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SCANNING THE LAWANG SEWU FOR ETERNAL HISTORICAL 3D DOCUMENTATION USING TERRESTRIAL LASER SCANNER

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ABSTRACT

Lawang Sewu is one of Indonesia's iconic historical buildings, located in the city of Semarang. It currently serves as a museum and historical tourist attraction, holding significant historical and economic value. The preservation of such heritage structures requires meticulous documentation and structural integrity assessment. A crucial aspect of preservation is comprehensive 3D recording to ensure authenticity and conservation efforts. In this study, Terrestrial Laser Scanner (TLS) technology was employed to capture highly accurate data. The data acquisition process resulted in a detailed point cloud dataset representing the position, shape, color, and texture of all visible building surfaces. The 3D documentation obtained from this process serves as an important historical record of Lawang Sewu as of 2022. The accuracy of the 3D data was validated by comparing it to direct measurement data, yielding an RMSE value of 9.5 mm, indicating high accuracy.

Keywords : Lawang Sewu, TLS, Conservation, Cultural Heritage Building

1. INTRODUCTION

Lawang Sewu is one of the historical buildings in Indonesia located in the city of Semarang. The construction began on February 27, 1904, and was completed in July 1907. This building has been used for various purposes that have evolved over time (Fig 1). Eventually, Lawang Sewu is currently managed by PT Kereta Api Indonesia (Persero) and functioned as a museum as well as a historical tourist attraction.

Asset management and preservation are essential for maximizing the utilization of an asset and systematically maintaining it. Asset managers need to have comprehensive and detailed asset data to facilitate decision-making. To carry out the preservation of historical buildings, two interrelated data are required: historical and architectural identification data along with the evaluation of the building's physical strength (Simeone et al., 2019). Conventionally, asset management data consists of printed documents and important letters related to the building. With the advancement of technology, this data is generally archived digitally and supplemented with physical data recording, which is then used in creating 3D models.

One of the technologies that is now highly reliable for documenting buildings as 3D data is Terrestrial Laser Scanner (TLS). Data recorded using laser scan methods consist of a large number of points, known as Point Cloud. The data recording density reaches an accuracy of 5 millimeters, making it highly suitable for the actual shape of the building. Subsequently, this data is modeled in 3D. Sampaio et al. (2021) explained that one of the requirements for documenting buildings is the availability of data from integrated 3D scanner, UAV, and photogrammetry technologies. This is crucial for asset managers as it enables them to understand the actual condition of the asset, thus facilitating planning, maintenance, and development of historical buildings (Osello et al., 2018).

According to Ebrahim (2015), there are three techniques for acquiring 3D data using Terrestrial Laser Scanning (TLS): (1) time of flight, (2) phase shifting, and (3) triangulation. All three techniques measure distances by actively emitting laser beams from the sensor to the object. These methods can be combined into a hybrid approach, but they are more commonly used separately.

In the time-of-flight method, distance is calculated based on the product of half the round-trip travel time and the laser velocity. The travel time refers to the duration required for the laser beam to be emitted from the sensor, reach the object, and then be reflected back to the sensor. Using this method, data recording can only be performed once at a time. Therefore, sensors are typically rotated in all directions to capture data around the TLS. Another variation involves using a rotating mirror to reflect laser beams from the sensor in multiple directions.

The phase-shifting method follows a similar principle to the time-of-flight method. The key difference lies in the recorded data, specifically the phase difference between the emitted and received laser beams. The phase shift of the laser beam is then compared to a standard phase shift to calculate distance. Although the phase-shifting method is faster than the time-of-flight method, it tends to produce data with higher levels of noise (Mechelke et al., 2007).
The triangulation method incorporates an additional camera into the TLS system. This camera helps form a triangle between the object, the laser sensor, and the camera itself. In this triangular configuration, both the distance between the laser sensor and the camera, as well as the angles of laser emission and camera capture, can be determined. Using this information, the distance between the object and the laser sensor can then be calculated.

2. Literature Review

2.1 TLS for 3D Data Capture of Historical Buildings

Numerous studies have explored the utilization of TLS for modeling historical buildings. Capolupo (2021) found that TLS methods excel in accuracy compared to RPAS SfM-MVS methods, with accuracy results of mean, minimum, and maximum errors were 0.004, 0.017, and 0.001 m respectively. Metawie & Marzouk (2020) observed that the quality of TLS data is influenced by the data acquisition positions. Careful planning is necessary to ensure adequate data coverage while minimizing the number of data acquisition positions, thereby enhancing the efficiency and effectiveness of data acquisition.
Several research endeavors have combined TLS with other technologies to enhance the accuracy and detail of 3D models. Guarnieri et al. (2006) combined digital photogrammetry with TLS for 3D modeling of historical buildings by using 1 cm spatial resolution of point cloud. Meanwhile, Fryskowska et al. (2015) integrated Aerial Laser Scanner with TLS.
In Indonesia, several 3D modeling projects of historical buildings have employed TLS. Kartini & Saputri (2022) modeled the cupola of the Bosscha Observatory. Mudzakir et al. (2017) conducted 3D modeling of the Indonesia Menggugat Building in Bandung. Additionally, 3D modeling of temple buildings had been undertaken, such as the Brahu Temple in Zakaria & Handayani (2016), as well as in Rahmawati et al. (2021). The results indicated that TLS was a reliable technology for modeling historical buildings.

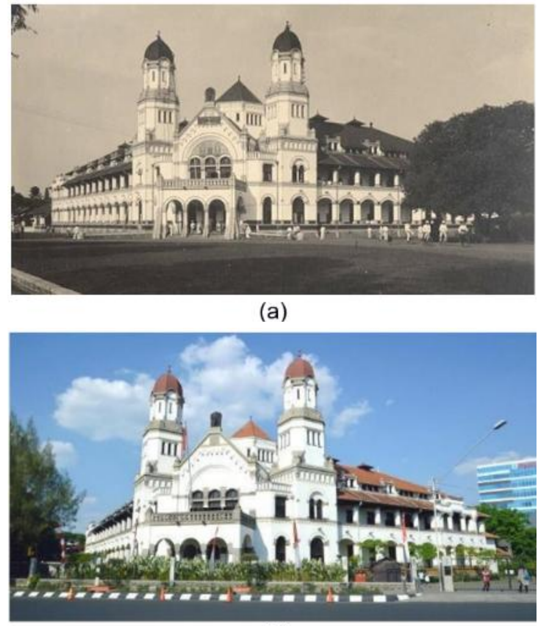
(a)
(b)

Fig 1. Lawang Sewu in the past (a) and present (b)
Source: kai.heritgae.id

2.2 3D Measurement and Documentation of Lawang Sewu

Previous research about Lawang Sewu mostly focused on themes related to social, cultural, historical, and touristic aspects. This is understandable given that Lawang Sewu is an iconic historical tourist attraction in the city of Semarang. Based on our investigation, several 3D modeling activities had been conducted on Lawang Sewu. The first one can be found on the website 3dwarehouse.sketchup.com. The 3D model underwent its last update in 2014, resulting in visually significant differences compared to the current appearance of Lawang Sewu.
The second 3D model was available on the website sketchfab.com, uploaded in 2020, and relatively reflects the current condition of Lawang Sewu. However, the data acquisition method, the accuracy, and the 3D modeling process were not explicitly described. Only the building structure was modeled, and the visual representation was limited to the exterior of the building.
The third study was conducted by Baris et al. (2015) which used close-range photogrammetry to model Lawang Sewu. However, the results were suboptimal due to low data accuracy (ranged from 1 mm to 128 mm and RMSE = 65 mm) caused by a limited number of photos taken and obstructions to the objects. This was a major problem because

Lawang Sewu was always crowded of visitors—even on weekdays.

The most recent modeling effort was conducted by Fanani & Syarif (2023), resulting in a virtual reality representation of Lawang Sewu. Their approach involved counting the number of floors in each room to calculate room dimensions. Object positions, such as doors and windows, were identified relative to the floor sequence. Some objects were also measured using a tape measure to obtain their dimensions. Additionally, blueprint drawings were used as references in creating the 3D model. The result showed great potential in visual similarity and size proportion. However, there was no evaluation of geometrical accuracy, which is necessary in conservation and rehabilitation purposes. In contrast to their approach, the method employed in this research utilizes TLS measurement. With this tool, building dimensions are recorded with significantly greater geometric accuracy.

3. METHOD

3.1 3D Scanning Using TLS

The scanning of Lawang Sewu was carried out from June 25th to June 28th, 2022. The entire physical structure of Building A—from 1^{st} floor to 3^{rd} floor—was scanned. The TLS was Leica RTC360. The point cloud was registered using cloud to cloud method. This method was more efficient because it eliminated the need for target placement. The measurement strategy involved scanning from room to room, with each room scanned at least once. To facilitate automatic registration, scanning was consistently performed with the device positioned at the door. It was a very important thing to do to make sure there were sufficient common points among scan stations.

The main challenge during the scanning process was the high tourist activity, especially on the 1^{st} floor. This occurred throughout the day during the opening hours of Lawang Sewu. Consequently, there were significant amount of noises in the form of human presences on the 1^{st} floor. Additionally, there were non-relocatable exhibition displays on this floor. This situatiatin affected the completeness of the point cloud. Many sides of the building (especially in room corners) could not be fully captured completely. Hence, the number of scan points was increased to cover the entire building facade. However, inevitably, the size of point clouds became larger and would impact the duration of point cloud processing.

This situation differed on the 2^{nd} and 3^{rd} floors. Conditions on both floors were much quieter as they were restricted areas. The layout of 2^{nd} floor closely resembled that of 1^{st} floor, consisting of interconnected rooms with doors. Meanwhile, the most prominent architectural feature on 3^{rd} floor was the steel roof framework.

The entire building scanning process was conducted 235 times. However, there were still several sides of the building that were not well-recorded. One side that lacked sufficient data coverage was the building's roof. This occurred because the TLS-emitted laser could not reach this side due to the steep angle of capture. Additional data in the form of measuring the dimensions of building features was also carried out for the purpose of testing the accuracy of the 3D scan results. Fig 2 shows the situation of scanning process on 1^{st}, 2^{nd}, and 3^{rd} floor.

Fig 2. Scanning process on (a) 1^{st} floor outside corridor; (b) 2^{nd} floor stair; and (c) 3^{rd} floor indoor.

3.2 Data Registration and Filtering

Registration is the process of integrating every scan stations to be one set of point cloud. There were 235 scan data sets that needed to be merged into one. The registration process was carried out automatically using the cloud to cloud method. This method utilizes overlapping scan points for alignment. The process is performed automatically, which mean the computer searches for thousands or even millions of overlapping points in the point cloud as reference points in the alignment process. This minimizes human errors in selecting the same reference points across point clouds. However, this comes with the consequence of longer processing times and requiring computer with high specification.

It should be noted that the registration process using the cloud to cloud method does not guarantee 100% success. There are several conditions that can lead to registration failures with this method. Objects with uniform appearances or features are often difficult to register using this method. This happened because the points in the overlapping area have similar appearances, making it difficult to identify unique points. Difficulty arose during the registration process at staircase locations. Several misaligned registration errors occurred, where stair step number-x on 1st floor was mistakenly considered as stair step number-y from the point cloud side of 2nd floor. Consequently, the 1st floor was shifted towards the positive z-axis and appeared higher than its actual position. The correction process for these conditions was carried out manually.

The subsequent process after registration is filtering, which involves removing noise or points that are not part of the scanned object. In this case, the primary noise that underwent filtering was located on the outer side. Some of the noise found consisted of dislocated objects—e.g. glass objects. In Lawang Sewu, there are numerous glass objects, especially in windows and glass ornaments in the main lobby. The transparent nature of glass caused these objects to be poorly recorded. Some of these objects were recorded but their positions were far behind their original positions. Another significant source of noise data was moving objects, such as humans—as mentioned on section 1 (Baris et al., 2015). The main lobby area had the highest amount of human noise as it is an iconic spot which often used for taking memorable photos.

To evaluate the accuracy of the point cloud results, direct distance measurements were conducted on several objects on 1st, 2nd, and 3rd floors. Ten samples were taken from each floor, resulting in a total of 30 samples distributed throughout the building. Those measurements were done by using a measuring tape. Each measurement was taken at least three times to make sure there was no blunder error.

4. RESULT AND DISCUSSION

Accuracy evaluation was done by comparing point cloud distance to direct distance measurements. The difference of each pair of measurements was calculated. Those differences then called as errors. As illustrated in Fig 3, a maximum error of 41 mm was obtained. The mean absolute error (MEA) was 5.9 mm. To determine the accuracy value of the point cloud, Root Mean Square Error (RMSE) calculations were performed. The RMSE calculation, as described by Hodson (2022), is as follows:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \quad (1)$$

where in this case, y_i represents the data of the point cloud measurement results with a total of n = 30 samples. Meanwhile, $\hat{y}_i$ represents the direct distance measurement data which are assumed as the true value. The RMSE calculation yielded a result of 9.5 mm.

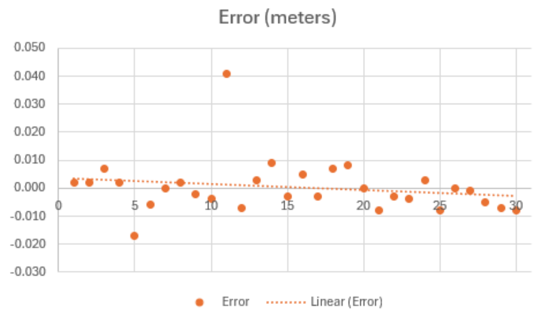

Fig 3. Graph of residual error between direct distance and point cloud distance.

Based on the comparison between direct distance measurements and point cloud distance measurements, a standard deviation of ±9.6 mm was obtained. Testing was conducted with the initial hypothesis (H_0) that the deviation between direct distance measurement and the point cloud distance measurement was zero (0). The test results with a 90% confidence level indicated that $t_0 = 0.0949$, while $t_{\alpha/2(n-1)} = 1.6991$. Since $t_0 < t_{\alpha/2(n-1)}$, H_0 was accepted. Thus, it can be concluded that there is no difference among those two measurements.

Fig 4. Result of point cloud with original color.

Fig 4 shows the point cloud results from several locations inside and outside Building A of Lawang Sewu. It can be observed that the displayed colors represent the original colors captured during daytime measurements. Information regarding colors, patterns, and ornaments on floors, walls, and other objects serves as semantic data that can be utilized in creating high-reality 3D models. The presence of historical objects (e.g., in the lobby area) is retained to serve as ambience of those rooms in 2022.

5. CONCLUSION

The results of this activity have comprehensively captured the physical data of Lawang Sewu building, particularly Building A. From the interior aspect, the data was well and completely recorded. On the exterior side, some data were not fully captured, especially the roof section. Additional scanning data is required using aerial survey methods to complete the roof-side data. However, for 3D modeling purposes, this point cloud data can be utilized up to Level of Detail 4 as it encompasses interior building data with an accuracy level of 9.5 mm.

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