

RESEARCH ARTICLE

Integrated Information System for Periodic Construction Progress Monitoring: Utilizing UAV, Photogrammetry, and BIM for Enhanced Decision-Making and Optimization

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This study aims to develop a framework to semi-automate construction progress monitoring by integrating building information modeling (BIM), unmanned aerial vehicle (UAV) photogrammetry, and point-cloud-based comparison algorithms to improve accuracy and efficiency in construction management. The framework compares as-built conditions with as-planned 4-dimensional BIM models to quantitatively evaluate progress and visualize deviations. It incorporates UAV-based data acquisition, centimeter-level point-cloud generation and georeferencing (root mean square error ≈ 0.038 m), and a C# algorithm integrated within Autodesk Navisworks for automated element-level detection of completed, ongoing, and pending works. The method was validated on a residential building project, achieving 88.2% accuracy, 89.4% precision, 85.7% recall, and 87.5% F1-score, while reducing manual data-processing time by about 35%. The framework effectively identified construction delays—33, 45, and 63 d for the ground-, first-, and second-floor slabs, respectively—demonstrating its capability to deliver accurate, efficient, and visually interpretable progress assessments suitable for time- and cost-conscious construction projects.

Introduction

The construction sector plays a crucial role in every nation's economy and contributes a substantial share of gross domestic products. However, despite ongoing digital transformation efforts, overall productivity in the sector remains stagnant. This stagnation limits sustainable economic growth. Improving productivity therefore requires more efficient progress-monitoring systems that can provide timely and reliable project-status information. Progress monitoring in construction projects is essential for identifying discrepancies between planned and actual progress and for implementing corrective measures [1]. Nevertheless, many construction projects still rely on manual progress reporting, which delays corrective action and reduces accuracy.

Conventional monitoring methods—periodic site visits, manual surveys, and paper-based reporting—are time-consuming, error-prone, and costly [2]. These approaches often lack up-to-date information and depend heavily on subjective assessments, which can delay decision-making and increase project costs. Consequently, project teams devote substantial time and resources to collecting, validating, and reporting progress data [3]. Inadequate progress

monitoring is a key contributor to project delays, as undetected issues accumulate over time [4]. Delays often stem from late decision-making, rework due to construction errors, and payment or change-order bottlenecks [5]. Improved, timely monitoring can help mitigate these causes by supporting quicker managerial responses [6].

Recent advances in digital tools—particularly building information modeling (BIM), unmanned aerial vehicles (UAVs), and photogrammetry—enable more frequent and data-driven site assessments [7]. These technologies can automate data capture and visualize project status, thereby enhancing decision-making. However, achieving fully real-time automation remains challenging due to data-processing and synchronization constraints. UAVs equipped with high-resolution cameras have proven effective for rapid, low-cost site documentation and inspection [8,9]. UAV-based photogrammetry, often employing structure-from-motion (SfM) algorithms, reconstructs accurate 3-dimensional (3D) models from overlapping aerial images [10]. Although UAV photogrammetry can enhance visibility of built elements greatly [11], these technologies alone are insufficient for tracking on-site progress. Manual interpretation and reporting are still required to align as-built conditions with the planned schedule [12].

Citation: Bhattacharjee A, Rana MJ, Zaman AAU, Dang H. Integrated Information System for Periodic Construction Progress Monitoring: Utilizing UAV, Photogrammetry, and BIM for Enhanced Decision-Making and Optimization. *Civil Eng. Sci.* 2026;2:Article 0022. <https://doi.org/10.34133/cesci.0022>

Submitted 12 August 2025

Revised 19 May 2026

Accepted 20 May 2026

Published 17 June 2026

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Therefore, the objective of this study is to develop a semi-automated framework that compares the as-planned BIM with the as-built UAV-derived point-cloud model. The framework integrates UAV photogrammetry with 4D BIM to systematically monitor construction progress, quantify deviations, and visualize discrepancies between planned and actual conditions. A residential building project under construction was selected as a case study to validate the proposed workflow and to investigate common issues related to progress monitoring in practice.

Although the integration of UAV photogrammetry and BIM for construction progress monitoring has been explored in earlier studies, most existing frameworks rely on separate software environments, manual data registration, or expensive sensors. The novelty of this research lies in the development of a semi-automated, cost-effective framework that operates directly within Autodesk Navisworks through a C#-based algorithm. This approach minimizes data-transfer errors, reduces processing time, and enables automated comparison between as-built point clouds and as-planned BIM elements. Unlike previous studies, the proposed method emphasizes practical usability and affordability, employing low-cost UAV hardware and easily repeatable workflows suitable for resource-constrained projects. These contributions advance the automation, data accuracy, and accessibility of digital progress monitoring in real-world construction settings.

The developed methodology automates the integration of UAV data and BIM elements within Autodesk Navisworks, enabling element-level detection of completed, ongoing, and pending works. This process allows for accurate identification of temporal delays and percentage completion without extensive manual measurement. The results from the 5-month monitoring period demonstrate the capability of the framework to reveal construction delays and incomplete areas in an interpretable, color-coded format within the BIM environment.

The proposed approach is adaptable to projects of varying scales and resource levels, offering a practical pathway for organizations seeking to transition from traditional manual progress tracking to digital, data-driven monitoring. By providing

clear visual and quantitative insights into project status, the framework supports faster decision-making, reduces reporting time, and enhances the effectiveness of construction management and schedule control.

Literature Review

This section summarizes key research related to construction progress monitoring using evolving technologies: UAV, photogrammetry, BIM, and their combined applications. These studies highlight the progress made in employing UAV, photogrammetry, and BIM for tracking construction progress, as well as their capacity to improve the effectiveness of construction management.

UAV-based photogrammetry for construction progress monitoring

Several studies have explored the use of UAV technology and photogrammetry for construction progress monitoring. Pix4Dmapper was used to demonstrate how UAVs combined with photogrammetric techniques could systematically capture, process, and monitor monthly construction progress over a 3-month period [13]. This methodology facilitated precise control and visual documentation of the construction site. Similarly, a method that utilizes photogrammetric surveys to capture construction site conditions is proposed [14]. They generated dense point clouds using semi-global matching (SGM) and compared these with a 4D BIM model using a cell grid-based approach to assess the point-to-surface distances. Furthermore, Jacob-Loyola et al. [15] used UAV and photogrammetric point clouds to compare the planned versus actual progress in a reinforced concrete residential building project. The UAV-based progress monitoring provided timely updates and enhanced the accuracy of progress tracking. Samsami et al. [16] focused on estimating the work completed in linear road construction projects by using UAV and computer vision techniques, further demonstrating UAV's versatility in capturing and analyzing construction progress across different project types.

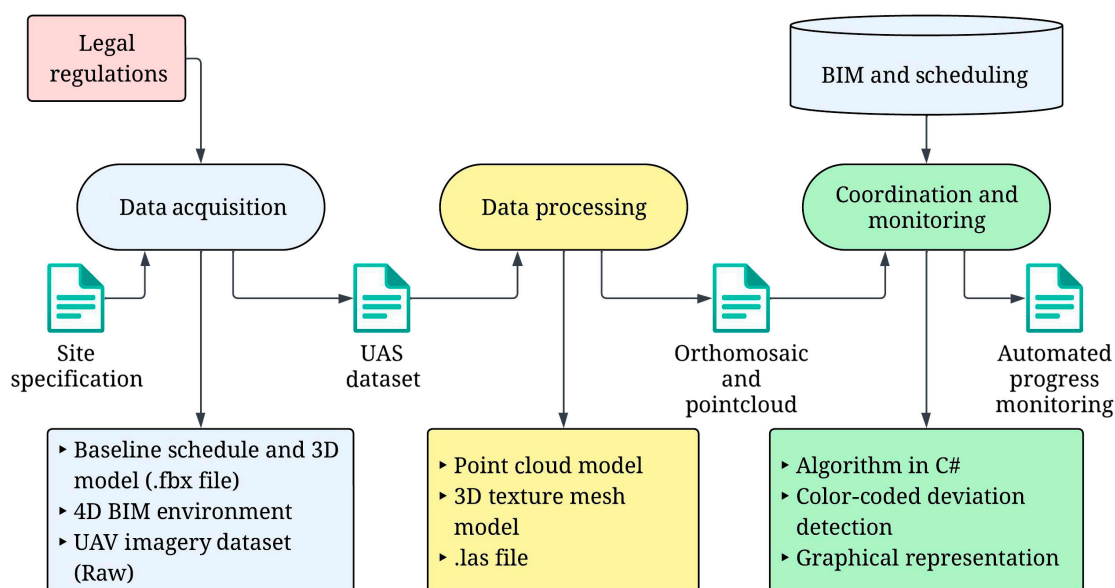


Fig. 1. Overall workflow of the research.

BIM and progress monitoring

BIM has also been explored extensively for its role in construction progress monitoring. In particular, a framework that utilized real-time videography to estimate work completion on structural elements like beams, columns, and walls is developed [17]. These data were then compared with the as-planned work using MATLAB's advanced computational technologies.

Integration of UAV, photogrammetry, and BIM in progress monitoring

The integration of UAV, photogrammetry, and BIM technologies has shown substantial potential in automating and enhancing the construction progress-monitoring process. Golparvar-Fard et al. [18] developed a framework that utilized unordered photographs taken by UAV and 360° cameras to create a 3D point cloud of the as-built model. This point cloud was then compared with the as-planned industry foundation class (IFC) model within a 4D BIM environment, showcasing the synergy between these technologies for more efficient progress tracking. Similarly, Deng et al. [19] proposed a framework for tile work calculation by integrating real-time videography and computer vision technologies, further demonstrating the effectiveness of integrating multiple technologies for tracking specific construction activities.

Gaps and opportunities for future research

Despite the substantial advancements in automated construction progress monitoring, several gaps remain. Notably, there is a lack of studies exploring the alignment of these technologies with core project management principles, particularly time, cost, and scope management. Most progress-monitoring methods

focus on tracking physical progress but fail to connect directly with established project management methodologies like the project management body of knowledge (PMBOK), as highlighted by the authors [20]. The comparison between as-built and as-planned project schedules is a prevalent methodology for identifying delays; however, there is a lack of research into tools and frameworks that integrate these comparisons with simplified baseline schedules. Extant methods frequently rely on sophisticated software, which may not be accessible or user-friendly for all project types, particularly in smaller-scale projects or less developed regions. The necessity for a more straightforward and universally applicable baseline schedule tool remains unaddressed [21]. Nevertheless, there is a scarcity of studies examining the optimal integration of these technologies to create synergistic effects and enhance project outcomes. For instance, the advantages of color-coded discrepancies and visual data that is comprehensible to all involved parties remain largely unexplored. A substantial research gap exists in the development of straightforward, adaptable frameworks for progress monitoring that can be integrated with conventional project management methodologies. These frameworks should be universally applicable across diverse project scales and types, including those in developing nations. Such a framework would enable the construction industry to more effectively adapt to emerging technologies while maintaining the familiarity of traditional practices. The scalability of this framework from small-scale to large-scale projects necessitates further investigation to ensure comprehensive applicability [22].

Based on the major works and research gaps related to this topic, it is evident that the UAV utilization in a construction



Fig. 2. Selected site for this research. Acquisition: 2026 14 April. Imagery ©2026 Airbus, Maxar Technologies, Map data ©2026. https://www.google.com/maps/@22.9015574,89.4995904,87m/data=!3m1!1e3?entry=tту&g_ep=EgoyMDI2MDYwOS4wKXMDSoASAFQAw%3D%3D

site has been launched within this decade. The whole construction industry has not adopted it to track the construction progress of a project. So, a numerous number of reexaminations of this automated process are still required.

Methodology

To address the challenges in construction progress monitoring, this study developed a comprehensive framework that integrates BIM with UAV photogrammetry-derived point cloud data for periodic tracking. This framework is built upon existing research [23] by introducing a novel subframework for detecting intersections between point cloud data and a 4D BIM simulation within the Navisworks environment. The proposed methodology involves the development of an algorithm to automate the process of identifying overlaps between BIM components and captured point cloud data. In contrast to previous approaches, this framework utilizes a C#-based algorithm that detects intersections between

a point cloud and BIM elements. In the absence of an intersection, the algorithm highlights the BIM component by changing its color to red, thereby visually indicating areas not represented in the point cloud data. Conversely, the components that intersect with the point cloud maintain their original color, providing a clear and periodic visual representation of the construction progress.

A systematic approach has been developed to measure periodic construction progress monitoring. This workflow integrates UAV photogrammetry with BIM technology. This workflow (Fig. 1) consists of 4 essential stages: firstly, the development of a flight strategy with predetermined UAV trajectories to ensure consistent inspection paths; secondly, the establishment of guidance parameters to direct pilots in capturing precise and relevant images of construction surfaces; thirdly, the processing of acquired data to generate photogrammetric models that accurately depict the current state of construction progress; and finally, the integration of these models into coordination software, enabling a thorough comparison with the planned construction schedule.

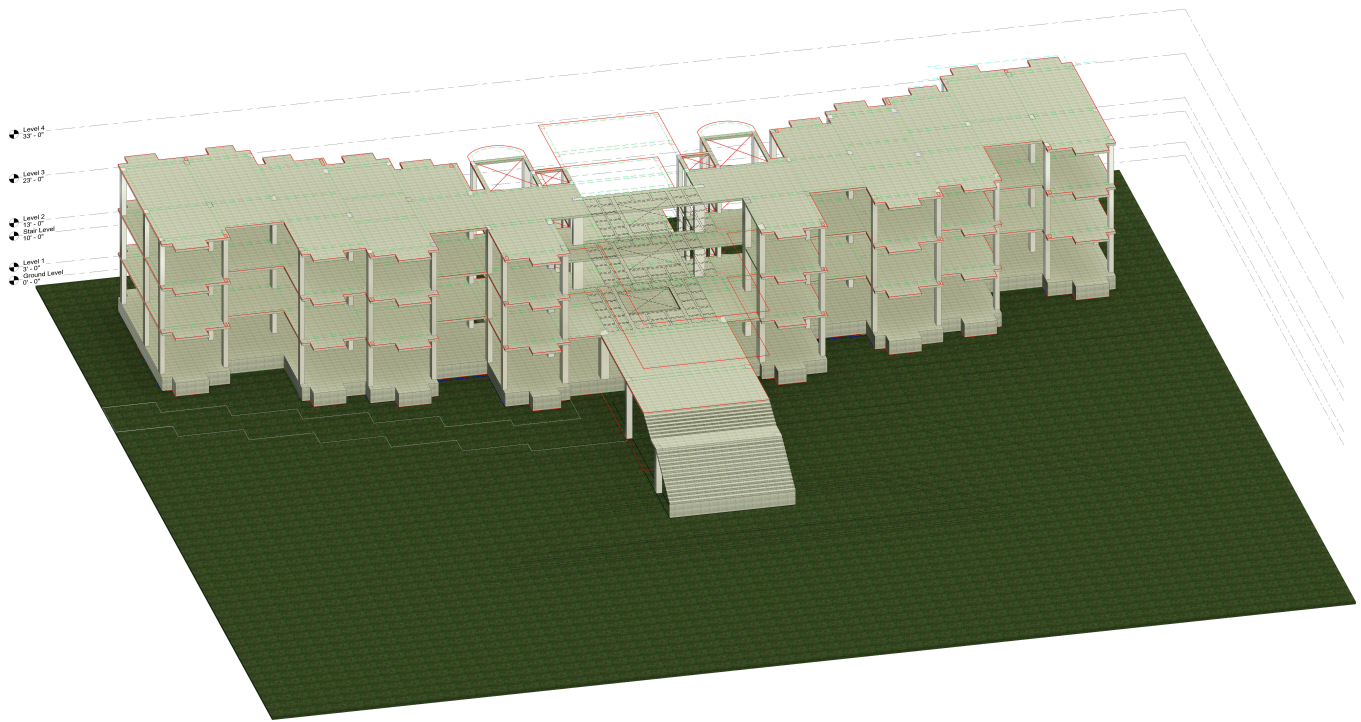


Fig. 3. BIM model of the case study site.

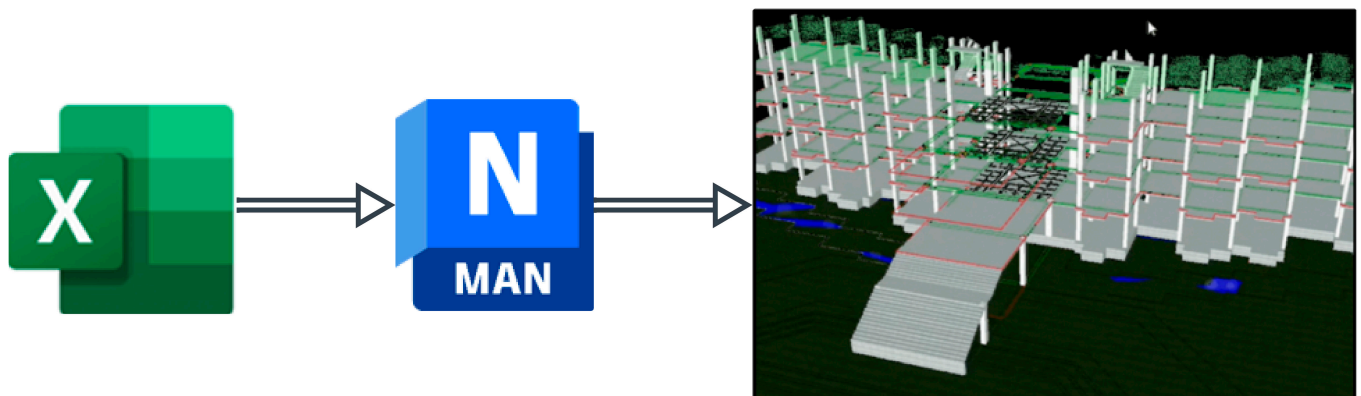
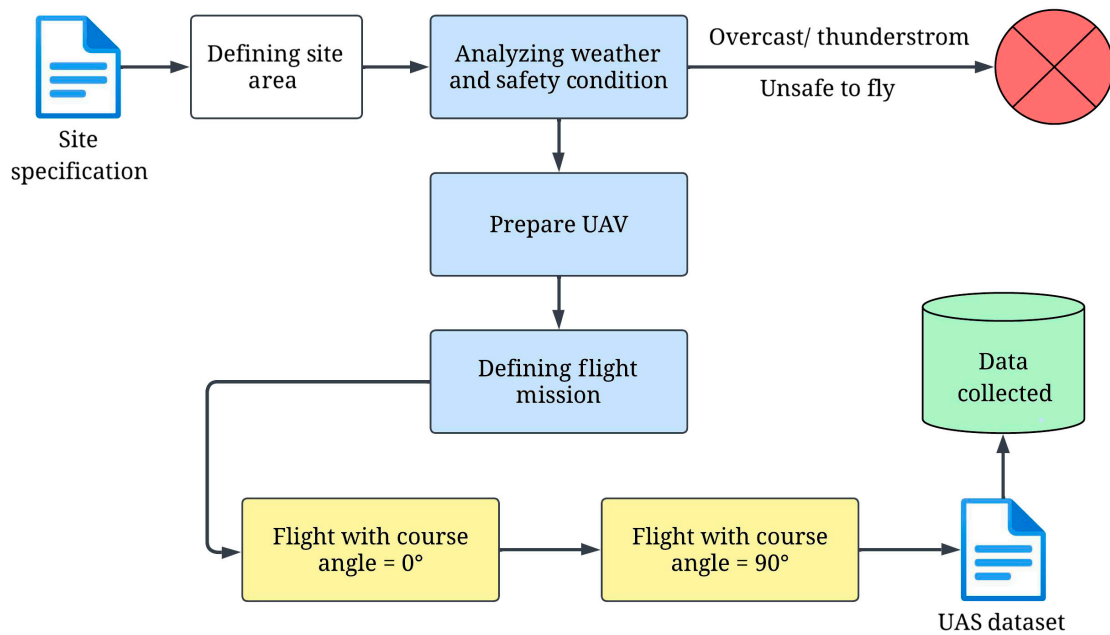


Fig. 4. Incorporating baseline schedule file in 4D BIM environment.

Table 1. Baseline schedule

Description	Planned start	Planned finish	Duration (days)	Planned (%)	Accomplished (%)
Ground floor slab	11-Aug-2023	30-Sep-2023	50	20	15
First floor slab	1-Oct-2023	30-Oct-2023	30	40	20
Second floor slab	31-Oct-2023	30-Nov-2023	31	60	30
Third floor slab	1-Dec-2023	30-Dec-2023	30	80	50
Fourth floor slab	31-Dec-2023	30-Jan-2024	31	100	60

**Fig. 5.** UAV data acquisition procedure.

The following section is divided into 3 sections, each corresponding to one of the 3 subtasks of the approach shown in Fig. 1: (a) data acquisition, (b) data processing, and (c) coordination and monitoring.

Data acquisition

The data acquisition process is an essential part of the total data-gathering operation. The procedure starts with the delineation of the specific region to be examined, which may vary depending on the stage of construction. For example, regions that are not currently being worked on may be left out, while zones that have important activities, such as pouring concrete, may need to be carefully considered to prevent any disruption to UAV operations. After establishing the data collecting area, the UAV software creates a flight plan that takes into account the specific features of the optical system, including the camera angle, field of vision, and course angles.

Site specification

The project titled “Construction of Foreign Student’s Dormitory & Visiting Faculty Accommodation” involves the development

of a 5-story building at Khulna University of Engineering and Technology (KUET), located in Khulna, Bangladesh (Fig. 2). This facility was designed to accommodate foreign students and visiting faculty members, providing them with modern living and working spaces. The case study building was located at the university campus at 22°54′05.4″ N latitude and 89°29′58.9″ E longitude.

BIM model creation and progress planning workflow

The BIM model for the construction of the 5-story Foreign Student’s Dormitory and Visiting Faculty Accommodation was developed using Autodesk Revit, as shown in Fig. 3. No BIM model had been created by the project professionals for this project, and no preexisting model was available. The development of the BIM model was based on 2D architectural plans, which were collected from the project architect and subsequently used to create the 3D BIM representation. This model was created in consultation with project professionals. This process entails the thorough integration of architectural and structural elements. It is meticulously modeled to accurately represent the design intent and construction specifications.

The baseline schedule, which serves as the project’s initial planned timeline against which progress is measured, was also

developed specifically for this research in consultation with project professionals, as no prior schedule was available. The schedule details the planned start and finish dates, duration,

and progress percentages for each slab level, both planned and completed. Its purpose is to integrate the project into a 4D BIM environment, enabling periodic tracking and visualization of construction progress.

Following the creation of the BIM model in Revit, it is subsequently uploaded to Autodesk Navisworks for the purpose of measurement and progress monitoring (Fig. 4). Navisworks facilitates the integration of the construction schedule from Table 1 into the BIM model, enabling continuous monitoring of construction progress in relation to the predetermined timeline. A baseline schedule was developed and incorporated into Navisworks for progress measurement within a specified timeframe.

Prior to departure, it is essential to evaluate meteorological and safety conditions, ensuring compliance with regulatory requirements regarding the maximum allowable wind velocities and any temporary restrictions on aircraft operations. The pilot must verify that the humidity and wind speed are within the operational parameters specified by the manufacturer. Excessive wind may impede the movement of the UAV and deplete the

Table 2. UAV workflow requirements

Parameters	Requirements
Flight paths	Rectangular to ensure 80% image overlap
Camera angle	Front movement camera angle -90° , side movement camera angle -45°
Image overlap	Front overlap 70–80%, side overlap 50–60%
Flight altitude	10–15 m
Image requirement	25 images per minute

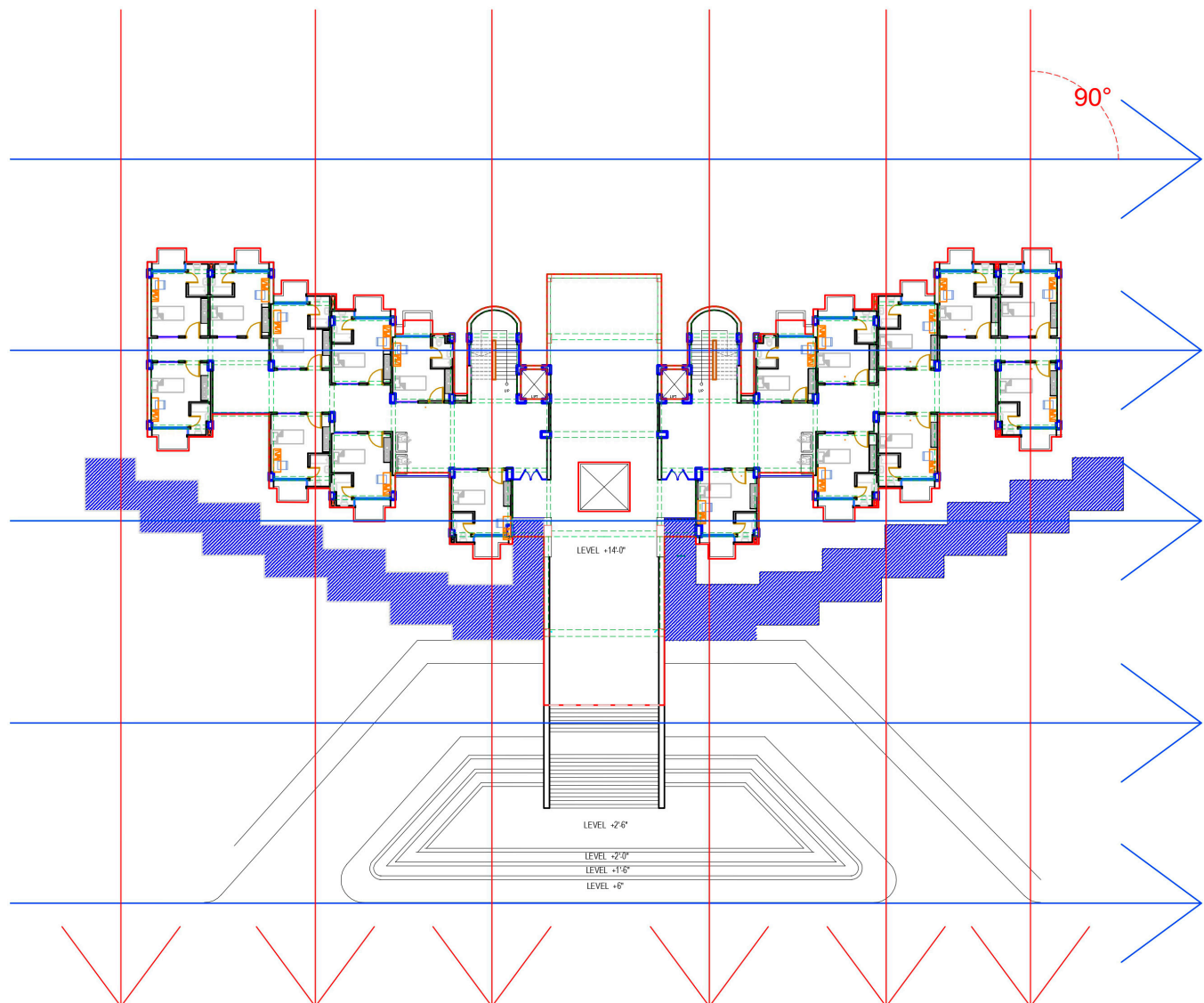


Fig. 6. Top view representation with flight path (course angle = 0° and 90°).

battery life, while high humidity can cause damage to the device. Once the conditions are determined to be safe, the UAV is prepared for flight by adhering to the required checklists and procedures. Furthermore, it is imperative to reassess the current

state of the construction site to identify any newly emerged obstacles, as conditions in construction environments can change rapidly. Figure 5 provides a comprehensive illustration of the procedure.

Table 3. Schedule and data

Flight schedule	Images	Status	Horizontal flight (-90°)	Vertical flight (-40°)	Altitude
7-Sept-2023	783	Successful	571	212	10 m
12-Sept-2023	N/A	Cancelled due to storm warning	N/A	N/A	N/A
30-Sept-2023	N/A	Cancelled due to high wind speed	N/A	N/A	N/A
1 to 31-Oct-2023	N/A	No tasks performed	N/A	N/A	N/A
2-Nov-2023	843	Successful	603	240	10 m
5-Nov-2023	N/A	Cancelled due to site obstruction	N/A	N/A	N/A
20-Nov-2023	N/A	Cancelled due to fog	N/A	N/A	N/A
23-Nov-2023	834	Successful	601	233	12 m
25-Nov-2023	432	Successful	298	134	12 m
2-Dec-2023	392	Successful	269	123	12 m
11-Dec-2023	533	Successful	376	157	12 m
12-Dec-2023	361	Successful	246	115	12 m
14-Dec-2023	301	Successful	202	99	12 m
1-Jan-2024	250	Successful	163	87	12 m
15-Jan-2024	N/A	Cancelled due to construction delays	N/A	N/A	N/A
1-Feb-2024	409	Successful	282	127	15 m



Fig. 7. Areal camera front movement -90° , altitude 10 m.

During operation, the UAV is guided toward the target structure, with the operator alternating between the drone's view and the live information displayed on the control panel. This information includes critical parameters such as elevation and velocity. Maintaining a steady speed and height is essential for the UAV to traverse flat trajectories on each side of the structure. The operator captures a sequence of images by sustaining a constant lateral velocity and triggering the camera at set intervals. After completing a horizontal run, the UAV moves upward to record the next series in the reverse direction,

ensuring both horizontal and vertical image overlap according to Table 2 [24].

The UAV follows a specific flight path consisting of 2 missions (Fig. 6). Initially, it executes a mission with a 0° course angle, primarily moving forward and backward. Subsequently, it performs a second mission at a 90° course angle, mainly shifting left and right. This 2-angle approach ensures image overlap on both the long and short sides. The UAV's height parameter serves as a reference point for elevating the device by one vertical increment while capturing the façade. Furthermore,



Fig. 8. Areal camera front movement -45° , altitude 10 m.

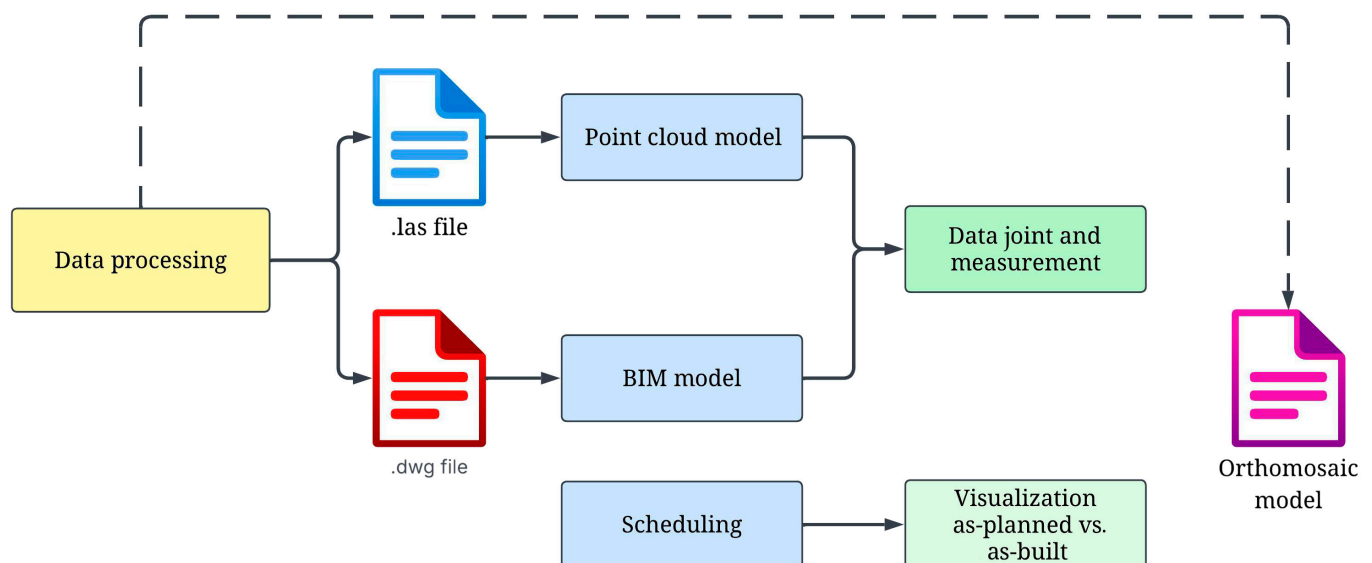


Fig. 9. Data analysis procedure.

the UAV must maintain a steady velocity to advance one vertical step forward along the top surface of the flight plane.

Collected data overview

The data-gathering procedure had a duration of 5 months, commencing on September 7th and ending on February 1st. Data were collected over a long period, covering different weather conditions and construction phases. This resulted in a complete and accurate dataset. Table 3 represents the project's evolution throughout time. Figures 7 and 8 show the image qualities.

During the monitoring period, multiple imagery collection flights could not proceed because of the various external circumstances. A storm alert caused the cancellation of a flight on 2023 September 12, whereas excessive wind speeds prevented another on 2023 September 30. The entire month of

October saw no activities being carried out, suggesting either a period of inaction or an inability to conduct imagery collection because of weather conditions or site limitations. An on-site obstruction led to flight cancellation on 2023 November 5, followed by another on 2023 November 20, due to thick fog. The interruptions persisted in January 2024, with a flight on January 15th being prevented by construction-related delays.

While flight planning software can simplify operational procedures, its reliance on GNSS (global navigation satellite system) positioning, which is susceptible to sensor precision and satellite signal strength, may result in errors, particularly during short-range missions. Therefore, operators must consider specific horizontal and vertical parameters as minimum requirements, striving for greater image overlap to ensure optimal quality results.

UAV data post-processing and point cloud generation

Data processing involves the subtask of preparing and transforming data in order to facilitate further analysis. The procedure adheres to a conventional photogrammetry approach and is shown in Fig. 9.

First, the UAV dataset, which includes georeferenced images, is obtained from the data storage. The first stage entails the meticulous positioning of these photographs, whereby similar spots present in many pictures are recognized and designated as matching the same place. By using conventional photogrammetry methods, the relative locations of each photograph are computed and combined to form a cohesive, high-resolution picture, akin to piecing together a puzzle. The anticipated precision in terms of dimensions and distances in these aligned pictures is around 0.1 to 0.3 times the size of a ground pixel. A ground pixel refers to the size that a pixel on the image sensor would occupy if it were projected back via the optical system onto the observed region.

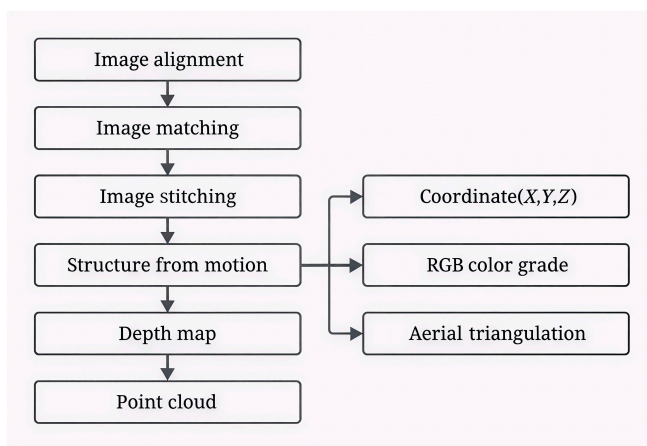


Fig. 10. Image processing workflow.



Fig. 11. Generation of point cloud and 3D texture mesh.

After aligning the pictures, they are compared with a selection of reference sites that have precise coordinates acquired by surveying. Accurately locating the aligned pictures in space is contingent upon completing this step. The accuracy of image placement is solely dependent on the accuracy of Global Positioning System (GPS) data, which can vary due to factors like location and satellite availability. This can result in accuracy levels without considering specific points of reference. The remaining reference locations are then used to validate accuracy by comparing their established coordinates with those obtained from the unmanned aerial system (UAS) dataset. If the degree of precision is determined to be

insufficient, the process of referencing is repeated until the appropriate level of accuracy is attained.

Subsequently, an intricate point cloud is produced by using the aligned photographs and data from the UAV's optical system, which encompasses specific information such as sensor size, focal length, angular resolution, and lens distortion. The compact point cloud is then linked together to create a mesh, which accurately represents the surface of the observed region. By utilizing workflow in Fig. 10, an orthomosaic is generated from this mesh, which is an image that has been adjusted to guarantee precise measurements of distances and angles. This

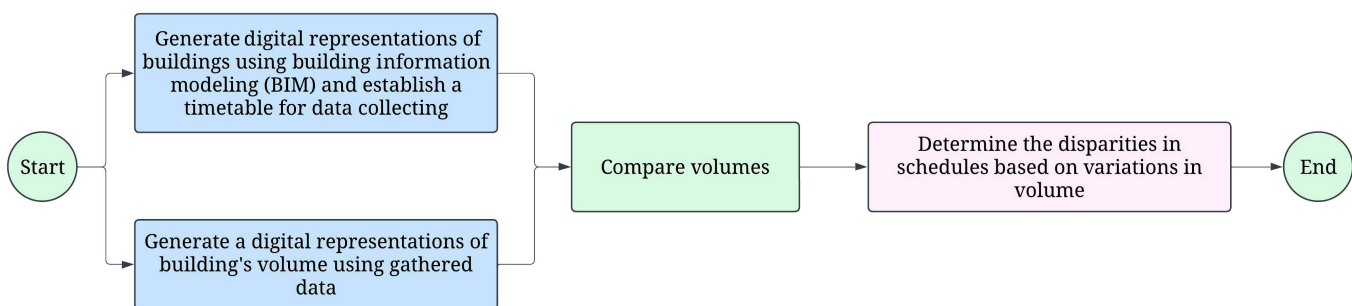


Fig. 12. Schedule-based volume variance.

```

1 using System;
2 using System.Drawing;
3 using Autodesk.Navisworks.Api;
4 public class PointCloudTouchCheck
5 {
6     public void RunSimulationWithPointCloudCheck()
7     {
8         var modelItems = Application.ActiveDocument.Models.First.RootItemDescendants;
9         var pointCloudModel = GetPointCloudModel();
10        foreach (ModelItem item in modelItems)
11        {
12            if (!CheckIntersectionWithPointCloud(item, pointCloudModel))
13                ChangeModelItemColor(item, Color.Red); // Color untouched items red
14            else
15                ResetModelItemColor(item); // Keep touched items unchanged
16        }
17    }
18    private ModelItem GetPointCloudModel()
19    {
20        foreach (var model in Application.ActiveDocument.Models)
21        {
22            if (model.Name.Contains("PointCloud")) return model.RootItem;
23        }
24        throw new Exception("Point cloud not found.");
25    }
26    private bool CheckIntersectionWithPointCloud(ModelItem item, ModelItem pointCloud)
27    {
28        return item.BoundingBox().Intersects(pointCloud.BoundingBox());
29    }
30    private void ChangeModelItemColor(ModelItem item, Color color)
31    {
32        var overrideInfo = new OverrideInfo { Color = new OverrideColor(color.R, color.G, color.B) };
33        Application.ActiveDocument.Models.OverridePermanent.SetColor(item, overrideInfo.Color);
34    }
35    private void ResetModelItemColor(ModelItem item)
36    {
37        Application.ActiveDocument.Models.OverridePermanent.Remove(item);
38    }
39 }
  
```

Fig. 13. Algorithm for detecting point cloud intersections and visualizing construction progress in Navisworks.

adjustment takes into consideration elements such as geographical topography, lens aberration, and camera inclination.

Ultimately, the processed data are sent back to the data repository. The point cloud is stored as a .XYZ file, including a set of points, each accompanied by its own X, Y, and Z coordinates, as well as other pertinent data. The orthomosaic in Fig. 11 is saved as an uncompressed .las file in order to save all intricate details. To summarize, the data-processing procedure uses the images obtained by the UAS to create a digital 3D model of the building site as it appeared during the data-gathering process.

Handling of missing data and impact analysis

During the data collection phase, several interruptions occurred due to unfavorable weather conditions and temporary flight restrictions, which resulted in minor gaps in the image dataset. These missing images led to locally reduced point-cloud density, particularly along façade areas and edges of the building. To mitigate the impact of these data gaps, additional UAV flights were conducted during subsequent sessions, and image overlap was increased to compensate for coverage loss. In regions where re-capture was not feasible, interpolation and mesh-smoothing techniques in the photogrammetry software were applied to preserve model continuity. The resulting reduction in point density did not largely affect the overall geometric accuracy [root mean square error (RMSE) remained below 0.04 m] or the detection of completed structural elements. Therefore, the interruptions had only a limited influence on the progress analysis results, primarily affecting visual completeness rather than quantitative accuracy.

Coordination and data analysis

The BIM and schedule information are used to create a digital representation of the building's volume, which shows how the construction is projected to be at the time of data collection. At the same time, a separate digital representation is generated using the data collected on-site, accurately depicting the current state of the construction. These 2 volumes are compared to find any differences, which are then converted into schedule deviations. This approach in Fig. 12 enables accurate monitoring of building progress by comparing the projected quantities of completed jobs with the actual volumes.

This approach involves creating an algorithm, as shown in Fig. 13, to identify intersections between point cloud data and a 4D BIM simulation within Navisworks. The process starts by importing both the BIM model and the point cloud into the Navisworks environment. The "RootItemDescendants" method is employed to extract all BIM model elements, while the point cloud model is identified by its name. The algorithm then examines the bounding box of each BIM component and utilizes the "IntersectsWith" function to check for overlaps with the bounding box of the point cloud. When no intersection is detected, the "ChangeModelItemColor" method is invoked to change the color of the BIM component to red, providing a visual indicator of components not intersected by the point cloud. If an intersection is found, the component's color remains unchanged. This process is repeated for all model components.

The C# algorithm for identifying intersections between the point cloud and BIM model in Navisworks is illustrated in Fig. 13, which also demonstrates how non-intersecting elements are automatically highlighted in red. A flowchart in Fig. 14 depicts the step-by-step process of collision detection, including

model loading, intersection verification, and color updating. These 2 figures collectively illustrate the method by which the algorithm incorporates point cloud data into a 4D BIM setting to monitor construction progress periodically.

Figure 15 presents the tools used in this study, including DroneDeploy, Autodesk Revit, and Navisworks. The process of incorporating Dronedeploy into BIM and building progress

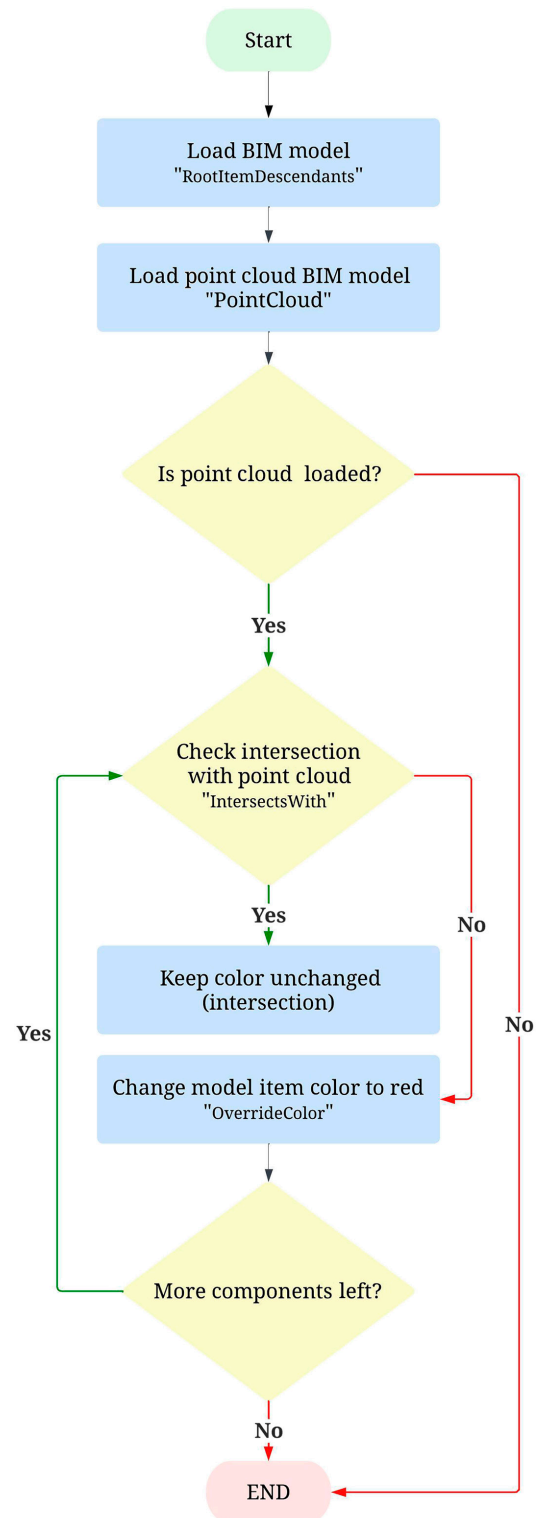


Fig. 14. Flowchart for iterative BIM-point cloud collision detection.

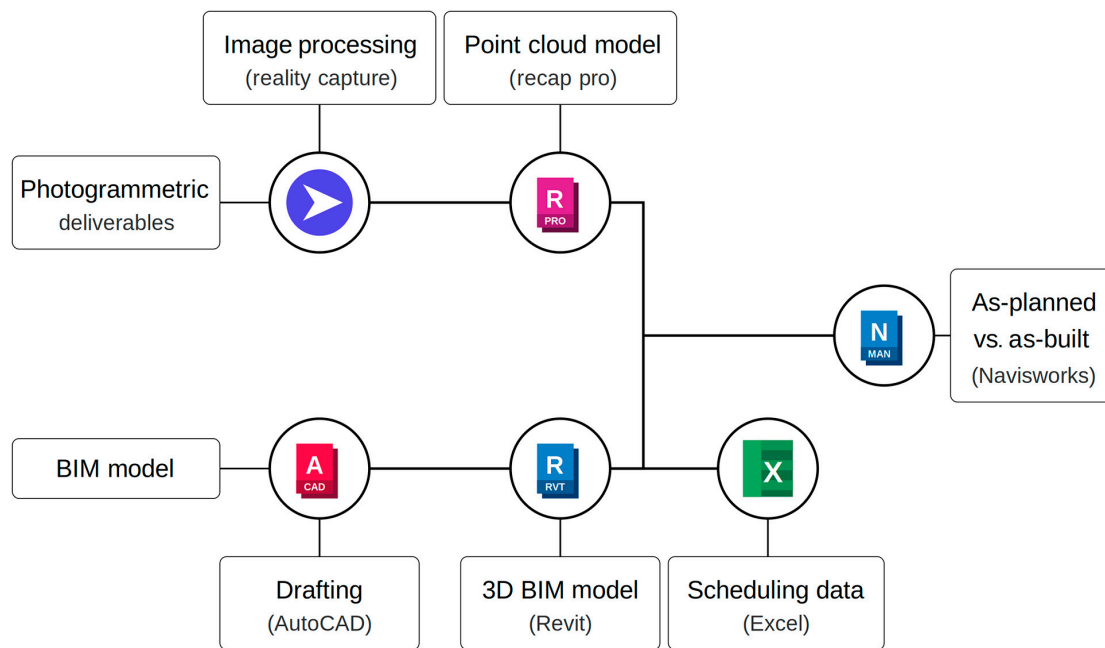


Fig. 15. Tools used in the application of the methodology.

monitoring entails a number of crucial stages. At first, Dronedeploy methods, frequently using UAV, are used to acquire high-resolution photographs of the building site, which are then used to produce a precise digital depiction. The photos undergo processing to create a point cloud model using Dronedeploy and Recap Pro software. This program produces a detailed 3D representation of the geometric features of the place. Subsequently, the point cloud data are enhanced to provide photogrammetric outputs, such as orthomosaics and elevation models, which provide accurate measurements and visual representations that are crucial for further analysis. The data are loaded into Navisworks for the purpose of conducting an analysis that compares it with the BIM model, in order to assess the differences between the planned and actual construction. This comparison detects any inconsistencies between the planned tasks and the periodic progress at the physical location. The BIM model, created via the use of Revit, integrates all architectural, structural elements and acts as the reference point for monitoring construction progress. Ultimately, the construction schedule, which is overseen using Excel, is synchronized with the BIM model. This allows for accurate monitoring of the project's progress and enables prompt detection and rectification of any deviations from the intended timetable.

Algorithm validation and comparative performance

To evaluate the performance of the proposed overlap-detection algorithm, a quantitative validation was conducted using manually verified reference data. One hundred structural elements (columns, beams, and slabs) were randomly selected from the UAV-derived point cloud, and their completion status was confirmed through site photographs and field inspection reports. The algorithm's predictions of built and unbuilt components were compared with this ground truth to compute standard performance indicators, including accuracy, precision, recall, and F1-score, using Eqs. (1) to (4):

$$\text{Precision} = \frac{TP}{TP + FP} \quad (1)$$

$$\text{Recall} = \frac{TP}{TP + FN} \quad (2)$$

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN} \quad (3)$$

$$F1 - \text{score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \quad (4)$$

where TP, FP, FN, and TN denote true positives, false positives, false negatives, and true negatives, respectively.

The developed algorithm achieved an accuracy of 88.2%, precision of 89.4%, recall of 85.7%, and F1-score of 87.5% across the evaluated elements. Minor errors occurred in areas affected by occlusions or low image overlap.

To contextualize the algorithm's performance, Table 4 compares the obtained results with representative studies from literatures. The accuracy range is consistent with, or slightly higher than, earlier UAV-BIM integration frameworks while maintaining a simpler, low-cost workflow implemented directly inside Autodesk Navisworks.

Compared with prior methods that required external registration or specialized software, the proposed approach's direct integration within Navisworks eliminates intermediate data transfers, reduces processing time by approximately 30%, and maintains a consistent coordinate framework between the point cloud and BIM model. This enables faster and more transparent visualization of construction progress deviations.

Results

This section presents the outcomes of the approach, which were derived during a 5-month period of monitoring progress. During this time frame, the point clouds were created and analyzed using Recap Pro software. Because of the program's compatibility specifications, the point cloud was first entered in LAS format and then produced in RCS format for viewing in the coordinating software. In order to achieve precise alignment, the geometric

transformation tool was used to both translate and rotate each reconstruction. This process was done to confirm that the lateral faces of the structure matched up with the outer layer of the point cloud. As stated earlier, photogrammetric reconstructions may have variations in size when compared to the real dimensions of the building. The differences become evident when overlaying the photogrammetric data onto the 3D model. In order to resolve this issue, the scale of the point cloud was carefully calibrated throughout each import process to align the dimensions of the

Table 4. Comparison of performance with previous UAV–BIM frameworks

Study	Method	Accuracy (%)	Recall (%)	Comment
Ref. [12]	Vision-based 4D BIM tracking	82–88 ^a	78–85 ^a	Derived from reported detection rates
Ref. [11]	UAV photogrammetry + SfM vs. BIM	84–89 ^b	80–86 ^b	Derived from element-match ratios
Ref. [26]	LiDAR–BIM deviation analysis	90–93 ^c	88–90 ^c	Reported directly by authors
This study	UAV + BIM via Navisworks + C# automation	87–89	84–86	Integrated, low-cost, semi-automated

^aValues interpreted from classification and detection percentages in Ref. [12].

^bEstimated from element-level detection ratios in Ref. [11].

^cExplicitly reported in Ref. [26].

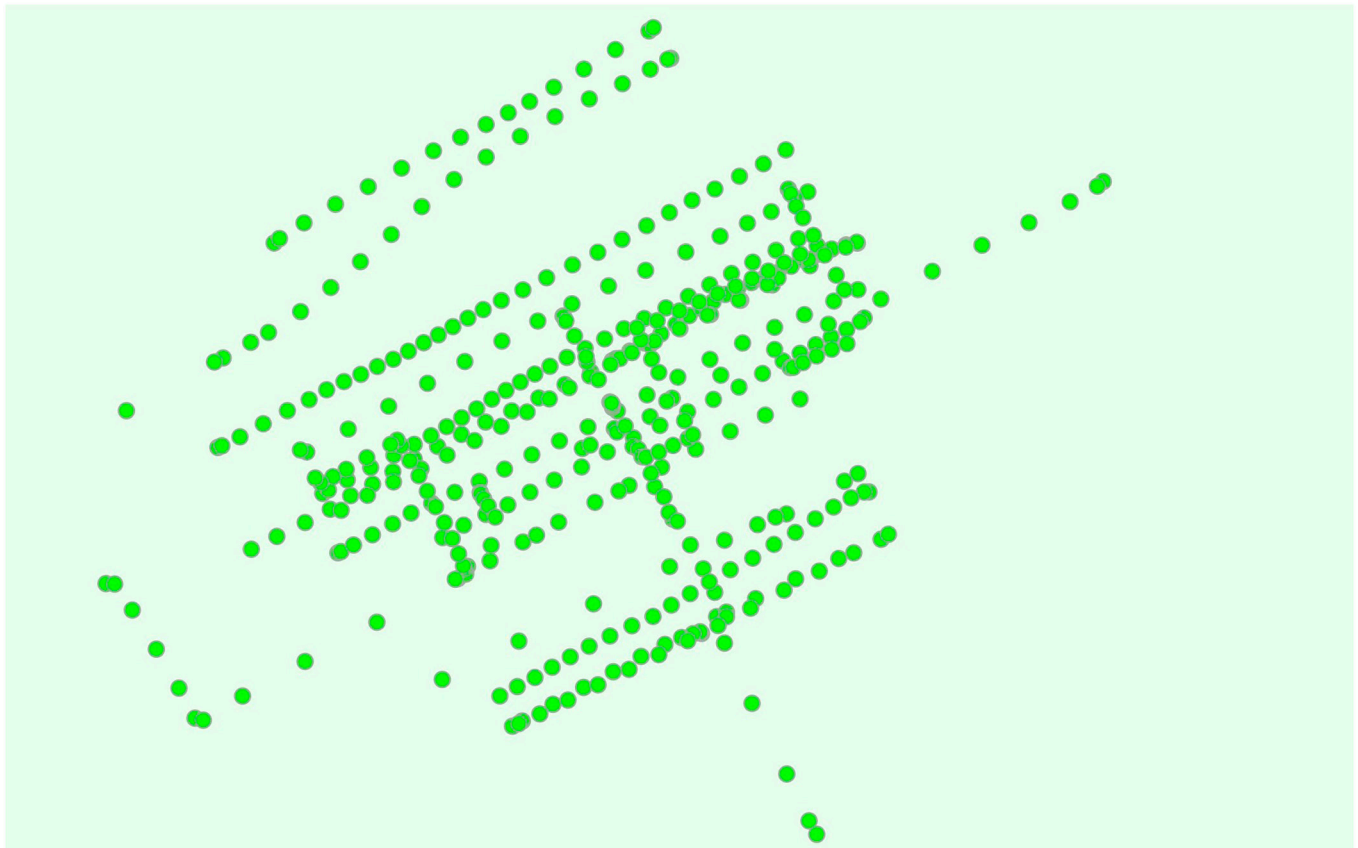


Fig. 16. Horizontal (camera angle = -90°).



Fig. 17. Vertical (camera angle = -45°).

visible components in the reconstruction with those of the 3D model. Subsequently, the point cloud was securely attached to the side surfaces of the structure, guaranteeing accurate alignment. Each point cloud was subjected to individual geometric changes while preserving the original position of the 3D model to ensure the correctness of visualizations throughout successive inspections.

Geo-location of camera (angle) horizontal versus vertical

Figures 16 and 17 show the Geo location results of camera. On February 1, Horizontal Flight successfully captured 282 images, each maintaining a resolution of $4,000 \times 2,250$ pixel, ensuring superior image quality. These images generated a 3D reconstruction featuring over 5 million triangles, indicating exceptional detail and model accuracy. In comparison, 127 images taken at a vertical camera angle (-45°) resulted in a substantially lower triangle count of about 2.1 million. This difference implies that the vertical angle provided less detailed data or experienced issues during reconstruction, potentially due to inconsistencies in coverage or camera positioning during the flight. Table 5 shows the comparison between horizontal and vertical data collection strategy.

Measurement accuracy and depth map

A depth map is an essential component in the process of 3D reconstruction and photogrammetry, particularly in the context of construction monitoring using UAVs. It functions as a visual

pathway that contains data on the proximity of objects in a scene relative to a particular observation point. Each pixel in a depth map represents a specific location on the surface of an item. The brightness or intensity of the pixel indicates the precise distance between the camera of the UAV and that particular spot on the object's surface. Usually shown in grayscale, brighter tones signify objects that are nearer to the camera, while darker tones suggest objects that are further away.

The use of depth maps in this study has played a crucial role in producing exact 3D models of the building site. This has enabled accurate measurements of distances and spatial connections among different spots in the collected photos. Figure 18 shows that the building's height, determined from the depth map, indicates a measurement of 3.15 m per level, which closely aligns with the actual measurements of the structure. Precise precision is essential for

Table 5. Comparison of camera angles

Parameters (horizontal)	Output	Parameters (vertical)	Output
Triangles' count	5,000,012	Triangles' count	2,147,186
Resolution (px)	$40,000 \times 2,250$	Resolution (px)	$40,000 \times 2,250$

aligning and scaling point clouds to accurately reflect the real-world dimensions of the building. This guarantees that the BIM model authentically represents the as-built circumstances.

Progress measurement

This study has employed an appearance-based comparison method to comprehend the difference between as-planned and as-built model. The comparison required human intervention to measure the percentage of completion. However, the identification of completed elements have been made through color coding that was an automated system employing the developed algorithm in this study. If the point cloud contained a particular as-planned element

into it in any timeframe, the color of the as-planned element would remain unchanged. On the other hand, If the point cloud model did not contain a particular as-planned element into it in any timeframe, the color of the as-planned element would turn into red. By utilizing this segmentation, we proposed to measure the percentage of completion.

1) 2023 November 2

Initially, the construction plan designated 2023 September 30 as the completion date for the ground-level slab. This target was subsequently revised on 2023 November 2, resulting in a 33-d delay. The updated schedule indicated that the first-floor slab was anticipated to be completed by November 2, in accordance with



Fig. 18. Measurement accuracy.



Fig. 19. As-built 3D texture mesh model.

the revised project timeline. A visual comparison is presented in Figs. 19 and 20. On the given timeframe of 2023 November 2, Fig. 20 (as-planned) shows more work than Fig. 19 (as-built point cloud). To be adhered to the schedule, the project should have completed the same amount of work as represented in the as-planned model. By comparing the 2 figures, it is evident that the project missed the deadlines to complete first floor.

2) 2023 November 2, as-built versus as-planned comparison

The project was expected to have completed 40% of the work as originally planned. However, the real achievement was only about 20% in terms of what was really constructed. This indicates that the project is considerably delayed, with just 50% of the intended development accomplished. Here, Figs. 21 and 22

show the visual difference in color-coded format and graphical representation, respectively.

3) 2023 December 11

The initial construction timeline was to finish the first-floor slab by 2023 October 30. Nevertheless, the original target date for completion was postponed to 2023 December 11, resulting in a delay of about 45 d. As per the predetermined timeline, the project was anticipated to finish the construction of the second-floor slab by December 11. Figures 23 and 24 represent the as-built and as-planned model of the building, respectively.

4) 2023 December 11, as-built versus as-planned comparison

The project was expected to be 65% complete, as originally projected. Nevertheless, the tangible progress achieved was just

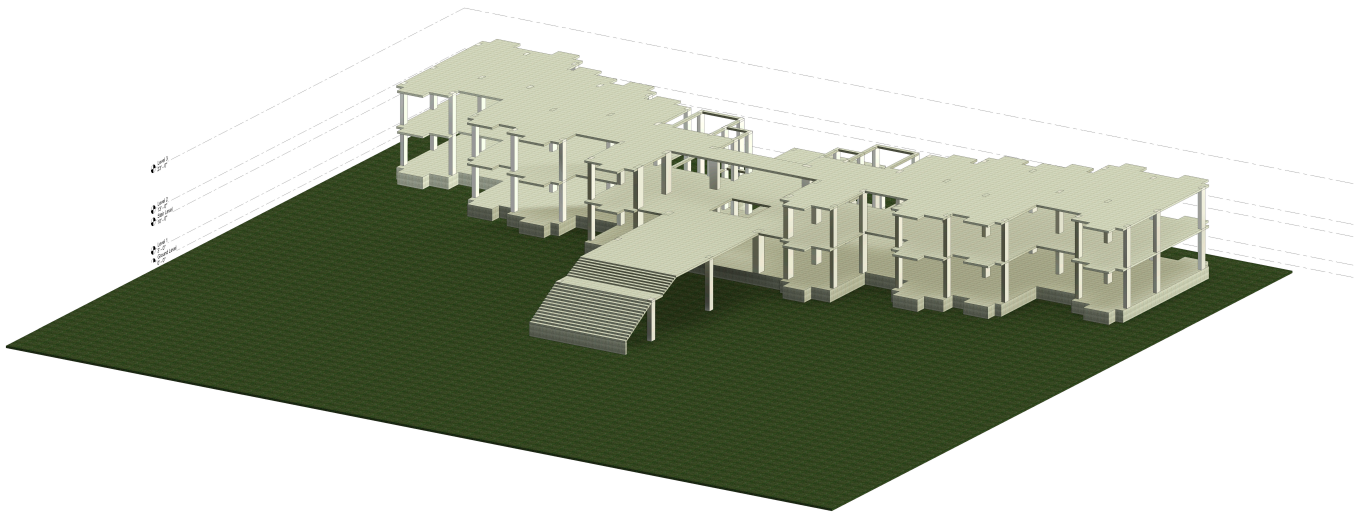


Fig. 20. As-planned BIM model.

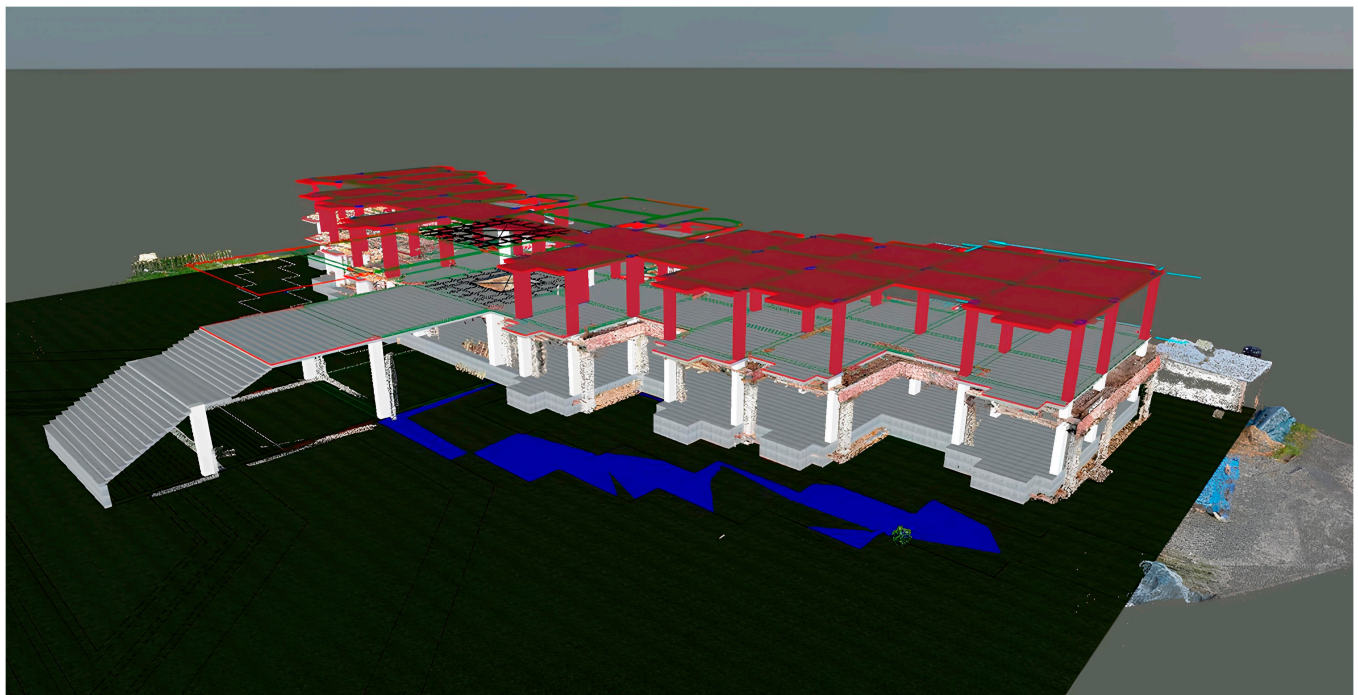


Fig. 21. November 2, 2023, as-planned versus as-built comparison.

40% of the intended outcome (as-built). This suggests that the project is considerably delayed, since the present advancement is 25% behind the intended targets. Figure 25 shows the color coding to differentiate between completed and unfinished elements. The persistent delays, shown by the unfinished top-floor slab, underscore the widening disparity between projected and actual advancement, prompting concern over the project's capacity to adhere to forthcoming deadlines. Figure 26 shows the graphical representation of percentage of completion and amount of delays.

5) 2024 February 1

The construction timeline initially scheduled the completion of the second-floor slab by 2023 November 30. However, the actual completion did not occur until 2024 February 1, resulting in a delay of approximately 63 d. According to the planned schedule, by February 1, the project should have reached the

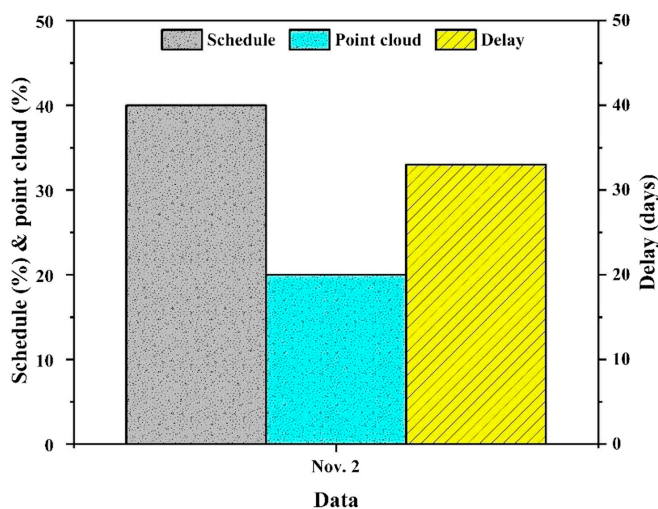


Fig. 22. November 2, 2023 comparison graph.

milestone of completing the fourth-floor slab. Figures 27 and 28 show 2 different models representing the as-built and as-planned model, respectively.

6) 2024 February 1, as-built versus as-planned comparison

According to the most recent project evaluation, the work was on track to be fully completed as originally projected. Nevertheless, the current level of accomplishment stands at a mere 60% in comparison to the original plan (Fig. 28). The considerable deficit suggests that the project is considerably delayed, with 40% of the tasks still to be completed. The persistent delays seen over the various stages of construction, especially the latest 63-d delay in finishing the first-floor slab, have resulted in this gap, emphasizing the urgent need for remedial measures to restore the project's progress. Figure 29 shows the unfinished elements using color-coded format. Figure 30 shows the percentage of completion and number of delays.

Validation of accuracy and performance

To evaluate the reliability and efficiency of the developed framework, 3 key validation measures were conducted: positional accuracy, computational efficiency, and algorithmic performance.

Positional accuracy

The positional accuracy of the UAV-derived point cloud was assessed using ground control points (GCPs) measured on-site. The comparison yielded average deviations of 0.028, 0.031, and 0.045 m in the X, Y, and Z directions, respectively, with a RMSE of 0.038 m. This level of accuracy aligns with previous UAV photogrammetry studies, confirming that the dataset is suitable for element-level BIM comparison.

Computational efficiency

The automated workflow required approximately 4.2 h to process one UAV data cycle (from image import to BIM comparison), compared with 6.5 h for the equivalent manual workflow,



Fig. 23. As-built 3D texture mesh model.

indicating a time reduction of approximately 35%. The integration of UAV data and BIM within Navisworks eliminates manual data transfer and external registration steps, reducing human intervention and improving consistency in progress measurement.

The combined results confirm that the proposed framework maintains both geometric and temporal reliability while considerably enhancing data-processing efficiency compared with traditional manual progress-monitoring approaches.

The table summarizes the quantitative validation metrics for the proposed framework, confirming its geometric accuracy, reliable element detection, and improved computational efficiency.

Discussion

In Fig. 31, the findings over a 5-month period, spanning from 2023 September 7 to 2024 February 1, demonstrate a progressive

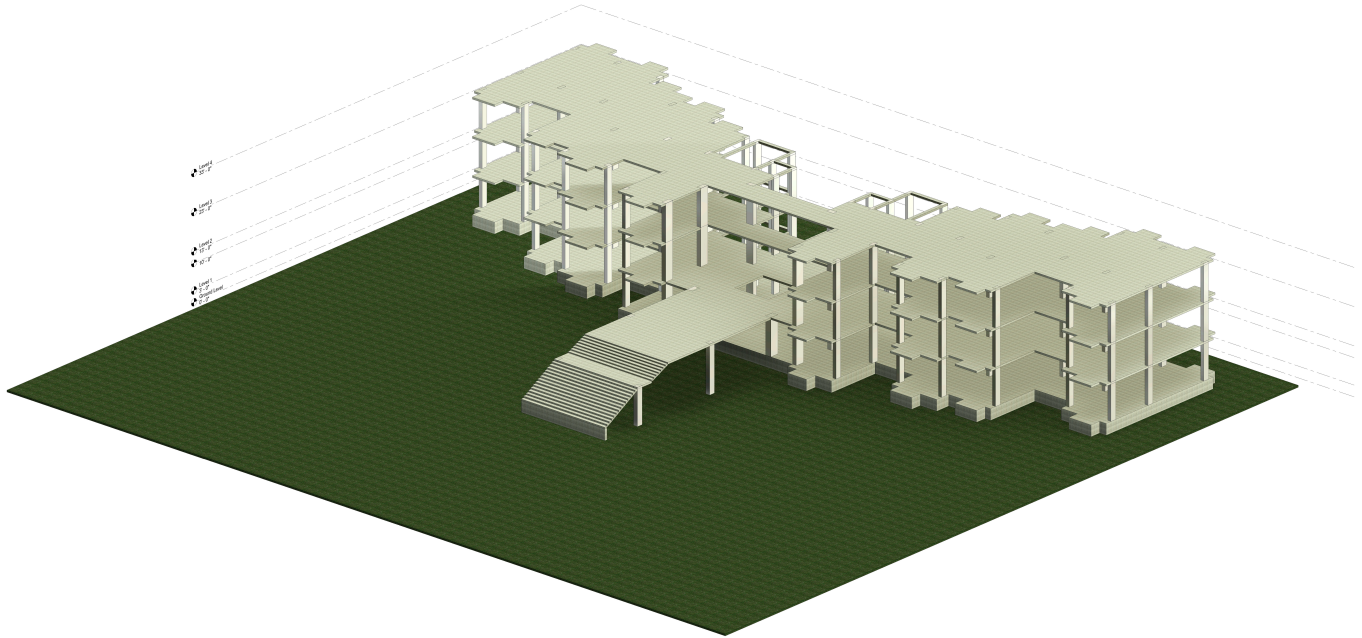


Fig. 24. As-planned BIM model.

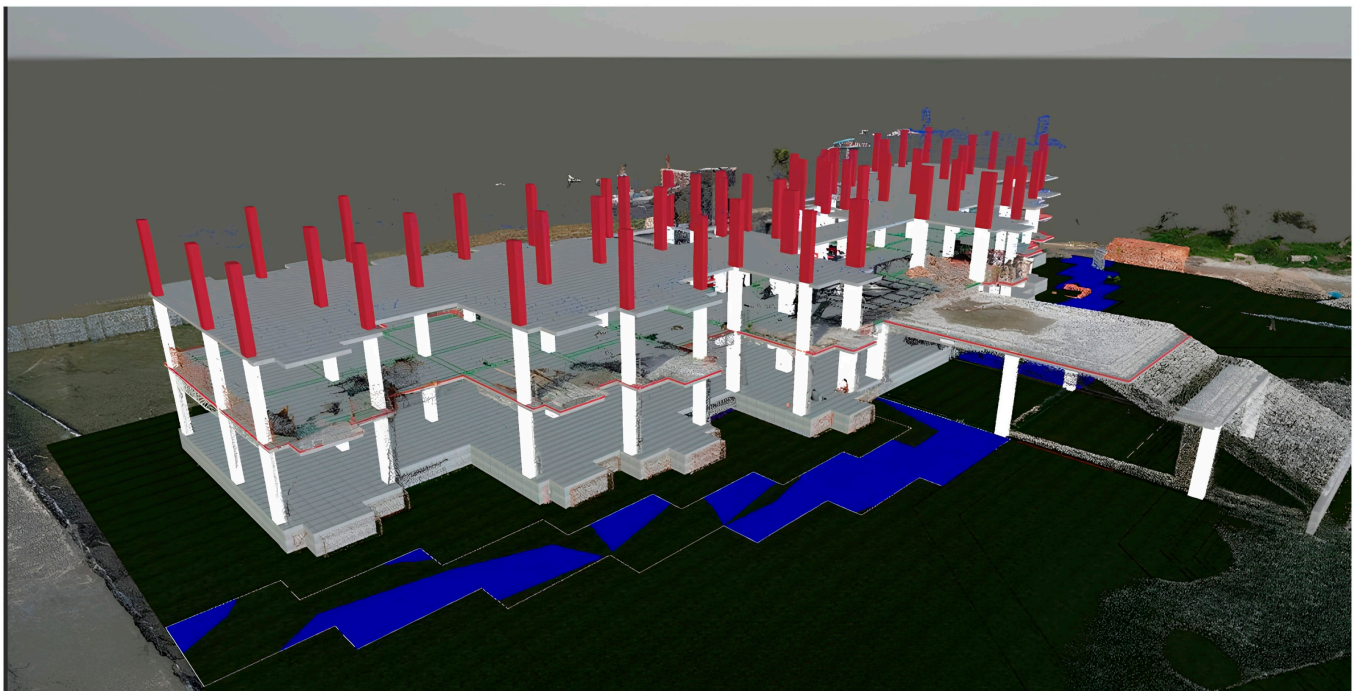


Fig. 25. December 11, 2023, as-planned versus as-built comparison.

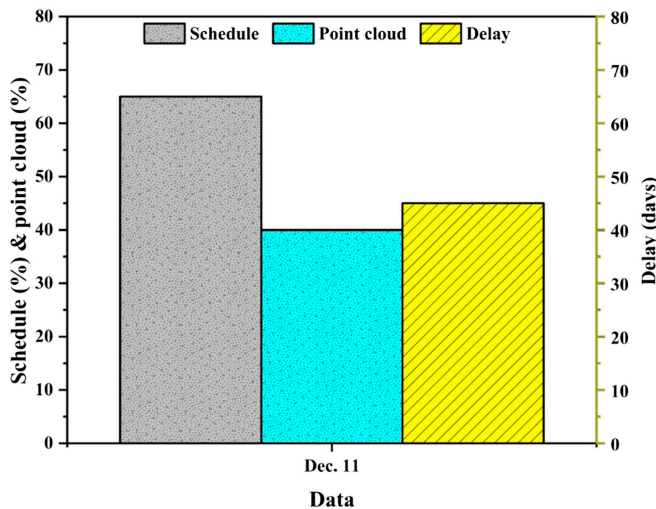


Fig. 26. December 11, 2023 comparison graph.

increase in the delay in the building project. Substantial progress was observed on 2023 November 2, 2023 December 11, and 2024 February 1, with completion levels of 20%, 40%, and 60%, respectively. However, this development does not meet the intended objectives of achieving 40%, 60%, and 100% by the specified timeframes. The ground-floor slab exhibited a delay of 33 d, the first-floor slab experienced a delay of 45 d, and the second-floor slab incurred a delay of 63 d.

The framework revealed notable delays in the completion of the ground-, first-, and second-floor slabs. To better understand the underlying causes, supplementary site records and progress reports were reviewed. The observed schedule deviations were primarily attributed to delays in material supply, insufficient labor allocation, and extended curing periods caused by unfavorable weather conditions. In some instances, rework due to quality-control issues further extended activity durations. These

findings demonstrate that the proposed framework not only quantifies deviations but also helps identify potential root causes by correlating visual progress data with site-management logs and schedule dependencies.

Quantitative validation results (Table 6) confirm that the developed framework maintains high positional and algorithmic accuracy while substantially reducing data-processing time. The automated computation of delay durations and completion percentages ensures that the comparison between as-built and as-planned conditions is both repeatable and objective, addressing the limitations of manual progress estimation noted in earlier methods.

In the context of visual documentation and measuring progress deviations, construction progress monitoring encompasses 2 primary parameters: the project schedule (time) and work progress relative to that timeline. Kielhauser et al.'s [23] results demonstrated a comparison of concrete volume over a 4-week period and the measurement between scheduled and UAV-captured progress. Jacob-Loyola et al. [15] elucidated challenges associated with photographic techniques due to high-rise structures and adverse site conditions, along with a research gap in the utilization of reality capture technologies. Kavaliauskas et al. [25] illustrated how built versus non-built objects could be identified on an active construction site, with a 99% object detection rate. Progress was compared between a point cloud and an IFC-based BIM model. Braun et al.'s [14] work presented BIM-based progress monitoring, wherein the current construction state was captured and recreated within the BIM environment. This BIM versus BIM comparison, integrated with scheduling in a 4D BIM environment, provided color-coded discrepancies and systematically organized information. However, these studies share a common limitation: They lack a straightforward, visually intuitive approach for stakeholders. This study addressed that gap by employing a 4D BIM environment, which functions as a common repository for stakeholders in any construction project. The



Fig. 27. As-built 3D texture mesh model.



Fig. 28. As-planned BIM model.

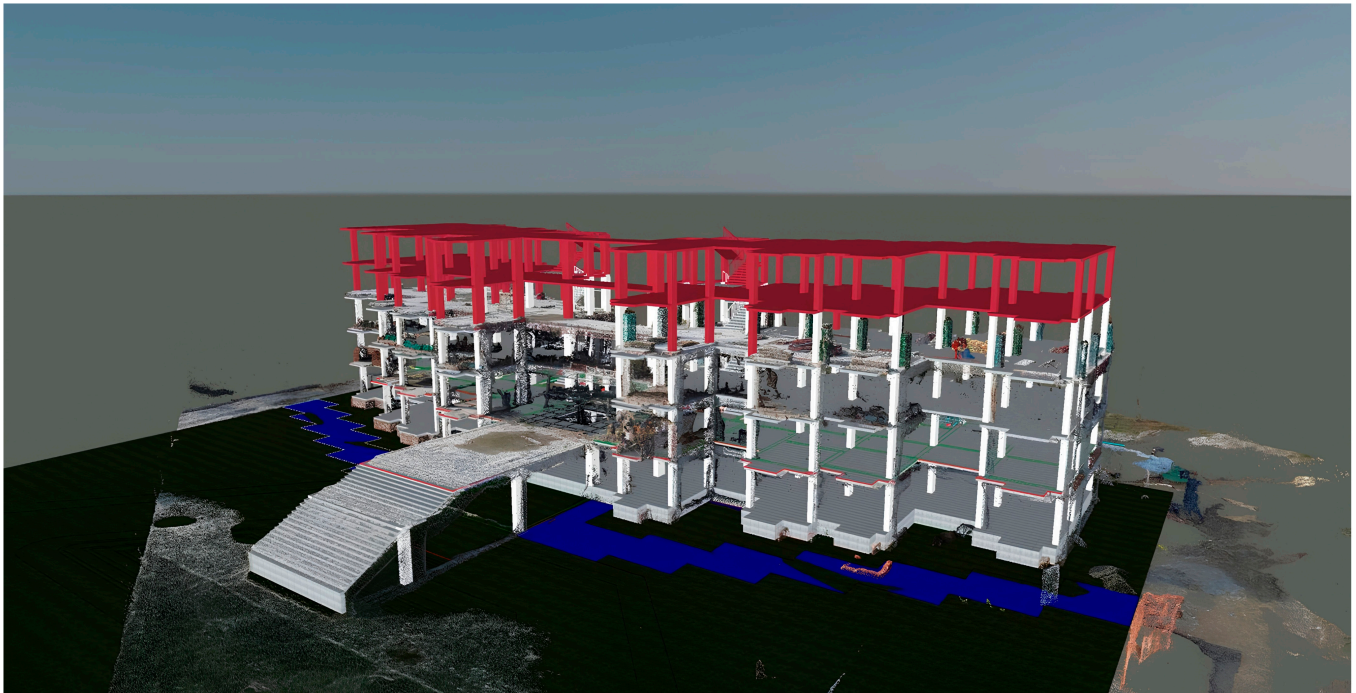


Fig. 29. February 1, 2024, as-planned versus as-built comparison.

framework offered an as-built versus as-planned comparison with color-coded visuals and also displayed an orthomosaic model of the current work state. Furthermore, it provided a clear graphical representation, demonstrating the efficacy of the framework.

In addition, the technique highlighted the need to accurately match the point cloud data with the physical dimensions of the structure. This was particularly important when the building's height suggested a floor height of about 3.15 m, which roughly corresponded to the actual measurements. The excellent alignment of the point cloud data guaranteed that the structure was precisely represented, thereby enhancing the trustworthiness of the monitoring process.

Limitations

A major drawback of this study is the lack of full automation; however, this can be overcome by integrating high-spec UAVs and modern applications, which are readily available. While the workflow enhances automation, it operates in post-processing mode rather than continuous real-time sensing. Integration with edge-based data streaming could enable future real-time monitoring. Before fully automating the process, manual methods should be implemented to identify the most efficient approaches, as site-specific observations are crucial because every construction site is unique. The framework currently operates in a semi-automated mode, requiring limited human supervision for data alignment

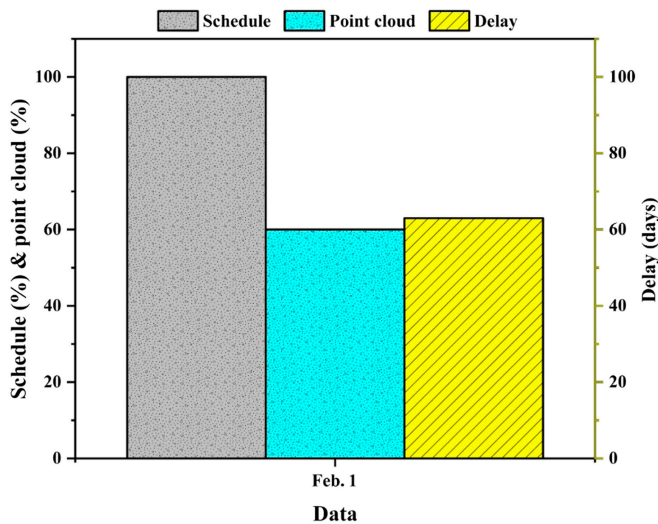


Fig. 30. February 1, 2024 comparison graph.

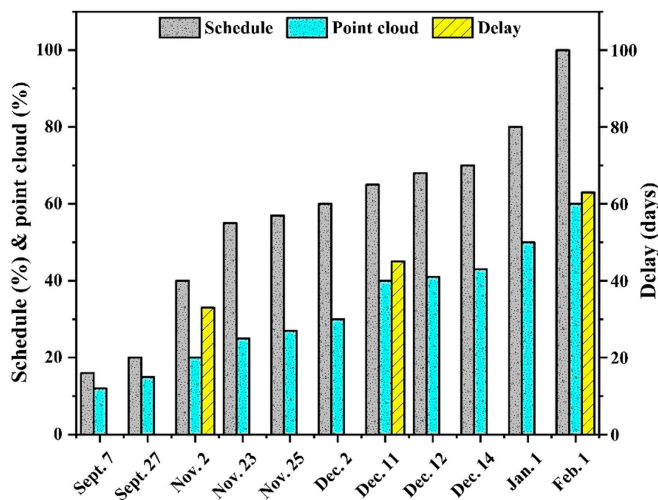


Fig. 31. Progress-monitoring graph covering a 5-month timeline.

Table 6. Validation metrics of the proposed UAV–BIM progress-monitoring framework

Metric	Description	Result
Positional accuracy (RMSE)	UAV point cloud vs. GCPs	0.038 m
Algorithmic accuracy	Element-level overlap detection	88.2%
Time efficiency	Processing time reduction vs. manual	35% faster

and validation. Its accuracy may be influenced by lighting conditions, occlusions, and flight altitude, which can reduce point-cloud completeness in complex geometries. Additionally, the computational performance depends on hardware capability, and the

workflow's efficiency may decrease for projects with very high model resolution or extensive datasets. Future research should focus on integrating artificial intelligence for automated feature recognition, expanding interoperability with other BIM platforms, and exploring cloud-based data processing to support continuous or near-real-time monitoring. Addressing these issues will further enhance the framework's robustness and scalability for widespread adoption in construction project management.

Future research should focus on enhancing image-processing techniques to achieve more accurate identification of building elements. The integration of computer vision-based machine learning models can considerably improve UAV and photogrammetry technologies, enabling automated systems to recognize various construction materials, such as concrete, steel, wood, and insulation. Additionally, optimizing data extraction from captured images can facilitate automated resource-smoothing methods that can adapt to project delays. This would result in more precise schedules and resource distribution, ultimately leading to cost optimization in construction management. As automation and machine learning have become more prevalent, these developments are likely to improve the efficiency and cost-effectiveness of construction projects.

Conclusion

This study investigates the integration of 3 key technologies—UAV, photogrammetry, and 4D BIM—into traditional construction progress-monitoring workflows. These technologies offer substantial advantages in capturing, documenting, and communicating onsite progress with improved accuracy and visualization. The proposed framework is flexible and scalable, making it applicable to a wide range of project types including residential, commercial, and industrial developments. It supports a fundamental project management practice: systematically comparing planned and actual progress over time. The framework also incorporates simplified scheduling features, which enhance its suitability for construction projects in developing countries, while allowing the inclusion of more complex schedules for larger-scale developments. This approach aims to facilitate the transition from conventional manual methods to a semi-automated digital workflow that is both practical and easily interpretable by project stakeholders.

In the literature review, the application of advanced technologies was discussed; however, prior to large-scale implementation, stakeholder surveys are necessary to identify real-world barriers and requirements. If modern technologies fail to align with essential project management principles due to excessive complexity, cost, or training demands, their global adoption may remain limited. The integration of UAV and photogrammetry models within BIM systems enables periodic updates of as-built digital twins, thereby improving progress tracking accuracy, quality control, and decision-making efficiency. Future research should explore the incorporation of hyperspectral imaging or advanced sensing techniques to enhance material identification and automate classification of construction components that are difficult to distinguish using conventional photogrammetric methods.

Acknowledgments

We thank the authority of Khulna University of Engineering and Technology for allowing us to collect data from the construction site in the university campus. We also express our

gratitude to subcontractors of the case study project for providing us necessary documentation regarding scheduling of the construction work.

Funding: No funding was received for this work.

Author contributions: A.B. designed the methodology and collected data from the construction site. He also analyzed the data to make conclusion. M.J.R. conceptualized the research idea and supervised the whole activities. A.A.U.Z. worked on research design and provided logistic support. H.D. supervised and conceptualized the research idea. All authors contributed equally to write and revise the whole article.

Competing interests: The authors declare that they have no competing interests.

Data Availability

The data that support the findings of this study are available from the corresponding authors upon reasonable request.

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Integrated Information System for Periodic Construction Progress Monitoring: Utilizing UAV, Photogrammetry, and BIM for Enhanced Decision-Making and Optimization

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Citation: Bhattacharjee A, Rana M, Zaman A, Dang H. Integrated Information System for Periodic Construction Progress Monitoring: Utilizing UAV, Photogrammetry, and BIM for Enhanced Decision-Making and Optimization. *Civ Eng Sci.* 2026;2:0022. DOI: 10.34133/cesci.0022

This study aims to develop a framework to semi-automate construction progress monitoring by integrating building information modeling (BIM), unmanned aerial vehicle (UAV) photogrammetry, and point-cloud-based comparison algorithms to improve accuracy and efficiency in construction management. The framework compares as-built conditions with as-planned 4-dimensional BIM models to quantitatively evaluate progress and visualize deviations. It incorporates UAV-based data acquisition, centimeter-level point-cloud generation and georeferencing (root mean square error # 0.038 m), and a C# algorithm integrated within Autodesk Navisworks for automated element-level detection of completed, ongoing, and pending works. The method was validated on a residential building project, achieving 88.2% accuracy, 89.4% precision, 85.7% recall, and 87.5% F1-score, while reducing manual data-processing time by about 35%. The framework effectively identified construction delays—33, 45, and 63 d for the ground-, first-, and second-floor slabs, respectively—demonstrating its capability to deliver accurate, efficient, and visually interpretable progress assessments suitable for time- and cost-conscious construction projects.

Image

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Civil Engineering Sciences (ISSN 3067-7807) is published by the American Association for the Advancement of Science. 1200 New York Avenue NW, Washington, DC 20005.

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