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Harnessing Multi Source Point Cloud Technology to Overcome High Resolution Building Information Modeling of Manganti Dam, Indonesia: A Preliminary Result

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ABSTRACT

Building Information Modelling (BIM) is a technology involving the generation and management of digital information of physical and functional characteristics of places (in 2D or 3D), which is developed to obtain built assets, planning, construction maintenance and operation, and construction management system. This case study is BIM development for the Manganti dam, located in Central Java, Indonesia. The dam itself is a vital irrigation system and is located in an earthquake-prone area, which makes significant risk factors for the surrounding environment. Therefore, continuous monitoring for the dam should be taken seriously into action by acquiring accurate information. Supporting that purpose, the spatial information of the dam, in 3D form, should be accurately presented in the mapping process. Although the Terrestrial Laser Scanner (TLS) is well known for providing accurate geometry information, its information detail is still limited to an accessible area. Consequently, it creates gaps in shadow areas which possibly can be compensated by the data from Handheld Laser Scanner (HLS). In this contribution, we are focusing on analyzing the reliability of TLS and HLS combination for high-resolution mapping and, possibly, high accuracy mapping. The geometric accuracy of the 3D model is comparing the dimension of the model to the dimension measurement by the Electronic Total Station (ETS) measurement.

Keywords: Building Information Modeling (BIM); management of digital information; Terrestrial Laser Scanner (TLS); Handheld Laser Scanner (HLS); high-resolution mapping; high accuracy mapping

INTRODUCTION

Building Information Modeling (BIM) is a digital form of building information including the assets that contain three components; technology, processes, and digital information that can be used to improve the operation of assets in buildings [1]. The digital forms can be either two-dimensional (2D) form or three-dimensional form (3D). Generally, the 3D form is used in Architecture, Engineering, and Construction (AEC) design [2]. In construction projects, BIM benefits not only during pre-construction and construction but also in post-construction by taking the stage in operation control and maintenance scheduling information, replacement parts ordering information [3]. BIM development can be seen as data transformation from the virtual BIM world to the construction site [2]. Consequently, low data quality and poor coordination between each user can lead to inefficient BIM utilization [4].

Several technologies are developed to facilitate the mapping method. The method experiences evolution from 2D into 3D mapping systems in global and local scales [5]. For instance, photogrammetry and laser scanning technologies can be used to provide visualization in the 3D map by generating Point Cloud Data (PCD) [2]. Moreover, laser scanning technology has the ability to produce high-quality 3D models in various fields, such as topographic surveys and industrial environments [6]. The difference between the aforementioned technologies is the previous technology generating the point clouds position from images, while the latter producing the image by assembling a group of point clouds [2]. The point clouds generated from photogrammetry are less dense and less accurate than laser scanning. It becomes even lower when the object's texture is poor [2, 7].

The laser scanning technology principally classifies twofold based on the data acquisition: moving laser scanner and static laser scanner. In this research, we only discuss the latter. The static laser scanner, namely Terrestrial Laser Scanner (TLS), is tailored for engineering and monitoring purposes. Although TLS outperforms other technologies in producing a 3D model of an object in its class, the level of accuracy depends on several aspects: coverage angle of scanning, the distance between the instrument and the scanned object, and material type of the object itself [8, 9, 10, 11, 12]. In its applications, TLS can monitor 3D objects by determining point changes in the structure and deformed shape of the structure [13]. However, the performance of TLS coverage in inspection and engineering activities is limited by its application design. In other words, it has difficulty to capture some shadow and narrow areas. Also, this function is compensated by using the Handheld Laser Scanner (HLS). Some variants of HLS, for example of Stonex F6, have better resolution, and require less time for acquisition and processing, but need some improvements in texture compared to the camera acquisition, (e.g. Canon) [14]. Based on the brief description of TLS and HLS, this contribution delivers a discussion about the result of 3D mapping using a combination of TLS and HLS. Specifically, its objective is to generate high resolution and high accuracy 3D map of the Manganti dam structure for spatial information of BIM infrastructure.

Manganti Dam located in Central Java, Indonesia is the main irrigation system supplying water for two neighboring regencies and their surrounding area. Unfortunately, this area experiences several earthquakes but no intensive mapping activity has been delivered to monitor the dam structure since its construction in 1970. There is a high possibility of deformation, cracks, and damages in the structure. An immediate engineering action must be taken into account before the failure of the dam structure takes casualties. One of the required pieces of information that should be delivered to the dam maintenance and repairmen is the geometric image of the physical dam in 3D form. The behavior trend of the dam structure can only be seen in continuous observation periodically. Hence, data acquisition is delivered by combining TLS and HLS.

MATERIALS AND METHODS

The general process of this research is illustrated in Figure 1. This contribution is tailored to fulfill its objective; generating a high resolution and high accuracy 3D map of the dam structure. The first stage begins with survey planning by considering effectivity and efficiency during acquisition. The effectivity relates to the TLS placement so that the scanning process reaches the optimum coverage of the object, and leave the gaps as small as possible. At the same time, the efficiency focuses on the minimum number of TLS stations and the working hour of the data acquisition.

Despite its high-resolution ability in object scanning, the use of TLS technology is limited to the area in which the instrument and its equipment, i.e.: the tripod, can be installed. In a particular area, especially in an area with limited access, the TLS will leave the object unscanned. Consequently, these gaps create blind spots that sometimes provide inaccurate necessary spatial information. This lack of information is compensated by operating the HLS. A combination of both technologies will provide high-density point clouds.

However, the HLS measurement provides no information on the coordinate system. Therefore, the HLS application is used to shape the reconstruction of an object without any georeferenced system. Anticipating this drawback, the operator should recognize some common point clouds resulted from both measurements during the registration process. These common points will be used as allied points for the transformation process adjustment.

The result of the registered point clouds is used to build the 3D model development. Hence, a 3D model of the dam can represent the best actual situation of the Manganti dam structure. For validation purpose, some quantities from the laser scanner combinations are compared with the ones which are obtained from ETS measurements.

This research process is divided into three stages, namely the scanning process, the BIM development, and the validation process.

SCANNING PROCESS

Two scanners were used in this research, namely the TLS Topcon GLS-2000 and HLS Stonex F6, as depicted in Figure 2.

The TLS location must be placed on the ground which had a wide viewpoint and nearest distance to the object. In order to generate registered point clouds, the measurement can be conducted using indirect geo-referencing or direct geo-referencing technique [15]. The previous technique combines multiple scans from different locations into one and they are transformed using three allied control points. As a drawback, this technique is seen to be less efficient than the latter technique, which is by an obligation of conducting an extra survey of the control points.

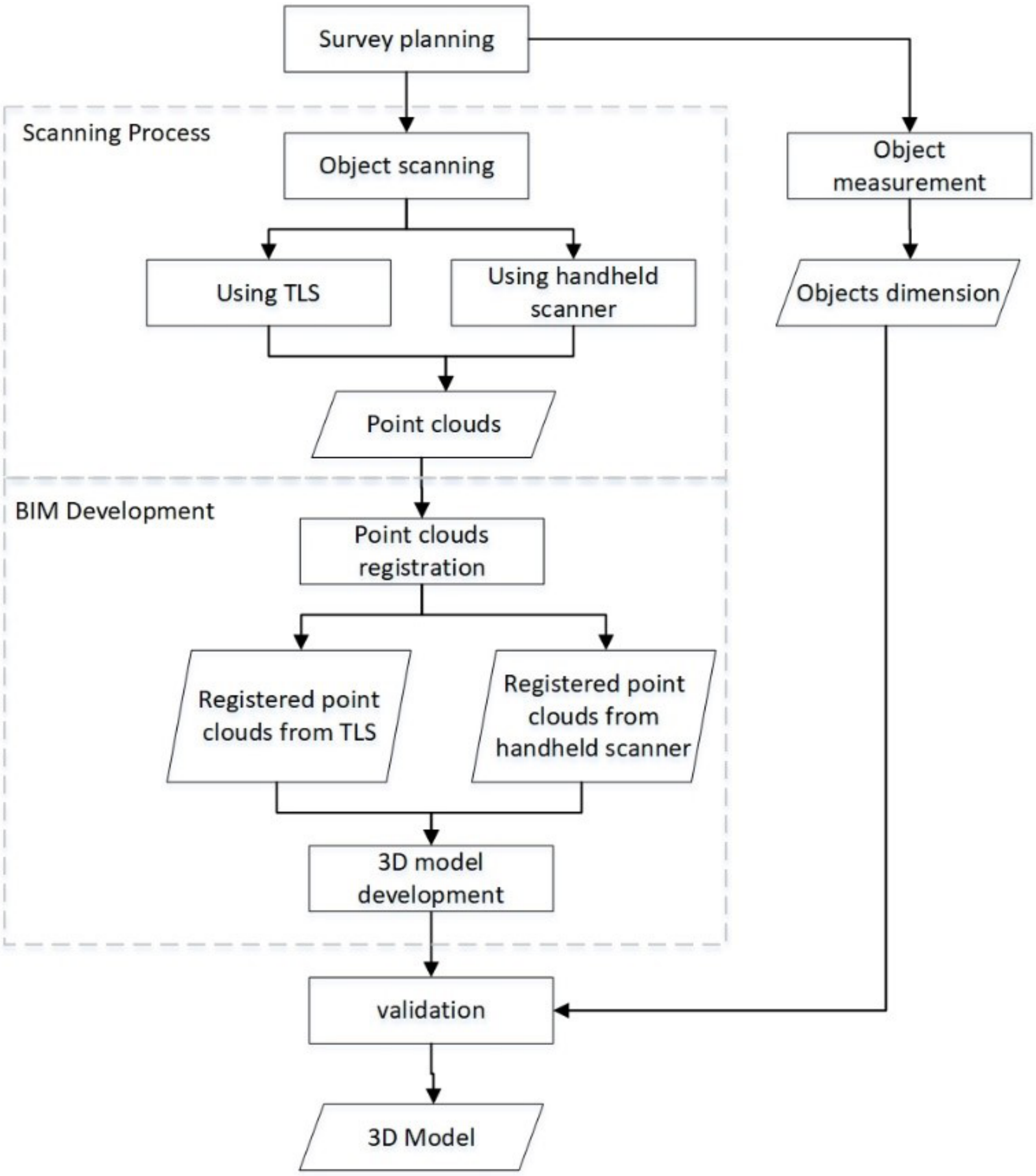

FIGURE 1. Research methodology

FIGURE 2. (a) TLS Topcon GLS-2000 (source: www.topcon.com); (b) HLS Stonex F6 (source: www.mantis-vision.com)

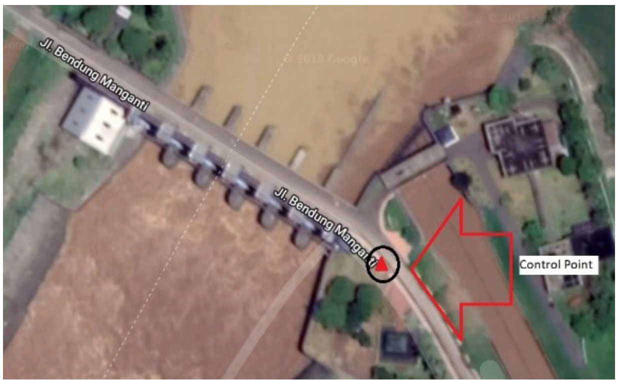

FIGURE 3. Location of control point (top view)
Source: https://maps.google.com/

TABLE 1. Coordinate of control points

Northing (m)	Easting (m)	Height (m)
9175973.902	248195.727	12.352

Both direct and indirect techniques were used to scan the dam buildings in this research because there was only one control point that has a global coordinate, as is shown in Figure 3 and its coordinate is represented by Table 1. The concrete structure of the dam was scanned by using TLS, whose distribution is shown in Figure 4 (left). The hydraulic pumps on the first and second floors were scanned by using HLS, as shown in Figure 4 (right).

Additionally, the ETS measurement is used to determine the dimension of an object from a group of particular points. The dimension can be represented by some distance quantities such as length, width, and height. The result from TLS measurement is then compared with the corresponding point clouds from the identical object. Since the ETS provides high-reliability data in terms of geometric accuracy, the coordinates resulted from ETS measurement are acting as reference quantities. Hence, results from TLS measurement will refer to the one from ETS measurement. Keawaram & Dumrongchai (2017) also showed that ETS is proven to be more accurate in the positioning of a specific point but fewer details than TLS in terms of spatial areas [16].

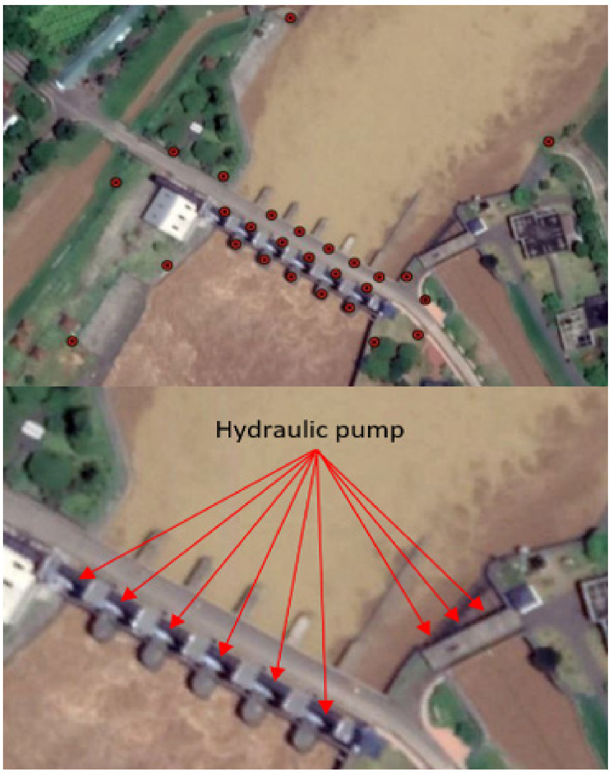

FIGURE 4. Distribution of TLS placement in red points (left), and location of hydraulic pump (right)
Source: google earth application

BIM DEVELOPMENT

The first step in data processing is discarding any noise contained in the point clouds set, namely filtering. The next step is a particular registration process, which is known as 'cloud-to-cloud registration', by taking manual and global registrations. This process was performed with the software Maptek i-Site Studio 7.0. As the point cloud data have a digital format extension of *.e57, it is exported to format extension of *.las. The filtering and registration produce the point clouds which are already transformed into a global coordinate system on a specific projection system. In this case, we are using the UTM zone 49s.

Once the point clouds are georeferenced the BIM model can be built, for instance using Autodesk Revit 2016. The 3D model development was designed by taking into consideration the user needs for maintenance of the dam structure. It leads to a complex processing algorithm, which involves many entities in the modeling.

VALIDATION PROCESS

The validation processed was done by comparing the dimension from the 3D model of dam building into dimension measurement using ETS. The dimension value that was considered to be the right value is the dimension measurement using ETS. The result of this validation processed is the root mean square error (RMSE).

RESULTS

The product of this contribution can be seen from different significant signatures, such as the component of hydraulic pump, the registered point clouds, the BIM model, and the object validation.

COMPONENT OF HYDRAULIC PUMP

Figure 5 shows the difference of point clouds that were produced from TLS and handheld scanner.

The handheld scanner produced more detailed components of a hydraulic pump than the scanning results from TLS. It is shown in Figure 6.

Figure 6 shows that the hydraulic components such as a bolt, casing, discharge nozzle, driveshaft, and swashplate could be shown from the handheld scanner. Meanwhile, the hydraulic pump from TLS scanning processed only produces the hydraulic pump generally.

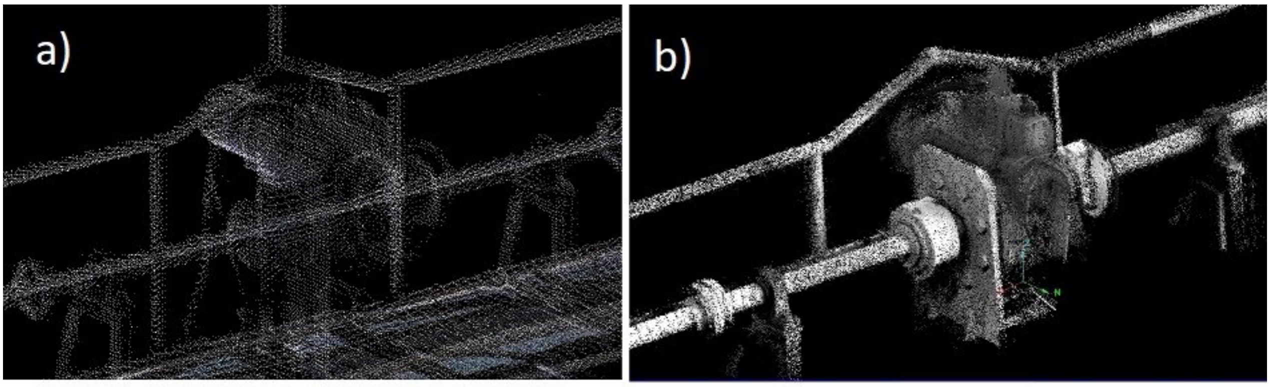

FIGURE 5. a) Scanning result of a hydraulic pump from TLS, b) scanning result of a hydraulic pump from the handheld scanner

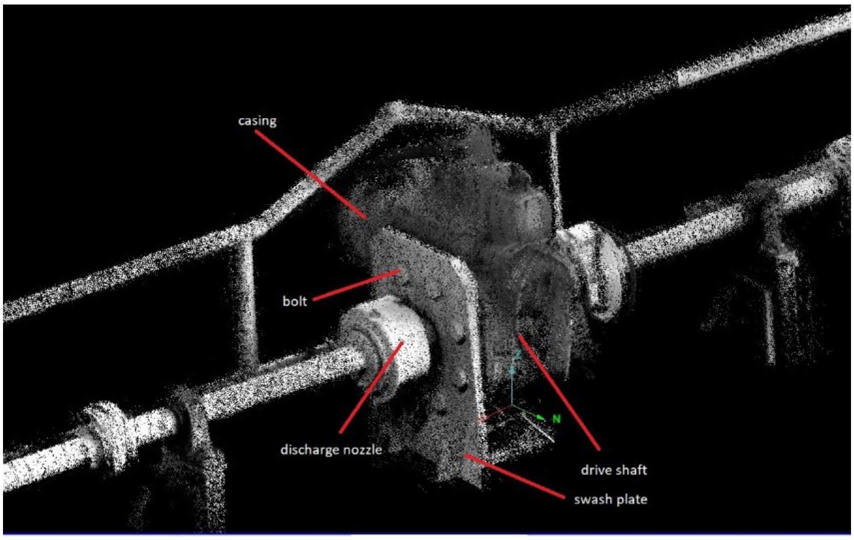

FIGURE 6. Hydraulic pump components result from handheld scanner processed

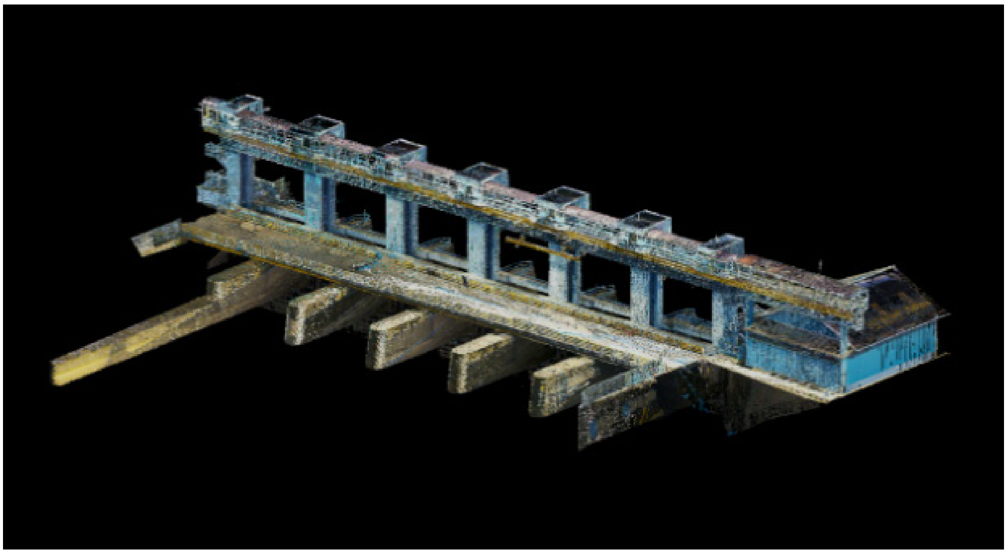

FIGURE 7. Registered point clouds from TLS scanning processed

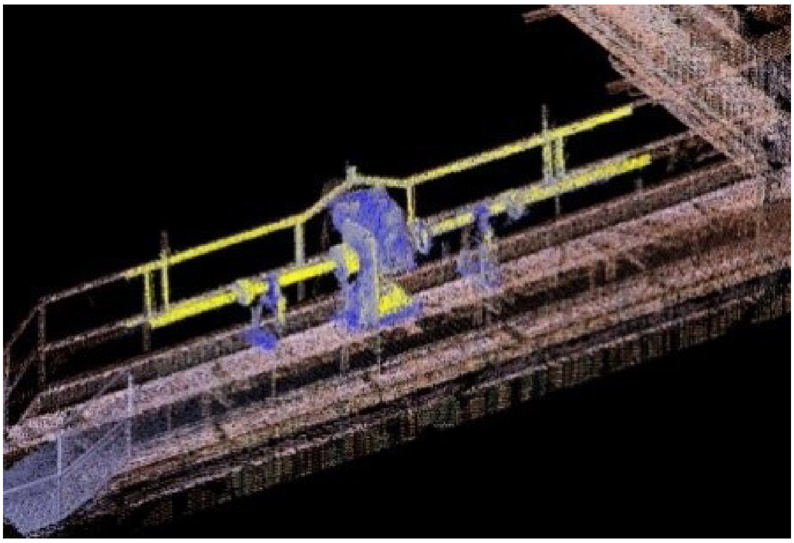

FIGURE 8. Registered hydraulic pump of registered point clouds from handheld scanner into point clouds from TLS

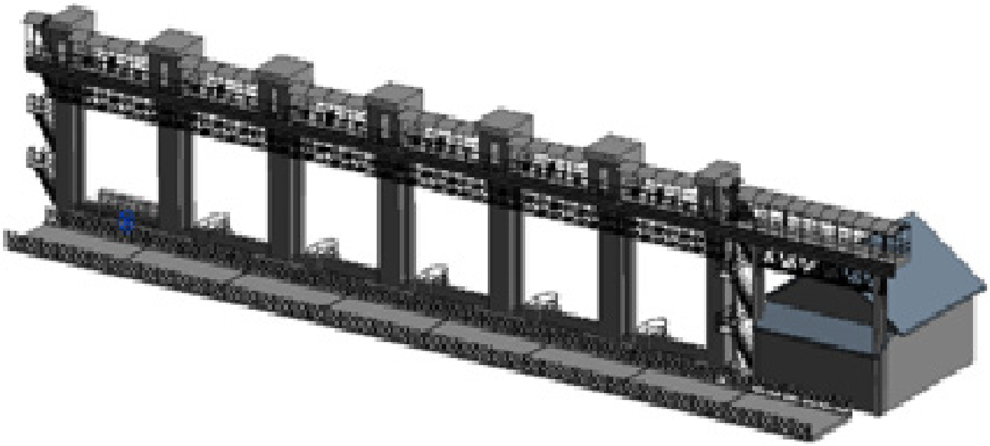

FIGURE 9. 3D model of dam building

The average RMSE of registered point clouds from TLS acquisition is 0.006 m. The RMSE of registered point clouds from the handheld scanner into TLS is 0.036 m with a scale factor is 0.001 m.

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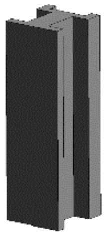
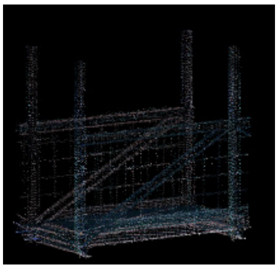
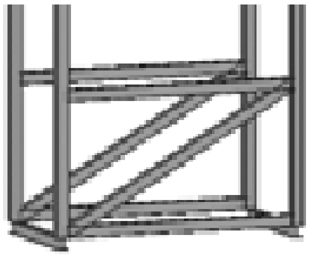
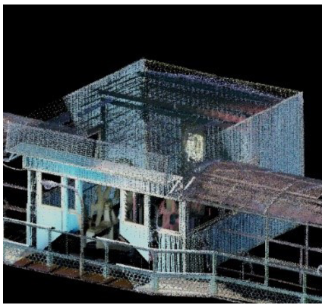
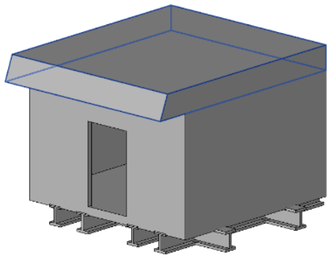
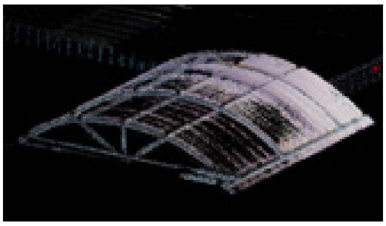
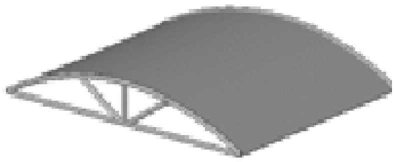
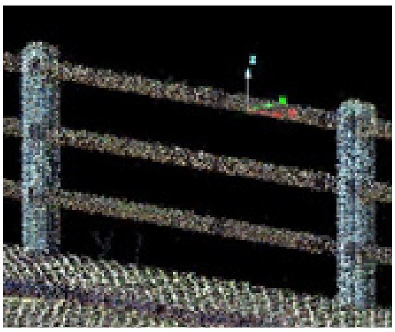
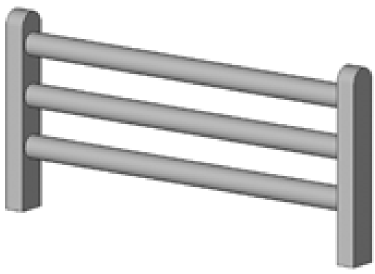
BIM MODEL

The BIM model processing was done by defining the model element into a specific model then added the semantic information of model. In software, the process to build a model was done using 'family' tools and adding the semantic data was done using 'schedule' tools. Each model is adjusted to the FM requirements, so the user who is responsible for managing the dam-building could manipulate the information of each element of the dam building. The whole 3D model can be seen in Figure 9 and components of the dam building shown in Table 2.

TABLE 2. Elements of dam building

Component of dam building	Point Clouds	3D Model
Main column		
Buffer Fence		
Engine house		
Roof		
Fence		

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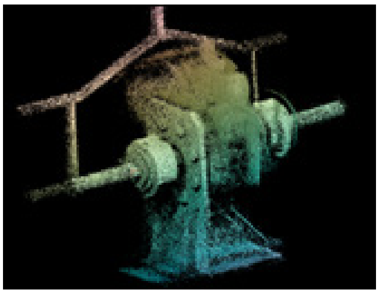
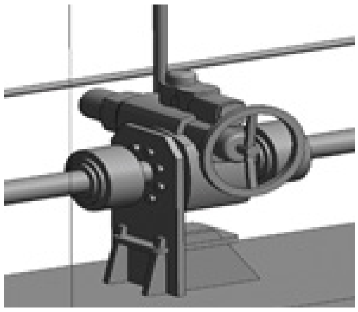
Hydraulic pump		

VALIDATION

The development of the 3D model of dam building needs validation whether the model is acceptable to be represented as the real object. The validation process needs the comparison of data, which takes the dimension of dam building from ETS measurement. As a comparison object, a pile that supports the dam structure is chosen. The object is measured by ETS and TLS. The representative quantity is the distance rather than coordinates. Figure 10 illustrates part of the pile to be taken as comparison components.

FIGURE 10. Pile of dam structure used as validation object between TLS and ETS measurements, with 1 = height, 2 = middle width, 3 = outer width, 4 = lengths, and 5 = width

Table 3 shows the difference of pile column dimension measurement between the 3D model from the TLS scanning process and ETS measurement. Width, height, and middle width components are facing the TLS directly during the scanning process, while the length and outer width are located at the inner side of the building, and limited access area. The limitation of TLS coverage at certain components of the pile column is confirmed by the deviations of the TLS scanning result with respect to ETS measurement, which is above a half-centimeter for length and outer width components.

TABLE 3. Column dimension measurement between 3D model and ETS

Dimension	Average ETS Measurement (m)	3D Model Measurement (m)	Deviation
Width	2.478	2.477	-0.001
Length	2.808	2.8	-0.008
Height	7.552	7.554	0.002
Outer Width	3.992	4.001	0.009
Middle Width	3.018	3.019	-0.001

The RMSE between 3D model of column and column measurement using ETS is 0.006 m. The margin of error with 95% confidence level of t distribution is 0.006 m.

DISCUSSION

Based on the results of scanned TLS and HLS, the TLS has the ability to scan the dam structure in high resolution that appears to be not sharp enough to map the detail of small objects such as pipelines and hydraulic pumps. It can be seen from Figure 5 a) that the scanned object from the TLS measurement provides lower point clouds density compared to the point clouds from the HLS measurement in Figure 5 b). The hydraulic pump resulted from the TLS scanning process can only produce the hydraulic pump in its rough form. Figure 6 shows that the HLS gives high point clouds density so that every small component of the pipes and pump can be identified correctly. The hydraulic pump components such as a bolt, casing, discharge nozzle, driveshaft, and swashplate could be shown from the HLS measurement. It is useful for the maintenance and renovation purposes of the object in BIM. Furthermore, it is also easier for the maintenance service division to change the part of the pumping system by identifying its accurate geometry through the scanning product beforehand. This innovation allows the inspector to estimate the budgeting of pumping system spare parts without going directly to the site.

Meanwhile, the RMSE of registered point clouds has the satisfaction result from the 12.5 mm mapping density. The RMSE of registered point clouds from TLS acquisition is 0.006 m with the average distance of scanning position to the object is 11-12 m. This result is said to be quite competitive if we compare it to other TLS measurements which obtained the RMSE up to 6mm and 12 mm, with the corresponding distances from the scanner to the object, are around 3.5 m and 7 m, respectively [17]. Meanwhile, the RMSE of registered point clouds from the handheld scanner to point clouds from TLS is 0.036 m using manual registration, which is incomparable in terms of geometric accuracy. That happened because the choices of natural point feature as the common point are not accurate [18]. Furthermore, the huge gap in RMSE could possibly happen because of the acquisition processed using the handheld scanner, which was using a hand to hold the device. The operation way of the handheld scanner and TLS is very different. Scanning process of TLS is more stable than the handheld scanner. Even though the RMSE of registered point clouds from handheld scanner is not good enough, but the detailed information of the hydraulic pump was visible as shown in Figure 6.

Although the TLS was placed at a far distance, the registered point clouds still can capture the detail of the dam structure resulting in the 3D model of the dam with an accuracy above 5 mm. The presented result might not optimal yet if the measurement will be applied to detect structural cracks below 3 mm. The result with the survey condition above can be applied for deformation application, which causes massive movement. Nevertheless, for BIM model development the result with the accuracy above can be considered giving moderate representative of the building

Moreover, the RMSE of the 3D model must be calculated using a comparison of the actual size of the dam building. The size comparison was measured using ETS. The margin of error of the 3D model is 0.006 m. Based on the U.S. Institute of Building Documentation (USIBD), the margin of error result is classified in LOA20, which is the second level of five class classification [19]. Even though it is recommended to use the object's surface from point cloud measurement to an actual surface of the object to determine the accuracy of the measurement process, the actual surface of the object using ETS measurement is difficult to provide. The point target in the column for ETS must represent the column surface so that the point targets distribution must have the same details as much as using TLS. Therefore, it is much better to measure the Euclidean distance of the column dimension using ETS as comparative data. ETS is proven to be more accurate in positioning specific points but fewer details than TLS which in terms of spatial areas, TLS gives more accurate results [16]. Furthermore, the RMSE of the 3D model of dam building is smaller than the sensor resolution. It is indicated that even though the sensor's resolution of 12.5 mm can provide the better results for the 3D model of dam building and the RMSE model is classified in relative accuracy because the accuracy validation is only a part of the 3D model of dam building, not a whole part.

The BIM modeling was performed by defining the model element into a specific model, as is shown in Figure 9. Then the semantic information is added to the model. Each model is then adjusted to meet the FM requirements. It gives a possibility for updating the information regarding the purpose of each element of the dam building. The 3D model of each element of the dam building shown in Table 2.

From a geometric point of view, the developed BIM in this contribution can be classified in level LOD350 since the geometric of BIM model is defined to the existing object and attached to other properties, such as a hydraulic pump that are connected to the other element of dam buildings, as they can be seen in Figure 8. This argument is also reasoned by the connectivity with an attachment of the hydraulic pump and its additional properties [20]. Moreover, each model of dam buildings represents a definite model, which has its information.

CONCLUSIONS

The TLS technology is used in a wide spectrum of 3D mapping, and it is known for its ability to provide high accuracy data. The density of the resulted point clouds depends on several factors; class/type of the instrument, distance from the scanner to the object, and material of the scanned object. The shorter the distance between the scanner and the object the denser point clouds would be generated, which also depends on the instrument specification. Besides that, the reflected transmitted signal is also influenced by the material of the scanned object. Some absorbent material will reflect fewer signals to the scanner. Nevertheless, combining TLS with HLS in 3D mapping purpose is seen as an innovation on the practical side.

Further, this contribution also showed that the georeferencing process of integrating registered point clouds from HLS and TLS can be done by performing manual registration of adjustment transformation using some common points with TLS measurement. Hence more detailed information about the dam can be visualized. A combination of both scanner technologies can be used to support the BIM development because the LOA of the 3D model is included in the suggested LOA of the USIBD guideline.

For future studies, the accuracy of scanning measurement from the combination of TLS and HLS needs to be improved by investigating an optimal mathematical model for the transformation adjustment process. Besides that, a standard of using HLS application for high accuracy mapping activity can also be formulated.

ACKNOWLEDGMENTS

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DECLARATION OF COMPETING INTEREST

None

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