTAINABLE CONSERVATION OF CULTURAL HERITAGE

GUSTI A. J. KARTINI[1,3], IRWAN GUMILAR[2], HASANUDDIN Z. ABIDIN[2], REYNALDI A. TAMRIN[1], MOHAMAD I. DWISATRIA[1], RASENDRIYA NABIL[1]

1. Departement of Geodesy and Geomatics Engineering, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung, Email: ayujessy@itenas.ac.id
2. Geodesy Research Group, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung,
3. Departement of Geodetics Engineering, Faculty of Civil Engineering and Planning, Institut Teknologi Nasional Bandung

Sari – Saat ini, teknologi survei dan pemetaan untuk akuisisi data berkembang dengan pesat. Seseorang dapat memperoleh ribuan hingga jutaan titik koordinat yang merepresentasikan bentuk suatu permukaan dalam satu pengukuran dengan menggunakan berbagai sensor. Perkembangan teknologi tersebut sangat bermanfaat untuk berbagai tujuan, salah satunya adalah untuk keperluan pelestarian warisan budaya. Penelitian ini bertujuan untuk melakukan akuisisi data bentuk Gua Pawon dan Stone Garden menggunakan multi-sensor yang dapat mendukung pelestarian cagar budaya di Bukit Pawon Jawa Barat. Penelitian ini dilakukan di kawasan Bukit Pawon, Jawa Barat dengan memanfaatkan teknologi geospasial, antara lain *Terrestrial Laser Scanner* (TLS), *Handheld Laser Scanner* (HLS), dan *Airborne Laser Scanner* (ALS). Data yang dihasilkan dari akusisi multi-sensor berupa point cloud. Dapat disimpulkan bahwa TLS mampu memperoleh sebagian besar area Gua Pawon dan Taman Batu secara terestris, dan HLS dapat digunakan untuk memindai area yang luput dari pemindaian TLS. Melalui udara, ALS mampu untuk memperoleh bentuk Taman Batu secara keseluruhan dengan dibantu UAV Fotogrametri untuk proses pewarnaan *point cloud*.

Kata kunci: TLS, HLS, ALS, UAV fotogrametri, *point cloud*

***Abstract** - Currently, surveying and mapping technology for data collection is rapidly evolving. Using various sensors, one can obtain thousands to millions of coordinate points that represent the shape of a surface in a single measurement. The advancement of this technology is extremely beneficial for a variety of purposes, including the preservation of cultural heritage. The goal of this study is to use multiple sensors to get information about the shape of Pawon Cave and Stone Garden, which can help protect cultural heritage in Bukit Pawon, West Java. Utilizing geospatial technology, including Terrestrial Laser Scanner (TLS), Handheld Laser Scanner (HLS), and Airborne Laser Scanner (ALS), this research was conducted in the Bukit Pawon region of West Java (ALS). The multi-sensor acquisition generates data in the form of a point cloud. TLS was able to acquire the majority of the Pawon Cave and Batu Park areas terrestrially, and HLS could be used to scan areas that were missed by TLS. Using UAV Photogrammetry, ALS was able to determine the general shape of Batu Park through the point cloud coloring process.*

***Key words**: TLS, HLS, ALS, UAV photogrammetry, point cloud*

1. INTRODUCTION

Caves result from ecosystem processes between nature (geological) and the surrounding environment that lasts for millions of years. Then, for tens to thousands of years, the cave became one of the locations used by humans as shelter, workshops, cemeteries, and now as a tourist area, education, or worshipping (Cigna & Forti, 2013). For scientific purposes, caves hold an important aspect of understanding civilization through cave paintings and areas that chronologically record climate and environmental changes (Straus, 1990; Cigna & Forti, 2013).

United Nations Educational, Scientific and Cultural Organization (UNESCO) guideline published in 2008, namely the Operational Guidelines for the Implementation of the World Heritage, describe how the main task of the state in caring for cultural heritage, such as identifying, protecting, caring for, presenting, and passing on cultural heritage values to future generations. One of the steps to take care of cultural heritage by paying attention to aspects of sustainable development is stated in another UNESCO guideline published in 2015, namely the Policy Document for the

Integration of a Sustainable Development Perspective into the Processes of the World Heritage Convention. One part of the guideline states that cultural heritage is represented as an asset that needs to be protected, one of which is from natural disasters and climate change. Three steps must be taken to boost cultural heritage resilience: (1) identify and promote the potential of cultural heritage, (2) reduce the vulnerability from disaster and climate change, and (3) raise preparedness for effective response in a disaster. If viewed from this guideline, there is a need for documentation that is carried out by considering the spatial aspect to protect the cultural heritage and the existence of the object of the cultural heritage itself. The documentation aspect of caves is still minimal because most of the cave area is not visible (Kambesis, 2007). Based on this, there is a need to research geospatial-based cave objects.

Several studies have been conducted to implement geospatial data for cave documentation purposes. For example, geospatial data-based documentation was used to find cave paintings using the Leica BLK360 Terrestrial Laser Scanner (TLS) utilizing intensity data (Jalandoni et al., 2021). Further, Büyüksalih et al. (2020) created Virtual Reality (VR) visualizations of caves using TLS data and a 360º camera, while Pennos et al. (2018) reconstructed the cave's ruins using photogrammetric techniques. The estimation of disaster risk in cave tourism areas using TLS had also been conducted by Mohamed et al. (2021). Giordan et al. (2021) integrated various sensors such as TLS, Portable LiDAR, and cameras to create 3D models of caves. These studies are still based on terrestrial data only and have limitations to cover the entire interest area, e.g., data gaps at the outer surface of the cave and in the narrow space. Therefore, it is necessary to utilize other techniques to fill this limitation.

Detailed mapping is needed through these studies, for example, Handheld Laser Scanner (HLS) can be used to obtain more data in the narrow space inside the cave. To create a 3D model of caves, we can utilize Terrestrial Laser Scanner (TLS) or a digital camera. While an Airborne Laser Scanner (ALS) can be utilized to collect additional data on the cave's outside surface. These technologies will give us accurate positioning, cost-effective technique, and rapid data acquisition; these are three aspects that formed a high-definition survey (HDS) (Fryer et al., 2005). We may obtain comprehensive geometric and semantic information about the cave to aid in the research with these features.

To carry out mapping in the context of preserving cultural heritage in detail—terrestrial and aerial, and to obtain geometric and semantic data, data acquisition with a multi-sensor approach is required. Laser-based acquisition data will produce many points in which there is information about the position and intensity values or commonly referred to as a point cloud (Quintero et al., 2008). We face challenges when we have comprehensive data to analyze, are different data quality, and how to integrate these data.

This study aims to integrate multi-sensors data and identify what are the advantages of using multi-sensor data for cultural heritage conservation. Pawon Cave is chosen as it is considered a protected area through the West Java Provincial Regulation No. 2 of 2006 concerning Management of Protected Areas in Article 62a, which is aligned with our intention. While Bukit Pawon is classified as Karst Class I, based on the Decree of the Minister of Mines of the Republic of Indonesia No. 1456 K/20/Men/2000 concerning Guidelines for Management of Karst Areas.

2. DATA AND METHODOLOGY

RESEARCH SITES

This study took place in the Bukit Pawon, which is in Cibukur Village, Gunung Masigit Village, Cipatat District, West Bandung Regency. The research location can be seen in **Figure 1**. Bukit Pawon is a limestone hill with a sloping layer to the north, and Pawon Cave is located on a steep northern slope. Bukit Pawon has an altitude of 709 masl, while the mouth of Pawon Cave is at an altitude of 570 masl based on altimeter measurements with an accuracy of

2.5 m (Yulianto and Brahmantyo, 2000). The caves in Bukit Pawon include cliff caves from west to east, namely Barong Cave, Peteng Cave, Pawon Cave, and Ketuk Cave (Yondri, 2019). The peak of Bukit Pawon, currently known as Batu Garden or Stone Garden, is an expanse of limestone chunks of various sizes that have undergone weathering. The limestone currently exposed is estimated to be 30 million years old.

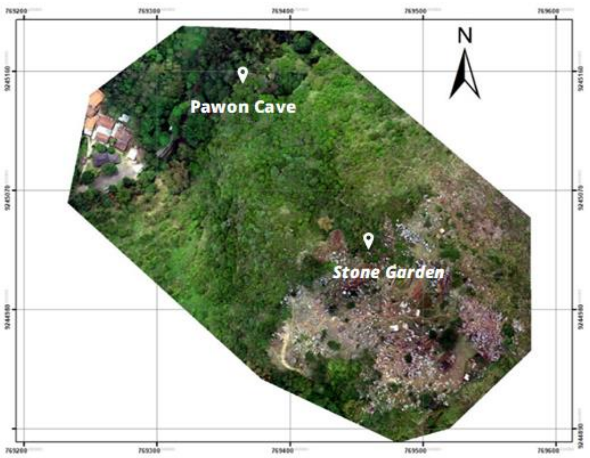

Figure 1. Research sites.

MULTI-SENSOR LiDAR

Vosselman and Maas (2010) stated that Light Detection and Ranging had been commonly used in topographic data acquisition to cultural heritage buildings. Both ALS and TLS can be used to capture and record geometry and even texture information from the surface of an object. Airborne and TLS measurement systems are classified as optical 3D-based measurements in the time-of-flight category. The main property of light waves is the speed of propagation. In a medium, light waves travel at a constant and finite speed. Time-of-flight is created by the movement of light on a medium originating from a wave source to a surface that reflects light wave to a source. It can be written by equation 1.

$$R = \frac{v.t}{2} \qquad (1)$$

Where:
R is range from instrument to object
v is the speed of light
t is the wave propagation time
The results obtained from LiDAR measurements are point clouds that have three-dimensional coordinates. A point cloud is a collection of points with a specific density in large numbers and can form a surface or be used as a three-dimensional modeling material (Quintero et al., 2008). Each point has a three-dimensional coordinate value (x,y,z) and intensity (i). The power of the laser influences intensity value, the nature of the object affects the reflection, the transmission of the atmosphere, the distance from the sensor to target, which can be written by equation 2.

$$P_R = \frac{P_E D_R^2 \rho cos\alpha}{4R^2} \eta_{Sys} \eta_{Atm} \qquad (2)$$

Where:
P_R is received laser power
P_E is emitted laser power
D_R is the aperture diameter
R is the range from sensor to target
ρ is the reflectance of the object surface
α is *incidence angle*
η_{Sys} is the system transmission factor
η_{Atm} is the atmosphere transmission factor

Table 1. Equipment specifications.

No	Name	Pulsed Laser	Accuracy	Range
1	Trimble TX8	1500 nm	22.6 mm @ 30 m	0.6—120 m
2	Leica BLK360	830 nm	6 mm @ 10 m / 8 mm @ 20 m	0.6—60 m
3	Velodyne's Puck Lidar Sensor	905 nm	± 3 cm	100 m
4	Stonex F6 Smart	845 nm – 856 nm	0.2% - 0.1% upon scanning distance	0.6—4 m

The results obtained from LiDAR measurements are point clouds that have three-dimensional coordinates. A point cloud is a collection of points with a specific density in large numbers and can form a surface or be used as a three-dimensional modeling material (Quintero et al., 2008). Each point has a three-dimensional coordinate value (x,y,z) and intensity (i). LiDAR is divided into two types: airborne LiDAR, which has a LiDAR topographic type and LiDAR bathymetry; and terrestrial LiDAR, which has mobile LiDAR and static LiDAR types. The results obtained from LiDAR measurements are the three-dimensional point cloud of the surface. **Table 1** lists the instruments used in this study. Error! Reference source not found. is a methodology of this research.

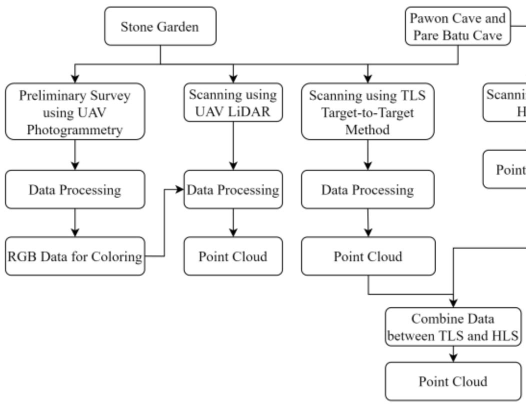

Figure 2. Research Methodology

TERRESTRIAL LASER SCANNER

The TLS was used to capture high accuracy point clouds of two locations at Bukit Pawon, e.g., Pawon Cave and Stone Garden. Multiple scans from different scan positions were performed to scan the entire area of interest. Different scan position has their own coordinate system. Therefore, it is necessary to tailor them into one complete point cloud representing details of the surface at Pawon Cave and Stone Garden using the target-to-target method. Additionally, GNSS observations at two tie points were introduced to replace the local coordinate system with the global coordinate system. Target to target registration is merging several scan world data from the data acquisition process using the target as a reference. The targets used in the data acquisition process can be flat targets and 3D-shaped targets (Reshetyuk, 2009). In the data acquisition process in the field, a minimum of 3 targets is needed so that the registration step can be carried out using the target-to-target method. The distribution of targets during data acquisition must be optimal to obtain results with high accuracy. The wrong shape of the distribution will impact the poor process of registration results using the target-to-target method. The instrument used at the Pawon Cave and Stone Garden locations are Trimble TX8 which has a wavelength of 1500 nm and a measurement distance of 0.6-120 meters. The target used is in the form of a sphere, totaling three pieces. The measurements of Pawon Cave were carried out for two days, with the number of tools standing 40 times. Meanwhile, the Stone Garden measurements were carried out with 29 tools standing for one day. The setup for employing a terrestrial laser scanner in Stone Garden is shown in **Figure 3**a, and the spherical target utilized in this research is shown in **Figure 3**b.

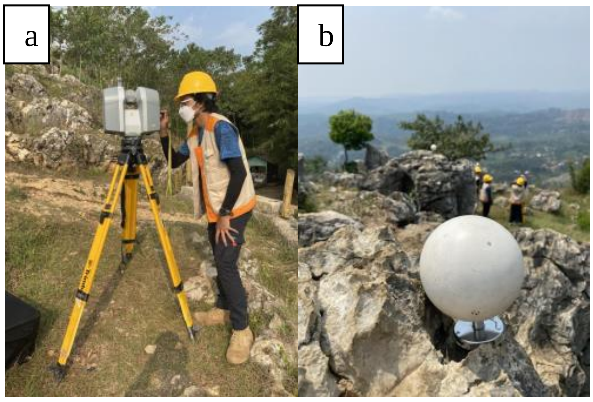

Figure 3. (a) Setup terrestrial laser scanner, and (b) spherical target.

AIRBORNE LASER SCANNER

Scanning using ALS begins with conducting a preliminary survey using photogrammetric techniques. Photogrammetric data was collected using the DJI Phantom 4 Pro V2.0 UAV device. The planned flight was carried out at an altitude of 50 meters above the surface of Stone Garden. In addition to being used as a preliminary survey, this UAV flight, the resulting RGB data will be used for coloring the airborne LiDAR data.

After conducting a preliminary survey, scanning is carried out using a TerraLiDAR device integrated with the Velodyne Puck LiDAR Sensor, which has a wavelength of 905 nm with 100 meters. Direct monitoring in the field determines if the entire region has been scanned. Every time the storage process is finished, the data will be downloaded immediately, and the results will be seen. After the safekeeping process is complete, the following process is to process LiDAR data.

DOI: 10.5614/bull.geol.2022.6.2.10

The LiDAR data was georeferencing using the RTKlib application pre-programmed by TerraDrone. The data is exported in LAS format and stained using UAV photogrammetry data.

HANDHELD LASER SCANNER

Scanning using HLS aims to complete data that is thought to be poorly covered by the TLS Trimble TX8 or Leica BLK360 scan. In addition, HLS data is expected to record more detailed handwriting in the Barong Caves. The HLS device used is Stonex F6 Smart with a wavelength of 845-856 nm with 0.6-4 meters. Before saving, the white balance is calibrated so that the colors received by the camera are more natural by firing the HLS camera at a white object (**Figure 4**). Data collection is carried out based on the difficulty at the location, starting from the most challenging area and ending in the accessible area. Every time the storage process is finished, the scan results are checked using an application integrated with the laptop. If many scans are not tied from one scene to another, then re-preservation is done at that location.

3. RESULT AND DISCUSSION

Multiple sensors such as TLS, HLS, and ALS must be used to get data for the Bukit Pawon region. We get a detailed image of the Stone Garden area from the air to the Pawon Cave area by taking this multi-sensor data. In **Figure 5**, an overview of the Stone Garden area is obtained using (a) TLS, (b) UAV, and (c) Airborne LiDAR. In Figure 5c, the LiDAR data has been colored using RGB data obtained from the UAV. Visually, photogrammetric data has a better appearance than Airborne LiDAR data. It is necessary to know further the maximum density that TerraLiDAR can acquire for an area such as Stone Garden.

The recording of the Stonex F6 Smart and Trimble TX8 devices in Pawon Cave can be seen in **Figure 6**. Figure 6a is the result of HLS storage. The resulting color is quite dark due to the lighting effects around the shooting location, but the point density level is high enough to perform more detailed scanning in that area. Figure 6b is the result of registration between TLS and HLS. Through this image, some areas are not appropriately scanned using the TLS Trimble TX8. One of the factors is the placement of the tool standpoints, which in the end, do not cover the entire area. However, these areas that are not covered can be well complemented by the HLS Stonex F6 Smart data.

Figure 4. HLS Stonex F6 Smart white-balanced calibration.

For the Barong Caves area, which has a smaller area, TLS Leica BLK360 is used. Measurement using the TLS Leica BLK360 gave researchers the flexibility to choose where to stand because the tool was relatively smaller in size, light in weight, and easy to mobilize. To ensure that all points are correctly registered, they can be viewed in real-time via the device on the Cyclone 360 application. If these points are not registered, additional measurements are taken to combine them.

These data will later be processed according to the objectives of each research. To model Bukit Pawon, it is necessary to integrate TLS, ALS, GNSS, and digital camera data. Position and intensity data from TLS and HLS are needed to identify fractures. To identify the type of material will use TLS with near-infrared waves. TLS data will be used and supported by the hypothesis compiled by Brahmantyo et al. (2001) to reconstruct the roof of Pawon Cave.

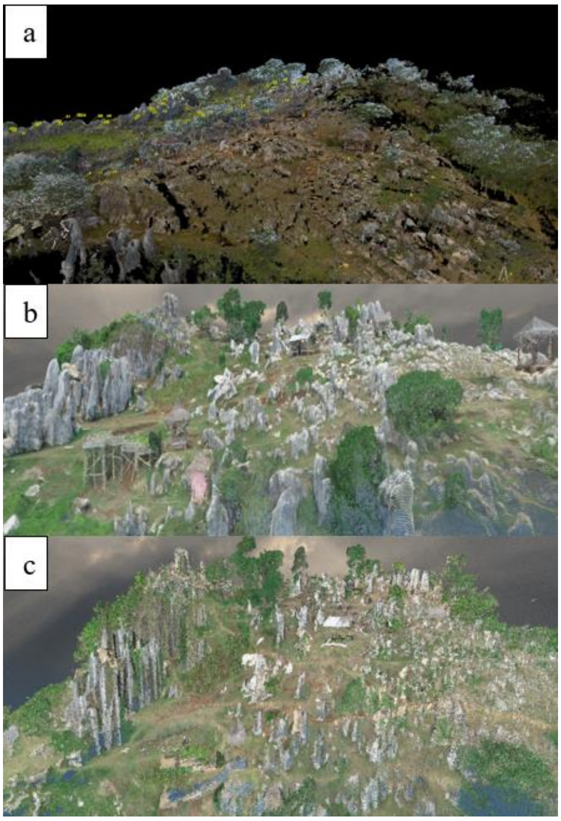

Figure 5. (a) TLS Trimble TX8, (b) photogrammetry, and (c) Airborne LiDAR.

4. CONCLUSION

TLS Trimble TX8 data may be used to create an image of the entire cave, while HLS Stonex F6 Smart data can be used to supplement an image of a cave in a specific location, creating a comprehensive picture of Pawon Cave. However, accessing HLS Stonex F6 Smart data presents various challenges, such as the impact of light during data collecting. The graffiti on the walls of the Barong Caves will be studied to determine the likelihood of cave rock art utilizing intensity data provided by a TLS Leica BLK360 equipped with near-infrared waves. Photogrammetry and LiDAR both have the capability of mapping the locations of cultural heritage sites. However, prior to mapping from the air, it is vital to understand the zoning of the cultural heritage region.

Multi-sensor data capture generates large volumes of complex data that require further processing to analyze. Integrating multi-sensor data is still a significant issue that will be investigated further with a large amount of data. Combining these multi-sensors will be beneficial for geospatial analysis and support cultural heritage conservation at Bukit Pawon, West Java. In the future study, a multi-sensor data integration algorithm will be created and will be used to detect geological fractures and classify cave materials using a deep learning approach.

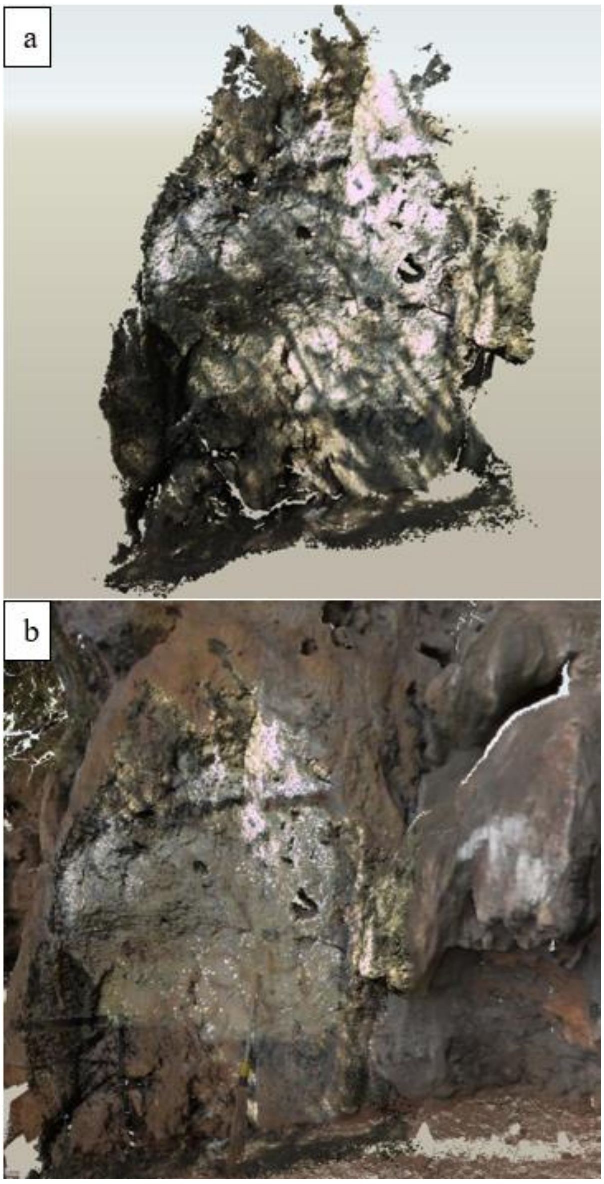

Figure 6. (a) Result from HLS Stonex F6 Smart and (b) registration between TLS Trimble TX8 and HLS Stonex F6 Smart.

ACKNOWLEDGE

We would like to express our gratitude to the following companies for their assistance with this research: PT. GPSLands Indonesia, which provided the Trimble TX8, PT. Leica Geosystems Indonesia, which provided the

Leica BLK360, PT. TerraDrone Indonesia, which provided the TerraLidar & Velodyne Puck LiDAR Sensor, and PT. Wisesa Berkah Bumi, which provided the Stonex F6 Smart.

REFERENCE

Büyüksalih, G., Kan, T., Özkan, G. E., Meriç, M., Isın, L., & Kersten, T. P. (2020). Preserving the knowledge of the past through virtual visits: From 3D laser scanning to virtual reality visualisation at the Istanbul Çatalca İnceğiz caves. *PFG–Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, 88(2), 133–146.

Brahmantyo, B., Yulianto, E., & Sudjatmiko, E. (2001). On The Geomorphological Development of Pawon Cave, West of Bandung, and The Evidence Finding of Prehistoric Dwelling Cave. *Jurnal Teknologi Mineral*, 8(2), 239.

Chase, A. F., & Chase, D. Z. (2017). Detection of Maya ruins by LiDAR: Applications, case study, and issues. *In Sensing the Past (pp. 455–468)*. Springer.

Cigna, A. A., & Forti, P. (2013). Caves: the most important geotouristic feature in the world. *Tourism and Karst Areas*, 6(1), 9–26.

Fryer J.G., Chandler J.H. & El-hakim S.F., 2005 - Recording and modelling an aboriginal cave painting: with or without laser scanning? *International Society for Photogrammetry and Remote Sensing*, 2: 1-8.

Giordan, D., Godone, D., Baldo, M., Piras, M., Grasso, N., & Zerbetto, R. (2021). Survey Solutions for 3D Acquisition and Representation of Artificial and Natural Caves. *Applied Sciences*, 11(14), 6482.

Hu, Q., Wang, S., Fu, C., Ai, M., Yu, D., & Wang, W. (2016). Fine surveying and 3D modeling approach for wooden ancient architecture via multiple laser scanner integration. *Remote Sensing*, 8(4), 270.

Jalandoni, A., Winans, W. R., & Willis, M. D. (2021). Intensity Values of Terrestrial Laser Scans Reveal Hidden Black Rock Art Pigment. *Remote Sensing*, 13(7), 1357.

Mohamed, Z., Rafek, A. G., Zhang, M., Chen, Y., Lai, G. T., Azahari, K., & Mohamad, Z. (2021). Leveraging on Multidisciplinary Expertise for Landslide Disaster Risk Reduction and Management: A Case Study of a Limestone Hill Rockfall Hazard Assessment. *Sains Malaysiana*, 50(8), 2179–2191.

Moyes, H., & Montgomery, S. (2019). Locating cave entrances using lidar-derived local relief modeling. *Geosciences*, 9(2), 98.

Pennos, C., Lauritzen, S.-E., Lonoy, B., & Tveranger, J. (2018). A 3D model of a cave collapse from Peristerionas cave, northern Greece. *EGU General Assembly Conference Abstracts*, 17322.

Quintero, M. S., Genechten, B. V., Bruyne, M. D., Ronald, P., Hankar, M., & Barnes, S. 2008. Theory and Practice on Terrestrial Laser Scanning (3D Risk Mapping), s.l.: *The Flemish Agency of The European Leonardo Da Vinci.*

Reshetyuk, Y. 2009. Self-Calibration and Direct Georeferencing in Terrestrial Laser Scanner. *Stockholm: Royal Institute of Technology*.

Straus, L. G. (1990). Underground archaeology: perspectives on caves and rockshelters. *Archaeological Method and Theory*, 2, 255–304.

UNESCO. (2008). Operational Guidelines for the Implementation of the World Heritage Convention. *Paris*.

UNESCO. (2015). Policy for the integration of a Sustainable Development perspective into the processes of the World Heritage Convention. In *Decisions Adopted by the General Assembly of the States Parties to the World Heritage Convention at Its 20 Session*. Paris: UNESCO.

Vosselman, G., & Maas, H. G. (2010). Airborne and terrestrial laser scanning. *CRC press.*

Yondri, L. (2019). Manusia dan Budaya Prasejarah di Gua Pawon. *Balai Arkeologi Jawa Barat.*