Monitoring Work Progress of Dam Construction based on Photogrammetric Point Clouds and BIM: Practical Approach to Teaching Industry

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ABSTRACT:

Industry 4.0 encompasses a range of ideas, technologies, and procedures that impact engineering education and other fields. Building information modeling (BIM) has become a widely adopted practice in Indonesia's construction industry, prompting polytechnic universities to incorporate BIM skills and concepts into their construction engineering and management degree programs. Nowdays, more than 50 dam construction works occurred in Indonesia from 2014-2024. Monitoring progress regularly is crucial to ensure a construction project's successful completion. This can be done by visually tracking the project's advancement, which enables the identification of any changes or deviations that occur. Accurate measurement data is essential for reliable progress management, as it allows for the prediction of future project success or failure. Image-based object detection is highly beneficial for retrieving site information and monitoring construction progress. To monitor the progress of a construction project, comparisons between the building's as-built and as-planned states are necessary. BIM is employed to establish the intended condition of a building by providing information regarding its geometric characteristics and construction schedule. In this paper, we present a novel method for producing a point cloud that accurately represents the dam building site using photogrammetry. To overcome the limitation of capturing photographs from every possible angle at a construction site, we employ a combination of structure from motion and control points. This approach allows us to generate a scaled point cloud in a standardized coordinate system. The building's as-built and as-planned states are then compared using this point cloud. Structure from Motion (SfM) disparity maps are fused to create dense point clouds, which are then compared to the goal state for updating 4D BIM. This makes it possible to identify missing building components. To validate the presence of building elements, a secondary examination is conducted using the positions in front of and behind the model planes constructed as per the original blueprint. The research paper explores potential approaches and presents empirical results obtained from an actual case study.

1. INTRODUCTION

Industry 4.0 encompasses a range of ideas, technologies, and procedures that impact engineering education and other fields. BIM has become a widely adopted practice in Indonesia's construction industry, prompting polytechnic universities to incorporate BIM skills and concepts into their construction engineering and management degree programs. Infrastructure development has been a significant focus of the Joko Widodo administration since he took office as President of Indonesia in 2014. One of the essential infrastructures that have been the government's primary concern is the construction of dams, which is considered a solution to overcome the problem of water shortage in several regions in Indonesia. He targets that by 2024, more than 50 new dams will be completed across Indonesia. Large-scale dam construction progress monitoring has never been easy. Dams are extremely complex constructions made from superb civil engineering, outstanding engineering performance, the technology utilized for irrigation, rainwater harvesting, and generating energy through turbine propulsion has been continuously refined and advanced over numerous years. For a variety of causes, the real construction (as-built) of dams may deviate from the original calculations made during the initial design phase (as-planned). In order to secure and maintain the structure's progress, close to real-time structure monitoring is required. To address this need, Jakarta State Polytechnic and construction service providers in Indonesia collaborated on research that compared the learning outcomes of polytechnic programs with industry requirements, developing a framework for integrating BIM content into undergraduate programs. In order to support the control of construction progress, BIM and surveying techniques have been deployed. The use of BIM will take over in the future. That indicates that a model will be available that contains details about the building's shape, its construction timeline, and its component parts' characteristics. The monitoring procedure must be applied directly to BIM in order to update the model depending on deviations found in the plans (Tuttas, S., et al., 2014). An automated surveillance system is employed to capture the current state of the building at a specific time interval (as-built), with the capability to identify any deviations from the original design (as-planned) documented in the BIM. The discovered deviations then result in modifications to the construction plan, such as adjusting the timeline to better accommodate delays. To facilitate the monitoring of construction progress at the Margatiga dam in Lampung Province, this research focuses on exploring the utilization of photogrammetric point clouds and BIM. This is crucial due to the limited accessibility of dams and the time-consuming nature of inspections using traditional methods. The study aims to deliver near real-time information for effective project oversight. As a result, deploying an unmanned aerial vehicle (UAV) to conduct a visual examination is considered more appropriate (Colomina and Molina 2014; Ellenberg., et al. 2015; Vetrivel et al. 2015). UAVs can aid in monitoring construction activities by utilizing their capability to carry cameras and capture high-quality videos. The UAVs can be operated automatically using advanced detectors, software, and GPS, which can be programmed in a stable, multi-tasking state. Recent studies for tracking data collecting with photogrammetric point clouds and BIM for construction progress (Greeshma, A. S., & Edayadiyil, J. B. (2022); Qureshi, A. H. et al. 2023) are available. Photogrammetric techniques are used to acquire the as-built point clouds (Tan, Y. et al., 2021; Nevalainen O., et al., 2017; Torres-Sanchez, J. et al., 2018). The idea of automated building progress monitoring using geometric restrictions based on BIM and photogrammetric point clouds was explained by Braun A. et al. (2015). In order to explore the potential of UAV in tying BIM to the real world and increasing productivity, Dupont, Q. F. et al (2017) provides prospective uses of UAVs along the construction value chain. UAVs were initially employed to acquire an as-built 3D model, which was then contrasted with an as-planned 4D model in a BIM setting (Rachmawati, T., & Kim, S. 2022).

2. METHOD

2.1 Study Area

This research provides a summary of the Margatiga Dam's major construction regions. The following topics are covered in the case study:

1. Regular monitoring of the primary dam structure through the utilization of photogrammetric point clouds and BIM.
2. Validation of the earthworks at the abstraction weir and earth-fill embankment dam is conducted through the integration of building information models (BIM) to facilitate monitoring.

The Margatiga Dam is situated within the Trisinar and Jemanten villages, specifically in the Margatiga District of the Lampung Timur Regency in Lampung Province. The irrigation area is expected to be 10.950 hectares, with a total capacity of 75 million cubic meters of water. The dam is being built to achieve national food and water security goals.

Figure 1: The location of the study

2.2 Image Triangulation

For metric reconstruction based on photographs, two fundamental requirements are the calibration of the camera and the proper orientation of the images. A concept that matches the circumstances on a building site with successive and overlapping photos produced from a tiny UAV is used for image orientation. During the stages of image orientation, DSM generation, and orthophoto creation, automation is increasingly required and practical. However, human engagement is still required for accurate feature extraction. When conducting field surveys using UAV systems for image-based data collection, certain tasks are typically involved. These include flight or mission planning, capturing pictures, calibrating the camera, orienting the images, and extracting 3D information through image processing. If necessary and available, ground control points (GCPs) are also measured to facilitate accurate geo-referencing. The operation, which encompasses flight and data collection, is organized using dedicated software. It commences by identifying the study area and determining the ground sample distance (GSD). Additionally, it involves gaining insights into the intrinsic characteristics of the digital camera installed for the task. Calibrating the camera and orienting images necessitate recognizing standard features visible in as many photographs as feasible to ascertain the intrinsic and extrinsic parameters of the camera to adjust for any image distortions. Aerial triangulation (AT) is used in aerial photogrammetry to accomplish this. A UAV flying at 150 meters collected many aerial images of the area with a scale about 1:5000. They corresponded to an 8-point GPS networks with 80% overlap and 70% side lap. According to the research conducted by Mora et al. in 2003, the residual bundle block adjustment for ground control points (GCPs) and tie points used for outer orientation resulted in an error of only a few centimeters. Currently, digital photogrammetric methods represent the most efficient means of automatically generating terrain models and orthophotos, which are critical for monitoring construction progress (Bitelli et al., 2004). For image processing, we utilized Agisoft Metashape software, which included alignment, progressive selection, and generating a thick cloud (Javernick et al., 2014; Uysal et al., 2015). We selected six photos with varied acquisition altitudes for aero-triangulation processing to examine the accuracy of relationship with the GCPs employed at the indirect orientation of sensor. The number of GCPs used in this test ranged from 2 to the maximum visibility in the image. The sensor orientation was carried out for each number of control points, and RMSE and the accuracy of the feasibled orientation instruments were recorded.

2.3 3D Mesh Modeling

Processing of photogrammetric data acquisition results of the Margatiga Dam Complex was carried out using Agisoft Metashape software. In Agisoft Metashape, the acquisition results were combined using the concept of Structure from Motion (SfM). In 3D mesh modeling, triangulation is the process of dividing a 3D surface or volume into a series of interconnected triangles. This is done to create a mesh or network of interconnected points, which can be used to create a 3D model of an object or scene. Triangulation involves creating triangles by connecting three or more vertices or points in 3D space. The vertices are typically determined by the intersection of multiple images or by scanning an object with a 3D scanner.

Figure 2: Alignment photos over the Dam area

The process of triangulation involves determining the precise location of each vertex and the angles and distances between them. Delaunay triangulation: This is a commonly used method that ensures that all triangles are well-shaped and have similar angles. Build Dense Clouds; this process continues the previous cycle, namely Alignment Photo. Build Dense Clouds combines the points generated by Alignment Photo by interpolating these points to form a 3D object which is still a point cloud. The results of Build Dense Clouds that have high quality will also facilitate processing in Build Mesh. In this process, point clouds are used as data sources for interpolating or reconstructing so that they become 3D shapes. The resulting mesh from the photogrammetric process represents the object or scene as a 3D model with a set of interconnected triangles, providing a detailed and accurate representation that can be used for analysis and visualization purposes. The resulting surface mesh may contain noise or roughness that needs to be smoothed or refined to improve its quality.

Figure 3: Build mesh image

A point cloud is generated by utilizing UAV image data obtained from a narrow unmanned aerial vehicle (UAV) equipped with a digital camera. The UAV-generated point cloud is typically in an unspecified reference frame that must be aligned with the coordinate system through the use of ground control points (GCPs). However, the point cloud obtained may exhibit sparse coverage in areas with complicated vegetation and land uses that have a uniform network. The area study of the Margatiga dam consists of various features such as farms, buildings, trees, and roads covered with asphalt or stone. The point clouds generated are accurate for a wide range of targets, including buildings, roads, and designated test sites. However, surfaces with vegetation, such as trees, shrubs, and grass, pose challenges as they are less stable targets for accurate point cloud representation.

3. RESULT AND DISCUSSION

3.1 As-Planned Model

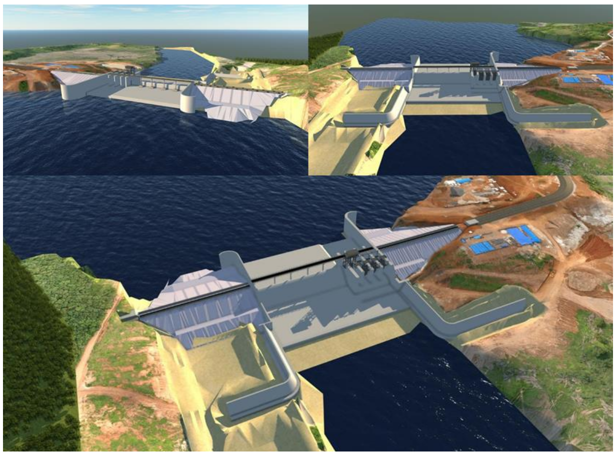

Figure 4: As-planned model

In order to monitor the progress of a structure and ensure consistency, it is necessary to automatically by comparing the as-planned information in BIM with the real as-built state of the building, it becomes possible to integrate the as-planned BIM information into the inspection process of actual as-built model.

3.2 The BIM Model and the Mesh Model are compared

This research utilized a BIM model that was specific to the construction period, created using the single dates of the construction elements as planned data, the 3D model derived from the as-built 3D point cloud data is utilized alongside the constructed 3D model. The 3D mesh model, generated from the 3D point cloud, is imported into the BIM model to facilitate a comparison between these two models. Overlaying BIM and mesh models can be a valuable tool for progress monitoring in construction projects. By aligning the two models, it is possible to compare the as-built condition of the construction site with the original design and identify any discrepancies or deviations that may affect the project schedule or budget.

The BIM model can provide a baseline for the construction progress, with information such as planned completion dates and quantities of materials required. The mesh model, on the other hand, can be utilized to visually represent and observe the real-time advancement of the construction job, with the surface geometry providing a clear visual representation of the physical state of the construction site. Overlaying the two models can help identify areas where the construction work is falling behind schedule or where changes have been made to the original design. It can also help identify any potential clashes or conflicts between the different systems or components of the building. Comparing BIM and mesh models for progress monitoring can provide a comprehensive and accurate view of the construction project, allowing for better decision-making and management of resources to ensure the timely and efficient completion of the project.

3.3 Project Evaluation Progress Application Plan

To create the study's basic plan, the as-built data collection date was determined by referencing the concrete deposition date and progress schedule. This schedule began with the actual concrete deposition once building began and continued until the division districts matched. Regarding the progress of timeline and collection plan, Figure 5 depicts the as-built data confirmation and collection dates.

Figure 5: Illustrates the as-built data

To create the model of as-planned visualization, a BIM template in 3D scene was produced based on the data collection plan, as shown in Figure 6. Using the BIM template calculation function, the template reflects what the project schedule anticipated and estimates the amount of construction that was scheduled to be accomplished at the appropriate project milestones.

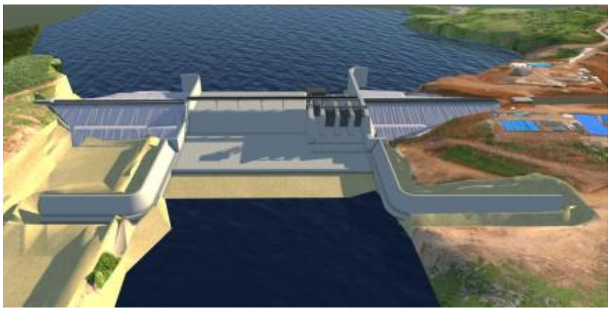

Figure 6: Illustrates the as-planned data

3.3.1 Visualization of project status and work progress comparison.

The data acquisition schedule for the case study site was followed to collect as-built data, which was then used to create a the matching model of 3D point cloud. During the scanning of the site, the density model have to be "low" as the site was large and there was a high chance of matching errors. To show the progress of the current study, it was necessary to bring together the 3D models set up on the as-planned and as-built data in the single place. This was achieved by transforming the final result of 3D mesh model, generated by matching 3D point clouds, In a single place, to be used alongside a BIM-based 3D model. Figure 7 depicts how the present level of the as-built image collection was visualized and compared to the progress timetable. This was accomplished by overlapping the 3D models and visually inspecting where differences were occurring.

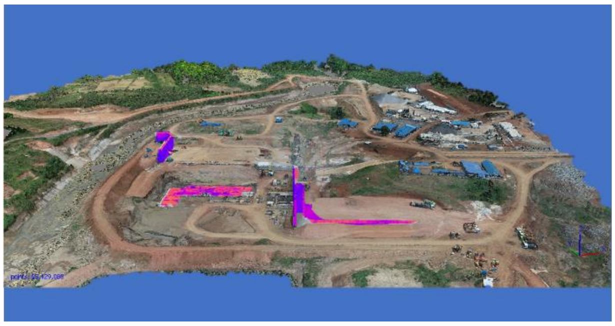

Figure 7: BIM-based as-built quantity calculation in the case study area.

Extraction of volume data from the BIM model is one method for comparing volumes for the proposed procedure. This model collects information on the quantity of each member during the design stage, allowing it to obtain volume information for the process. The data suggest that the percentages for the confirmed locations are close to 95%. The results of the technique presented in this study may differ based on the user's proficiency in modeling, the extent of missing data in data match of 3D point cloud, and the level of overlap with the as-built data. The accuracy of the resulting 3D model was verified by comparing it with the concrete measurements obtained on-site for each schedule of the as-built data.

3.3.2 In cut and fill work, photogrammetry and TS are compared.

We made efforts to process elevation data from the exact measurement on the as-built model compared to field measurement data on cutted anf filled job using the Total Station (TS) tool so that it becomes information that can be compared to see the accuracy of carrying out measurements using UAV. Figure 8 below is the as-planned data; the red line is the location used as a sample to compare the UAV and TS work results. The green part is the next job data we can do the same analysis. Because we realize that there is a lack of information related to construction work, such as the actual budget, time for planning and construction implementation, contract documents, and so on. Then a job comparison is obtained, as shown in Figure 9.

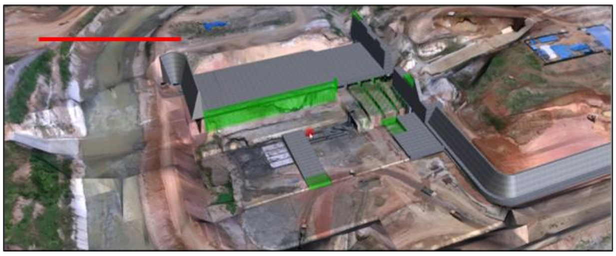

Figure 8: as-planned model at case study area

Using the Total Station for site surveying to precisely map reference locations around the research area is a common approach to getting "ground truth." Using error propagation theory, the accuracy of Total Station data was determined to be 1 cm in location and 2 cm in elevation. In order to gauge the precision of the georeferenced point clouds and examine their influence on the accuracy of GCPs, we conducted a comparison with a reference cross-section derived from the Total Station dataset. Validation on cutted-filled works are comparable across photogrammetry and total station.

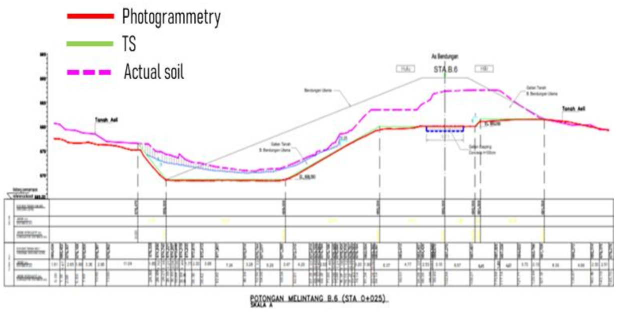

Figure 9: Comparison of photogrammetry technique and total station in cross section

Our next step will be to calculate the Evaluation of Progress Status based on project contract documents, such as The Earned Value Management System (EVMS), The evaluation of project integrity, considering both time and cost, enables project risk assessment using the Earned Value Management System. The assessment of project integrity involves analyzing planned earn value, project earn value, actual earn value, variances, and performance indices. Schedule Performance Index and Cost Performance Index are analyzed with variance, including schedule and cost.

3.4 Future Perspective

Some ideas for further research related to this topic, such as better domain mesh generation, adaptive mesh refinement, solving potential using General-Purpose computing on Graphics Processing Units (GPGPU), or domain partitioning, could raise computational efficiency enough for real-time motion control implementation with AI. AI can be used in construction monitoring progress in several ways. One of the primary methods is using computer vision algorithms, which can analyze images and videos taken on the construction site to track progress and identify potential problems. These algorithms can also detect safety hazards and monitor compliance with safety regulations. Another way AI can be used in construction monitoring progress is through sensors and IoT (Internet of Things) devices. These devices can be placed throughout the construction site to monitor temperature, humidity, and vibration. This data can be analyzed using AI algorithms to identify potential issues or track progress, for example, AI can be used to provide a'map' of the building to ease navigation and provide sufficient navigation data, along with localization, to enable a proper autonomous flight plan to be developed for drone activities within a building. Drones flying on a construction site are not confined to a single drone. Several autonomous drones operating together can easily boost productivity.

Additionally, AI can analyze data from scheduling software and other project management tools to identify potential delays or issues. This can assist project managers in making improved allocation of resources and scheduling decisions to keep the project on track and deliver actual productivity advantages in developing an integrated environment where the data site is linked to an existing BIM software. Overall, using AI in construction monitoring progress can help improve efficiency, reduce costs, and improve safety on construction sites.

4. CONCLUSION

We employ photogrammetry to generate the point cloud for the as-built data since it offers greater flexibility compared to a laser scanner. in terms of accessible acquisition sites and low cost. Material overload, construction failure risk, and job redundancy can all be avoided by closely monitoring construction progress. Over the study area, the point cloud percentages for areas covered are close to 95%. We must consider GCPs distribution, image overlap, UAV altitude, the optical of sensor resolution, and calculating the Evaluation of Progress Status based on project contract documents, such as The Earned Value Management System (EVMS), to analyze project risk by taking into account time and cost to evaluate the project's integrity for future development based on AI.

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