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Utilization of Terrestrial Laser Scanner Technology for Analyzing Shape of Dutch Cave (Bandung, West Java)

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Abstract. Technological developments in the field of surveying and mapping remain in progress. One technology that provides precise and accurate results is the terrestrial laser scanner (TLS). This technology can generate millions of points in a short time and represent objects in 3D. TLS technology has become famous for heritage documentation purposes due to its ability to obtain detailed geometry and information from maintaining historic buildings. This research is in the Dutch Cave, Djuanda Forest Park, Bandung, West Java, to map and document 3D. To produce accurate data, frame measurements were carried out using a total station, GNSS, which ended with acquisition using TLS. The registration method used is the target-to-target method. The goal of this research is to create as-built drawings of the Dutch Cave in analyzing the Dutch Cave's form in greater detail. This investigation determined that the Dutch Cave measures 124.435 meters in length and has a height difference of 69.7 cm between the entrance and the exit. The as-built drawing of the Dutch Cave illustrates that the shape of the cave varies from entrance to exit. There is a cave chamber that widens by 18.8 cm toward the cave's center and narrows by 20.7--32 cm toward the cave's exit. The Dutch Cave has a slope of between 1 and 5 degrees. The Dutch Cave 3D data can be used for a documentation archive for the Djuanda Forest Park.

Keywords: Terrestrial Laser Scanner, Target-to-Target Method, Point Cloud, Heritage, As-Built Drawing

1. Introduction

Cultural heritage is a place where important or historical events occur that can be used as a medium for connecting with the past and can also function as a learning tool and open a view of the importance of a historical event. The Dutch cave as a cultural heritage in the city of Bandung needs to be documented. According to RI Law No. 11 of 2010, to preserve cultural heritage, documentation activities need to be carried out before there are activities that can cause changes to their authenticity. Documentation in preserving cultural heritage includes taking photos and videos, measuring and depicting objects of cultural heritage.

Mapping and modeling the geometry of caves has traditionally been a challenging task, and this is due to limited access and very minimal light conditions [1]. The development of survey equipment technology continues to progress, providing convenience in data acquisition and processing with precise and accurate results, one of which is Terrestrial Laser Scanner (TLS) technology [2,3,4]. The utilization of TLS technology has become famous for documentation of heritage and archaeological sites, geomorphology, paleoclimatology and paleontology, passage stability, and visualization and education application [5]. TLS technology offers a range of advantages concerning traditional cave mapping, including the possibility of measuring high roofs, high operational speed, accuracy, abundant measured points, and construction of realistic 3D models of caves, including cave walls with centimeter resolution [6].

A survey method using TLS produces a set of information in millions of point clouds that already have coordinates for 3D modeling visualization. Point clouds provide significantly more correct geometric completeness and detail [7]. Getting the shape of an object in a 3D model takes several times to stand the tool. Point clouds recorded at each device stand need to be combined in the same coordinate system, commonly referred to as the registration process.

The TLS technology can be used for 3D modeling of cultural heritage sites because it can produce accurate building details. The TLS technology will scan Dutch Cave to document cultural heritage locations, mostly underground. The three-dimensional model created from TLS data is utilized to estimate the Dutch Cave's current state. The goal of this research is to create as-built drawings of the Dutch Cave in analyzing the Dutch Cave's form in greater detail.

2. Data and Methods

2.1. Control Point Data Acquisition

GPS measurements were made using a Trimble 5800 receiver and the differential static technique. Surveys were made for two hours using a thirty-second interval using the radial approach. The distance between the Lembang base station (CLBG) and the Dutch Cave rover is 4 kilometers. Observations were taken at two sites outside the Dutch Cave's entrance, as well as in chosen regions with quite open surroundings, as seen in Figure 1. Trimble Business Center 3.5 was used to handle the data produced by GPS measurements. Table 1 contains the results of GPS data processing with precision in each point.

Figure 1. GPS observation in the front area of the Dutch Cave, left side is measurement in BM1 and right side is in BM2.

Table 1. GPS Measurement Results.

ID	Easting (m)	Northing (m)	Elevation (m)	Solution Type	H. Prec. (m)	V. Prec. (m)
BM1	791521.296	9241561.352	924.533	Fixed	0.018	0.032
BM2	791515.150	9241577.514	924.416	Fixed	0.059	0.086

Electronic Total Stations are carried out to create a basic framework for detailed mapping measurements. Measurement of the basic mapping framework begins by using two tie points located in front of the entrance to the Dutch Cave. There are ten measurement points for the basic framework of an open polygon with a measurement length of 163 meters. The sketch of an open polygon can be seen in Figure 2.

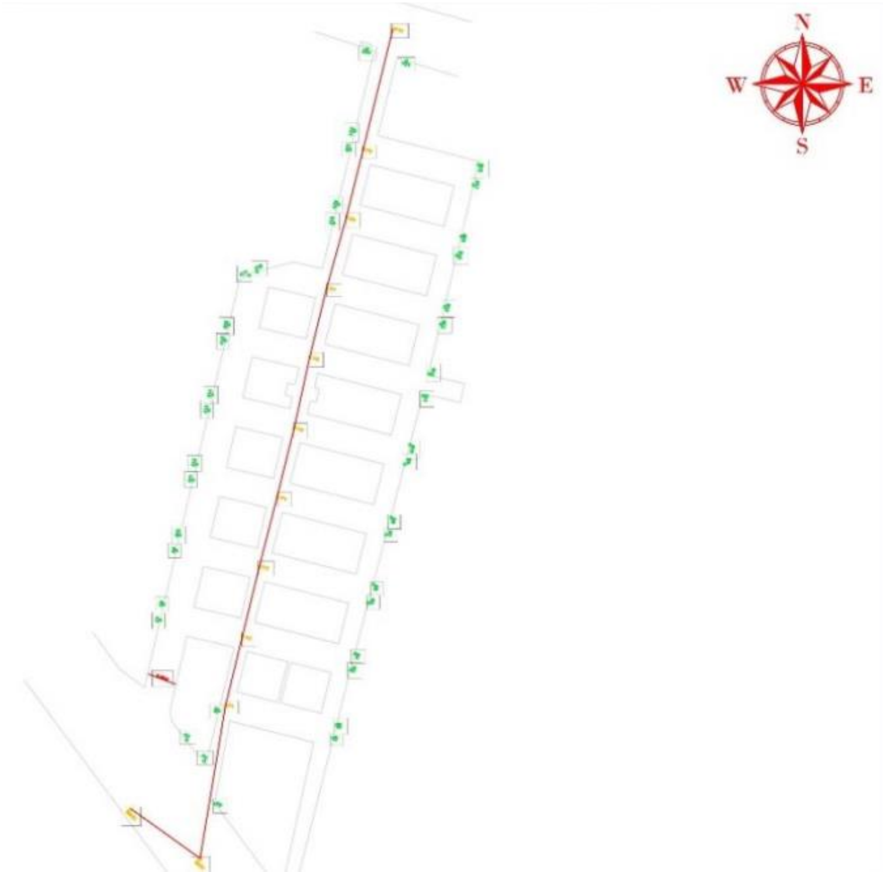


Figure 2. Sketch of polygon measurement, the red line represents a polygon that goes from the entry to the exit gate.

2.2. Point Cloud Data Acquisition

Measurements are made considering several aspects, such as the device's location, the placement of the target, the breadth of the field-of-view or scanning range, the length of storage time, and the resolution used. The total area of the Dutch Cave measurement area is 330 meters. We used six pieces of spherical ball targets and checkerboards that had been previously installed in the outside and inside the Dutch Cave. Trimble TX8 can only display in black and white; thus, photographs for point cloud coloring must be taken using a 360 camera. Trimble TX8 is capable of scanning at 340 meters at a rate of 1 million meters per second. The Trimble TX8 produces an error range of less than 2mm across 2—120 meters.

Figure 3. Spherical target position

Target placement is carried out with the consideration that the target can be scanned or visible from a minimum of two stations so that the point cloud of at least two stations can be registered with a critical point in the form of a target and an overlap between the two stations is 20-40%. The target placement is as much as possible spread out or not in a straight line so that the accuracy of the registered point cloud is evenly distributed, and the target must not change position during the scanning process as in Figure 3.

The density or intensity in the point cloud is adjusted to the object to be scanned. In this study, the thickness of the point cloud using the Trimble TX8 tool at level 2 with a point spacing of 11.3 mm at 30 meters with a storage duration of 11 minutes. The number of scan world is 18 points. The following is an example of a TLS measurement, as shown in Figure 4.

Figure 4. TLS measurement outside Dutch Cave (left) and inside Dutch Cave (right).

2.3. Target-to-target Registration

Target-to-target registration merges 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 [8]. Flat targets are a reasonably familiar target type found in the data acquisition process, as for the form of flat targets such as checkerboards. 3D shaped targets are another type of target with a spherical shape; there are distinct advantages in using this type of target. The advantage of spherical over flat targets is that they can be easily identified from various storage directions by the TLS instrument compared to flat targets, which are limited by the viewing angle of the TLS instrument. 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 the 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 registration process is carried out using Trimble Realworks software. The target-to-target registration process is relatively easy, especially if the target points are well planned. The georeferencing process defines the coordinate system on measurement data into the global coordinate system (UTM). Georeference is done using Trimble Realworks software for both registration methods. In this study, three georeferenced control points were used in the front and back of the Dutch Cave. The three georeferenced control points used are spherical ball target objects, namely Target 1, Target 3, and Target 37. The coordinate values of the three points are obtained from the value of the ETS measurement shot, which FBK has processed in Civil 3D 2017 software. The processing uses the Georeferencing tool; then, the three control points were picked manually by entering the coordinate values (x, y, z) and point names. The georeferenced process in the target-to-target model produces an average RMSE of 0.0056 m.

3. Result and Discussion

3.1. Data Acquisition and Processing

The measurement of the Dutch Cave using the Trimble TX8 laser scanner was carried out 18 times scan world at 18 points. Each storage measurement is carried out for 11 minutes with a point spacing of 11.3 mm at 30 meters because the distance of each scan world is not more than 30 meters. At stations 7, 11, 12, and 14, the scanning duration is 7 minutes. In Figure 5, the red dot represents the scan world point, which encompasses the whole research region of the Dutch Cave. The TLS measurement produces raw point cloud data with a maximum of 94,035,667 points and a data size of 12.3 GB.

The target-to-target method has the lowest level of practicality in data acquisition planning because it must determine at least three stable (no shifting) target points that can be seen from two TLS stands (scan world). The other factors that affect this method are the distribution of target points and the type of target. The target placement is spread out as much as possible or does not form a straight line so that the accuracy of the registered point cloud is evenly distributed. This study used two targets: a checkboard and a spherical ball.

When processing registration data, the Trimble Realworks software can automatically detect the target point object with the same name. The RMSE value of this research registration is 6,579 mm. The registration RMSE value refers to the Trimble tolerance reference value in general, with a tolerance value of 8 mm. The target-to-target method uses target point definition, and the software can automatically define the target.

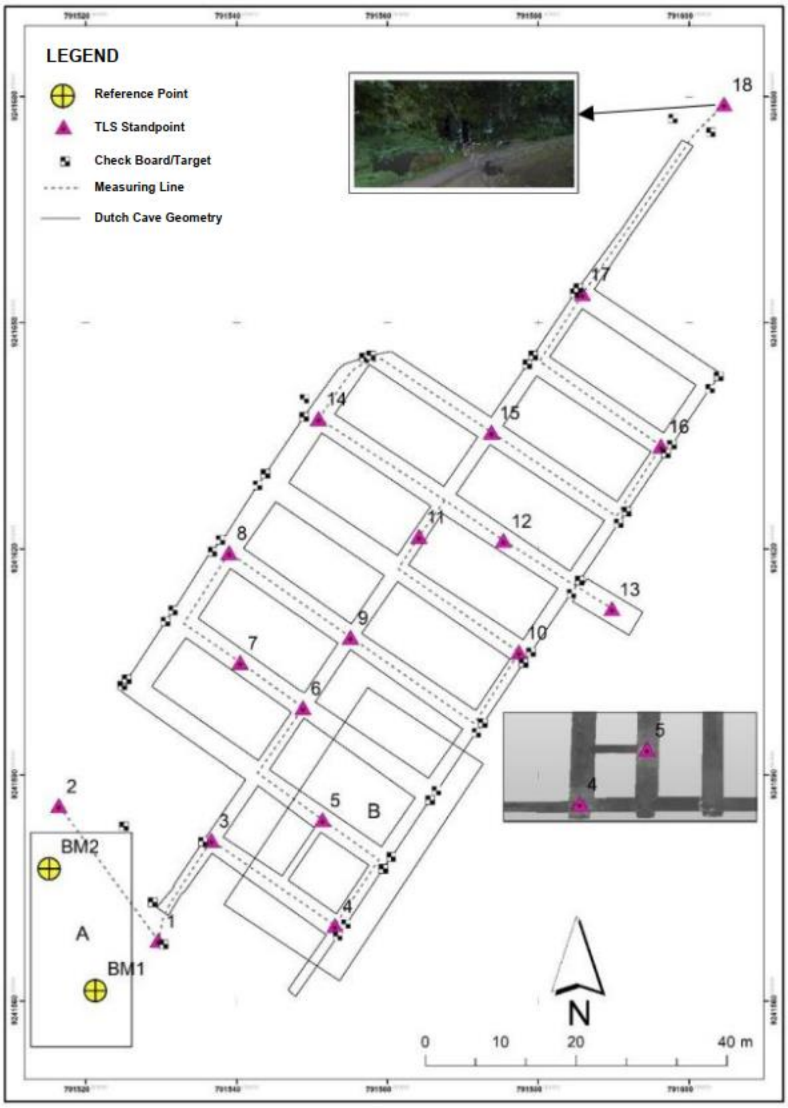


Figure 5. TLS positioning.

In the georeference process carried out using Trimble Realworks software, Target 1, Target 3, and Target 37 are in the front area of the Dutch Cave and selected on the GCP for the ETS measurement. RMSE from the georeferenced results is 0.0057 m. The registration result is still said to be quite good because it reaches the accuracy of the millimeter fraction. The registration result can be seen in Figure 6.

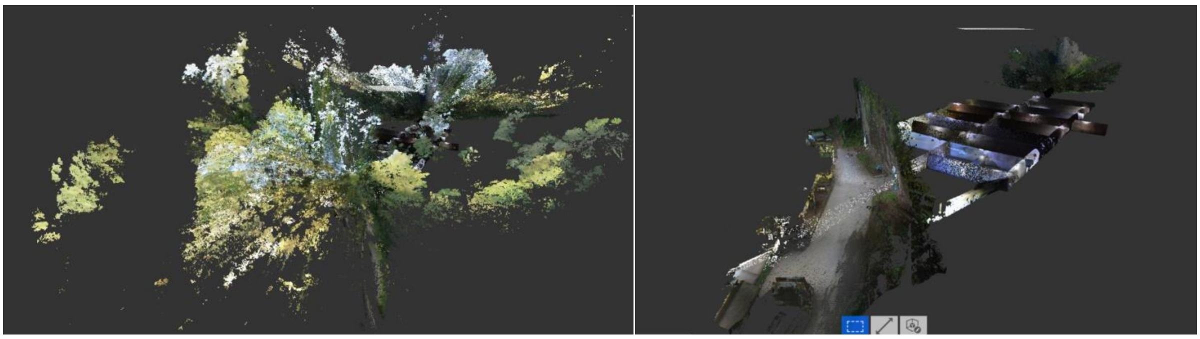
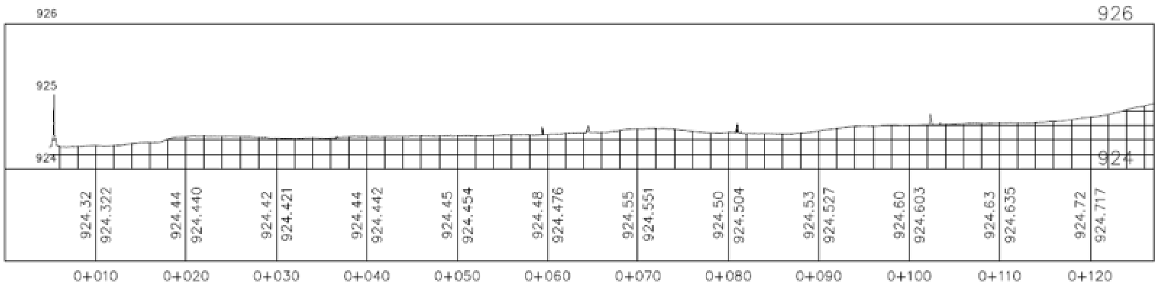


Figure 6. The registration result using target-to-target method before filtering (left) and after filtering process (right).

3.2. Utilization of 3D Point Cloud Data

The main tunnel has a length of 124.435m, measured from the entrance gate to the exit gate of the Dutch Cave. Point cloud TLS measurement results can record points with millimeter accuracy. The surface area of the central aisle increased by 69.7 cm between the entry and exit gates, as we can see in Figure 7. There is a slightly bumpy surface in the main hallway, which is about 40–100m from the entrance gate of the Dutch Cave.



Scale: Horizontal 1:200 Vertical 1:25

Figure 7. Profile of Dutch Cave.

We collect several cross-sectional samples in the central aisle for analysis. The cross-sectional shape sampled is from the entrance to the exit gate on the main corridor. There are 13 cross-sectional forms. The parameters used to analyze the shape of the cross-section of Dutch Cave are width, height from the lowest point, elevation from the east and west sides, the slope of the wall with a reference perpendicular to the tunnel floor. Figure 8 is an example of cross-sectional samples.

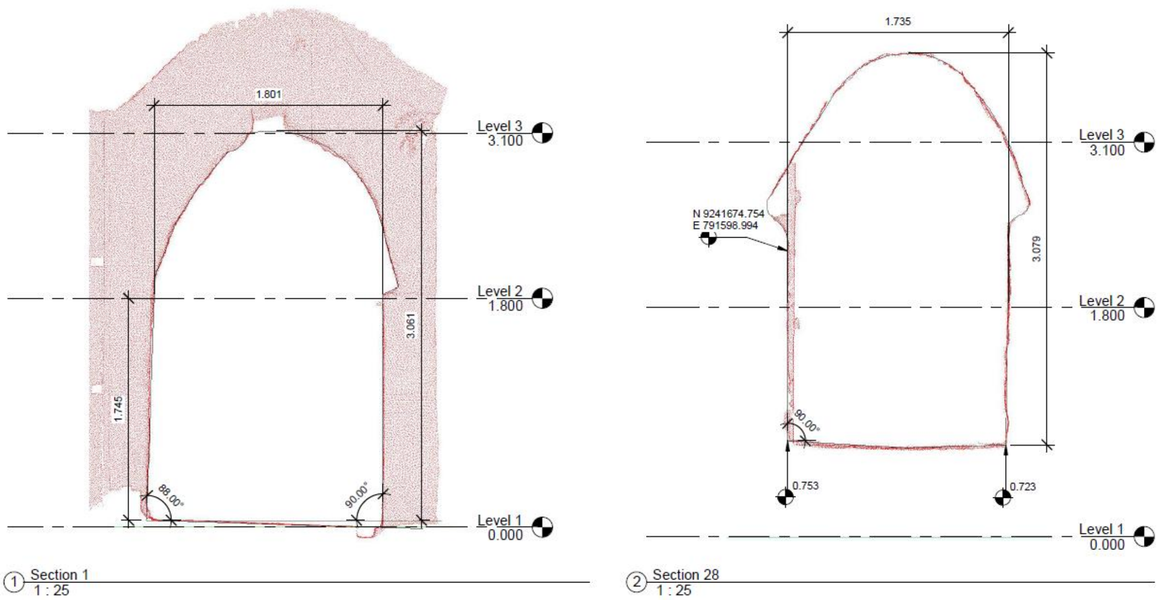


Figure 8. Example of the entrance gate (left) and the exit gate cross-section (right).

There are several results of the cross-sectional analysis that can be seen in Table 1. They widen the side of the cave from the entrance to the cross-sectional point no. 21 by 18.8cm. From the cross-section point no 21 to the exit gate, there is a narrowing ranging from 20.7--32cm. The tunnel height ranges from 2.941—3.179 m, with an average of 3.035 m. The west side of the tunnel surface is 4 cm higher than the east side, and the slope of the tunnel wall is 1°-5°. Table 2 shows the results of the cross-section analysis.

Table 2. Cross-section measurement.

Cross-section Number	Width (m)	Height (m)	Elevation (m)		Slope (°)	
			West	East	West	East
1	1.801	3.061	0.055	0	88	90
3	1.825	3.043	0.075	0.025	91.67	91.67
5	1.956	2.992	0.165	0.078	90	90
7	1.964	3.053	0.133	0.102	90	90
9	1.920	3.018	0.143	0.087	90	91
12	1.940	3.005	0.176	0.116	92	91
13	1.962	3.067	0.179	0.129	90	89
17	1.909	3.047	0.271	0.265	90	90
19	1.917	3.043	0.342	0.269	91.29	91
21	1.989	2.941	0.343	0.32	91	89
23	1.685	2.954	0.359	0.357	93.92	92.87
25	1.669	3.056	0.383	0.383	95	95.58
28	1.735	3.079	0.753	0.723	90	90

4. Conclusion

Technically, the target-to-target method’s measurement looks more complicated, but it is easier to process. With TLS capabilities that can reach a millimeter accuracy level, the resulting point cloud data can provide a detailed description of the condition of the Dutch Cave. If there is data about the Dutch Cave from its first construction or discovery, we can observe the changes since it was found. The Dutch Cave 3D data can be used for virtual tourism needs and as a documentation archive for the Djuanda Forest Park.

5. References

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Acknowledgments

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