Conservation of Balinese Customary Buildings with BIM Technology Approach

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Abstract. Digitizing architectural heritage information has become an important task during these past years. However, only a few studies have addressed the digitization of historic building models for conservation and restoration purposes. As historical building conservation began to decline, many historical buildings are being abandoned and converted into modern facilities in response to our changing needs. The conservation attempt can be made simple by utilizing the Building Information Modeling (BIM), and High Definition Survey (HDS) approaches. These technologies are considered brand new in managing important information related to 3D models, providing us with semantic information and accurate information in both position and elevation. HDS data is constructed in the form of point clouds generated by the collaboration of survey equipment such as GNSS, Drones, Terrestrial Laser Scanning, and high-performance computers. Point cloud data is registered, filtered, and georeferenced before using BIM modeling. This study resulted from registering point cloud data with RMSE 3mm and customary semantic information. The BIM model based on accurate point cloud data is expected to be a solution and a reference in carrying out the conservation and reconstruction of historical buildings in the future.

1. Introduction

Indonesian architecture is unique because it is influenced by the country's diverse culture, history, and geography. Various architectural designs left by colonizers and ancestors have significant cultural and historical value. However, as technology advances, the existence of historic buildings is diminishing and being left behind in their preservation because the space requirement is very high to accommodate the dynamics of the population that occurs. Moreover, it does not care about the damage to historic buildings, so conservation and restoration measures are required.

In Indonesia, conservation activities for historical buildings only take the form of databases and 2D forms based on measurements and interviews [24]. Conservation is preserving and protecting rare
objects of historical value [1]. Preservation of historic buildings requires knowledge and understanding of these resources and their history. Protection requires proper resource management and systematic procedures in conservation work [2]. In recent years, Building Information Modeling (BIM) was developed as an approach to providing digital data related to building construction and can create a consistent relationship between geometric data and non-geometric information in a building model, BIM, known as parametric design, is gradually being used in the design realm. Construction and management of modern architecture [3]. The digitization of architectural heritage information has become an essential work in the architectural heritage field. However, only a few studies have discussed the digitization of historic building models using BIM for conservation and restoration purposes.

BIM is the process of producing, managing, and delivering information among project stakeholders. It promotes collaborative working practices through defined processes and technologies, with the potential for increased performance and efficiency, resulting in significant benefits for the construction industry [4]. Laser scanning data in the form of a point cloud that resembles the shape of the original building is required for BIM implementation. [5]. Scan to BIM is a collaborative technique between High Definition Surveying (HDS) and computer science. The HDS method uses GNSS technology, Drones, Terrestrial Laser Scanning (TLS) or Multisensor Survey Equipment, and computers with sufficient specifications to produce high-accuracy point clouds.

This research aims to digitize historical building assets to preserve them and solve problems that may arise with the BIM and HDS approaches. Models created with BIM and HDS can help with conservation efforts. The next sub-chapter will explain the stages of this research.

2. Related Work

High Definition Surveying (HDS) is a combination of terrestrial laser scanning (Terrestrial Laser Scanning), computer technology, and high-precision control nets [6]. HDS provides a method for storing physical reality on computer devices so that engineers/designers can easily access essential data and provide specific information to guide making decisions and optimizing the value of these facilities/objects. Along with its development, HDS is collaborated with photogrammetry applications by taking pictures using an Unmanned Aerial Vehicle (UAV) around objects [7]. HDS method can be applied to several measurement needs and circumstances. The first requirement is to measure structures with complex geometries and details so that it is not technologically (and time-consuming) to use traditional survey methods (Terrestrial Point Surveying). This method is also needed for surveying objects that are difficult to reach or dangerous to measure at close range. Then, this method is also applied to objects that are used continuously so that the possibility of changes to these objects is quite large and requires precise and fast as-built information.

The basic principle of the laser scanning process is the calculation of the travel time of the laser electromagnetic wave since the sensor emits it until it is reflected by an object towards the sub-system of the receiver or receiver. The receiver will calculate the average distance traveled (distance to the object + distance to the receiver). The distance between the sensor and each object being scanned is obtained by knowing the average travel time and the speed of light waves. The basic formula for its calculation is as follows:

\[ R = \frac{C \times T}{2} \]  

Where, \( R \) is the distance between the sensor and each measured point object (m), \( C \) is the constant of the speed of light (299,792,458 m/s), \( T \) is the laser travel time interval (ns).

Point clouds are collections of three-dimensional points with the same coordinate system (X, Y, and Z). The angle and distance data measured from the target determine the position of a point cloud in TLS. Calculations based on travel time can calculate the distance (time of flight). While the angle is calculated using the Angle Measuring System (AMS) in TLS. AMS measures changes and movements of the tool horizontally and vertically to obtain an angle, which is then used as the azimuth angle to calculate the position of the point concerning TLS using the polar method [8].

\[ X = R \cdot \cos(\varphi) \cdot \cos(\alpha) \]  
\[ Y = R \cdot \cos(\varphi) \cdot \sin(\alpha) \]
\[ Z = R \cdot \sin(\varphi) \]  \hspace{1cm} (4)

Where, \( R \) is the distance from the device to the target point (m), \( \alpha \) is the azimuth from the device to the target point: the Y axis is pointing north, \( \varphi \) is the angle formed by the horizontal plane of the device with the target point.

After obtaining the point cloud data, noise filtering must be performed. The noise is then manually filtered by looking at distant points that are not in the object research section. Then, the Iterative Closed Point (ICP) algorithm will be used. The algorithm concept calculates the correspondence between two scans and the magnitude of the transformation to minimize the distance between the corresponding points [9]. This algorithm uses the idea of the K-D Tree, which is generally applied in searches with a range search and nearest neighbor search [10]. Thus, the distance between the data point clouds in the reference dataset is checked with this algorithm. The transformation estimation is carried out by merging the two datasets continuously/iteratively until the point clouds converge. The ICP algorithm is used to determine the rotation matrix (R) and the translation vector (T) between a set of plotted points (S) and a set of reference points (M) [11].

In this paper, it will combine TLS data with UAV based on a corrected point cloud to the same system (georeferenced). With the formula published by [12];

\[ PCD_F = PCD_T + PCD_U \]  \hspace{1cm} (5)

where PCDT represents the TLS-based point cloud, PCDU represents the UAV-based point cloud, and PCDF represents the fused TLS- and UAV-based point cloud.

The accuracy of the point cloud data registration process is assessed from the Root Mean Square Error (RMSE) value. The RMSE value is inversely proportional to the quality of data accuracy, where the higher the RMSE value, the smaller the value of the quality of data accuracy. One of the RMSE assessment parameters is to compare the RMSE value with the single point positional accuracy value, which is a value that represents the positional accuracy for each of point clouds data [13]. The RMSE value is determined by equation 5.

\[ RMSE = \sqrt{\frac{\sum (R - R_1)^2}{n}} \]  \hspace{1cm} (6)

Where, \( R \) is the value that is considered correct, \( R_1 \) is the value of the measurement result and \( n \) is the number of measures used.

With a single point positional accuracy value of 3.5 mm [14], for a 95% confidence level, the error tolerance value is as follows:

\[ Fault \ tolerance \ value = 1.96 \cdot \sigma \]  \hspace{1cm} (7)

Where, \( \sigma \) is the single point positional accuracy of a device. From the above calculations, it can be concluded that the registration process can meet the 95% confidence level if the RMSE value is less than 7 mm.

Conservation is a concept used to preserve and maintain historical objects or cultural heritage, and it is necessary to take conservation actions in an area with historical value. Cultural heritage is a non-renewable, irreplaceable resource and a common good. Still, it is often threatened by environmental challenges and climate change, disaster risk, neglect, decay, and lack funds [15]. Conservation requires proper resource management and systematic procedures in conservation work [16]. Considering the demand for comprehensive legacy information storage architecture, it is necessary to systematically categorize and input each at the beginning and during the modeling process according to the information record and protection principle. As a result, database development cannot be completed without a BIM model. In recent years, Building Information Modeling (BIM) has been developed to provide digital data related to building construction and a consistent relationship between geometric data and non-geometric information in a building model. BIM is also known as parametric design, and it is increasingly being used in construction design and modern architectural management [3]. With the BIM approach, digitization of architectural heritage information has become an essential work in the
architectural heritage field. However, only a few studies have examined the digitization of historic building models using BIM for conservation and restoration purposes.

3. Data and methods
3.1. Study Area
Penglipuran Traditional Village is geographically located at coordinates 8°25'18.7"S - 115°21'32.5"E. This area is located in Kubu District, Bangli Regency, Bali Province as shown in Figure 1.

Figure 1. Research location in Penglipuran traditional village

The research was conducted in the Penglipuran Traditional Village area, which has a spatial pattern based on the Tri Hita Karana concept and carried out by several previous researchers, including [17],[18],[19],[20],[21],[22],[23], and can be used as a reference in conducting this research. Tri Mandala (horizontal axis) and Tri Angga (vertical axis) are the concepts of Tri Hita Karana used in the spatial pattern, which includes the Utama, Madya, and Nista spaces [23].

Penglipuran Village is a traditional village located in the Kubu Village area, Bangli District, Bangli Regency, Bali Province. The size of this village reaches 112 hectares with an altitude of about 500 - 600 meters above sea level. Penglipuran Village is one of the traditional villages known as a tourist village in Bali because of its people who still preserve and practice local wisdom and traditional Balinese culture in their daily lives. The people of Penglipuran Village follow customary rules called awig-awig. This awig-awig is an embodiment of local understanding, which is a strong foundation in good natural resource and environmental management and is customary law in the form of regulations or laws drawn up and stipulated by the residents of the Banjar and Subak villages regarding the order of life. Society in the fields of religion, culture, and socio-economics in Bali.

In the spatial concept of the Penglipuran Traditional Village, the environmental arrangement is oriented towards the north. That concept is influenced by the old cultural heritage that places the north as the highest and most sacred place. In this case, the symbolic orientation is Mount Batur. This
mountain is located north of the village of Penglipuran, which they believe has magical and religious powers. Thus, the placement pattern of village buildings always crosses from north to south, with the north as a sacred part.

Penglipuran village follows the development procedure according to the architectural rules contained in awig-awig. In addition to the outline of the Penglipuran Village landscape, the Tri Hita Karana concept is also applied in the arrangement of the Penglipuran Village community's complex. The idea used is still in the Utama, Madya, and Nista zones divisions. These zones also impact community activities, such as the Madya zone, which is where the majority of human activities occur. The Utama zone is where people worship, and the Nista zone is where the community does things like welcome guests, conduct sales transactions, and raise livestock.

3.2. Data Used
The data used in this study is static data from the GNSS survey (Stonex S800A) with observations for 3 hours (8 – 11 pm) to avoid disturbance (humans, animals, and others). Penglipuran Traditional Village is a dense tourist spot with tourists visiting, and many satellites pass at four points (GPS1, GPS2, GPS3, GPS4) by forming a radial method while being observed at night. Data collection was carried out on January 16-21, 2020, with a Universal Transverse Mercator (UTM) coordinate projection system for zone 50s, and the four data were corrected by CORS located in Mataram, NTB under the name CMAT, hereinafter as a binding point in other measurements. The data quality test was carried out using the KKH and KKV methods at each station to be controlled better.

Furthermore, scanning measurements were carried out using Terrestrial Laser Scanning (TLS) at controlled points. TLS (Topcon GLS-2000 series) using a density of 12.5 mm at each point of survey stations with standard mode. Between the two device survey stations, it should consider overlaps (30%-40%) to make registering easier. Then, it was continued to collect data using the photogrammetric method because it requires complete data information (Roofs that are not covered in scanning using TLS). The UAV used is a DJI Phantom 4 Pro Drone with 24 megapixels in JPEG files and has a battery life of up to 25 minutes. Flight planning with AOI ±11 hectares (Ha) considering front overlap and side overlap (75%, 65%), with a flight height of 70 m, was carried out in the morning (8.30-9.00) on January 18, 2020. It can be seen in Figure 2, which shows the results of the tie point, the point of establishment of the TLS, and the consequences of orthophoto. This paper focuses on House No. 5 because it will represent the research's overall objective, which explains that HDS and BIM technology can be used for conservation and reconstruction in the future.

![Figure 2. (left) distribution of control points, (right) control points in the house no 5.](image-url)
buildings. The following results from the two methods are depicted in Figure 3. The integration of point clouds obtained RMSE around 0.003 or 3 mm.

4.2. Model Validation
BIM model validation is carried out to provide trust to interested stakeholders. In this case, carried out at house No. 5, the results of point cloud integration are compared with ETS measurements to provide precise and accurate coordinates. Because in this case, conventional measures using a Total Station are still considered precise and accurate. Figure 4 provides information related to measurements in the field and coordinates in the point cloud.

Because it is forbidden to attach the target to the sacred statue, the installation of the target point does not interfere with the existing ornaments. Given that this village is the cleanest and has the highest spiritual level, this is accomplished by affixing the target to the measuring sign. The RMSE of the comparison results at all points is 0-2 mm. Furthermore, point clouds are validated using the BIM model created from existing point clouds data. The outcomes of the point cloud comparison with the BIM
model. The size dimension comparison information provided in the BIM modeling is then compared to Point Clouds. The size comparison results in an RMSE of about 0.019 m. (19 mm).

4.3. Conservation and Reconstruction activities

BIM modeling can provide information related to spatial and temporal dimensions, legal and customary [22],[23]. However, conservation activities need presentations related to visualization and digitization that can provide historical information. This preservation can last a long time, so there is the possibility of a conflict, be it change, erasure, or shifting youth's thinking about cultural heritage. Figure 3 provides the results of 3D modeling with BIM for Conservation activities.

![Figure 3: 3D modeling with BIM for Conservation activities](image)

**Figure 3.** 3D modeling with BIM for Conservation activities

Then to reconstruct historical buildings, it can stake out by looking at position data (x,y,z coordinates), traditional semantic information, and cultural space information. Figure 4.9 provides information on coordinate positions for preparation for reconstruction activities.

![Figure 4: Coordinate positions for reconstruction activities](image)

**Figure 4.** Coordinate positions for reconstruction activities

![Figure 5: Spatial information in Balinese customary for conservation activities](image)

**Figure 5.** Spatial information in Balinese customary for conservation activities

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5. Conclusion
The following information may be obtained based on the analysis findings: (a) Various data may be inventoried in digitalization using BIM technology. All of the data is integrated and provides personalized semantic information. As a result, cultural heritage information will not be altered or erased. (b) The RMSE for point cloud validation is 0.2 mm, and the RMSE for comparison of point cloud dimensions with the BIM model is 0.019 m. (c) An accurate BIM model can be used as a model for conservation actions by displaying the usual semantic information and providing information about its position and dimensions; (d) The role of surveyors in the conservation and reconstruction of historic buildings becomes clear by using the High Definition Surveying and Scan to BIM method approaches to take a holistic inventory of digital data related to historical building information. Using the BIM approach has provided information on customary semantics and visualizations associated with the representation of the Penglipuran traditional village. The community can find out historical information on the traditional buildings in Penglipuran Village.

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