

Applications of Unmanned Aerial Vehicles (UAVs) in Construction Site Monitoring and Progress Evaluation: An Empirical Performance and Photogrammetric Accuracy Analysis

Himani Joshi¹, Tanveer Mehta²

ABSTRACT

Automated monitoring and precise progress evaluation represent critical paradigms in modern construction engineering, where project schedule delays and cost overruns frequently stem from inefficient data collection, poor communication, and lag times in tracking field activities. Traditional ground-based manual inspection methodologies are resource-intensive, safety-critical, highly localized, and prone to significant human error. This research paper systematically evaluates the application and performance accuracy of Unmanned Aerial Vehicles (UAVs), commonly termed drones, integrated with advanced Structure-from-Motion (SfM) photogrammetry and light detection and ranging (LiDAR) payloads for construction site monitoring and automated progress tracking. Over a 180-day field tracking campaign encompassing a multi-story mixed-use commercial development project, multi-rotor and fixed-wing UAV platforms were deployed to capture ultra-high-resolution aerial imagery, thermal datasets, and dense 3D point clouds. To establish a rigorous volumetric and geometric accuracy framework, drone-derived datasets were cross-validated against ground truth measurements established using high-accuracy Real-Time Kinematic Global Navigation Satellite Systems (RTK-GNSS) and terrestrial laser scanners (TLS). The experimental findings demonstrate that UAV photogrammetric networks, when constrained by strategic Ground Control Points (GCPs), achieve a root-mean-square error (RMSE) of less than 1.8 cm in horizontal axes and 2.4 cm in the vertical axis. The generated orthomosaics and digital surface models enabled fully automated earthwork volumetric calculations, yielding a negligible error margin of 1.25% compared to conventional cross-sectional surveying

techniques. Furthermore, automated alignment of the drone-derived 3D point clouds with the building information modeling (BIM) architectural baseline allowed for four-dimensional (4D) progress deviation mapping, enabling the identification of micro-level variations in concrete formwork, steel reinforcement alignment, and masonry assembly within hours of structural completion. This study concludes that the deployment of automated UAV flight patterns lowers field inspection cycles by 85%, reduces total project tracking costs by 45%, and significantly enhances construction site safety by eliminating the need to physically access high-risk zones. Ultimately, the scientific significance of this research lies in providing a standardized geometric validation matrix that supports the integration of UAV analytics into automated, smart construction lifecycles.

KEYWORDS: *Unmanned Aerial Vehicles (UAVs), Construction Site Monitoring, Automated Progress Evaluation, Photogrammetry, Building Information Modeling (BIM), Structure-from-Motion (SfM), Volumetric Analysis.*

INTRODUCTION

The construction sector is experiencing a major technological shift driven by the need for greater efficiency, accuracy, and safe field operations. Historically, mega-scale infrastructure developments have faced significant delays, with over 60% of projects exceeding their planned timelines and budgets due to miscommunication and delayed site data [1]. Monitoring large-scale construction sites using manual methods presents challenges. Field inspectors rely on physical visual checks, handheld laser meters, and total stations to log progress, verify spatial layouts, and check compliance with engineering designs [2]. These ground-based inspection workflows are slow, labor-intensive, and subjective. They also expose personnel to hazards such as open excavations, moving machinery, and high-altitude environments. Additionally, because manual data collection is done infrequently, it creates data silos, preventing project managers from recognizing critical schedule deviations until they cause major delays.

To solve these operational challenges, the architecture, engineering, and construction (AEC) industry has adopted Unmanned Aerial Vehicles (UAVs), or drones, as an essential platform

for aerial data collection [3]. Drones offer a cost-effective way to quickly capture high-resolution imagery and spatial data across large project areas. Equipping drones with advanced sensors—such as high-resolution RGB cameras, thermal sensors, and miniaturized Light Detection and Ranging (LiDAR) systems—allows project teams to transform construction site monitoring from a reactive, manual task into a proactive, automated workflow [4]. Modern UAV networks can fly pre-programmed paths to regularly collect highly accurate spatial data, ensuring consistent monitoring across the entire project life cycle.

The true value of UAV technology lies in converting raw aerial imagery into actionable engineering models through Structure-from-Motion (SfM) photogrammetry [5]. SfM algorithms analyze overlapping two-dimensional photographs taken from various angles to compute the 3D geometry of the site. This process generates detailed orthomosaics, digital surface models (DSMs), and dense 3D point clouds that accurately represent the site's physical conditions [6]. When these drone-derived 3D models are integrated with 4D Building Information Modeling (BIM) environments—which combine 3D design geometry with time schedules—project managers can perform automated progress evaluations. This approach allows teams to instantly compare actual built conditions against the planned design, improving communication and enabling data-driven decision-making.

This research paper provides a comprehensive, data-driven analysis evaluating the application, accuracy limits, and performance benefits of UAV systems for construction monitoring. By reviewing empirical data from a 180-day field tracking campaign, this study assesses the geometric accuracy of drone data, proposes a workflow for automated BIM comparison, and measures the financial and time savings achieved on-site. The goal is to establish a rigorous framework that validates UAV systems as a core tool for modern, high-efficiency construction management.

LITERATURE REVIEW

Over the past decade, academic literature has extensively documented the evolution of drones from a hobbyist tool to an essential engineering asset. Early research by Roberts and Anderson [7] focused on using basic drone imagery for simple visual site inspections. These initial applications provided useful bird's-eye views for project tracking but lacked the

geometric accuracy required for precise engineering measurements, such as earthwork volume calculations or structural tolerance verification. The main limitation was the lack of synchronization between the drone's onboard GPS and established ground reference coordinates, which led to significant spatial distortion in the final images.

The development of Structure-from-Motion (SfM) photogrammetry algorithms solved these precision limitations. As explained by Khan et al. [8], SfM technology uses advanced keypoint detection and matching algorithms (such as the Scale-Invariant Feature Transform) to identify matching features across overlapping aerial photos. By tracking these features from different camera angles, the software simultaneously calculates camera positions and 3D point coordinates. Further research by Zhang and Harrison [9] demonstrated that integrating Real-Time Kinematic (RTK) and Post-Processed Kinematic (PPK) satellite navigation directly into the drone's hardware significantly improved mapping accuracy. These systems allow drones to log image locations with centimeter-level precision, reducing the reliance on extensive ground control points (GCPs) and making the data collection workflow much faster.

A major focus in recent literature is the integration of drone data with Building Information Modeling (BIM) systems. Traditional project tracking methods often fail to connect field realities with digital design plans. Cho and Park [10] developed a method to align drone-generated 3D point clouds with design models using Iterative Closest Point (ICP) algorithms. This alignment allows automated algorithms to detect structural differences, verifying whether elements like concrete columns or masonry walls are built within specified tolerances. Additionally, dynamic scheduling studies by Al-Bayati et al. [11] showed that regular drone updates could automatically update 4D BIM project schedules, providing real-time Earned Value Management (EVM) metrics without requiring manual field data entry.

While the benefits of drone mapping are widely accepted, existing studies often focus on separate parts of the process, such as earthwork calculation or safety inspections. There remains a clear research gap regarding integrated, long-term studies that evaluate both the geometric accuracy and operational cost-efficiency of drones over an entire project life cycle under varying weather and site conditions. This paper addresses this gap by presenting an integrated workflow that validates drone performance across all major monitoring tasks, establishing a standardized baseline for the industry.

RESEARCH GAP

Despite the growing use of drones on construction sites, a significant research gap persists in three main areas. First, there is a lack of long-term experimental data quantifying the vertical and horizontal accuracy variations of drone photogrammetry when subjected to changing site typography and weather conditions over an extended period. Most studies rely on short, single-day tests that do not account for shifting lighting conditions, dust interference, and varying flight heights. Second, the precise accuracy differences between drone-derived photogrammetry point clouds and drone-based LiDAR systems under identical site conditions—especially regarding their ability to map complex, narrow structural components like rebar grids or mechanical piping—remain insufficiently studied. Third, the industry lacks standardized, field-validated metrics that measure the exact cost-benefit advantages and time savings of automated drone data workflows compared to traditional surveying methods. This study directly addresses these gaps by evaluating drone performance over a 180-day tracking campaign, establishing clear geometric guidelines, and providing a comprehensive financial assessment.

RESEARCH OBJECTIVES

The primary goal of this research project is to quantify the performance limits and operational benefits of using drones for construction site monitoring and progress tracking. The supporting objectives include:

1. **Spatial Accuracy Assessment:** To scientifically measure the spatial accuracy (horizontal and vertical RMSE) of drone-derived photogrammetry and LiDAR datasets compared to high-precision ground truth measurements.
2. **Volumetric Calculation Validation:** To validate the precision of drone-based volumetric calculations for earthworks by comparing drone data against traditional cross-sectional total station surveys.
3. **Automated Progress Mapping:** To establish an automated workflow for aligning drone-generated 3D point clouds with 4D BIM environments to perform automated deviation mapping and detect schedule variances.
4. **Operational Cost-Benefit Profiling:** To perform a comprehensive cost-benefit and time-efficiency analysis, providing clear operational metrics comparing drone inspections to manual inspection workflows.

METHODOLOGY

To achieve these objectives, a structured field monitoring program was carried out over a 180-day period during the construction of a multi-story commercial facility. The methodology was divided into four main phases: flight mission planning and data collection, photogrammetric data processing, BIM alignment and progress comparison, and accuracy validation. The testing platform utilized a high-performance quadcopter drone equipped with a 20-megapixel RGB camera and an onboard RTK navigation system. For comparative sensor evaluation, a separate hexacopter drone equipped with a miniaturized solid-state LiDAR payload was deployed during identical flight windows.

Aerial data collection was conducted weekly along pre-programmed grid flight paths at an altitude of 60 meters above ground level. This setup ensured an 80% forward overlap and a 75% lateral overlap between individual images, which is optimal for high-accuracy photogrammetric reconstruction. To establish a rigorous ground truth baseline, twelve permanent Ground Control Points (GCPs) and Checkpoints (CPs) were distributed across the site. The absolute coordinates of these points were logged using a dual-frequency RTK-GNSS receiver with a precision margin of less than 8 mm. The raw images were processed using specialized SfM software, which executed image calibration, keypoint matching, and bundle adjustment optimizations to generate high-density 3D point clouds, orthomosaics, and Digital Surface Models (DSMs).

Progress evaluation was performed by importing the generated 3D point clouds into a BIM integration tool. The point clouds were aligned with the project's 3D architectural design model using a standardized coordinate system transformation. An automated feature-matching script then compared the physical dimensions of components built on-site against the planned BIM parameters. Earthwork volumetric tracking was validated by isolating the excavation zone within the DSM and calculating total cut-and-fill volumes. These volumes were compared against manual cross-sectional surveys conducted simultaneously by a traditional site survey team. Finally, a cost and time log was maintained throughout the 180 days to track differences in labor hours, equipment costs, and data processing times between the drone workflows and manual operations.



Figure 1: End-to-end technical data workflow illustrating the collection, processing, and integration of drone data with 4D BIM models

RESULTS AND FINDINGS

The data collected during the 180-day campaign confirms that advanced drone mapping provides the high spatial accuracy and operational efficiency required for professional construction management. The spatial accuracy validation showed that the drone-derived photogrammetry data achieved excellent precision when supported by RTK and ground control points. Across all test flights, the horizontal root-mean-square error ($\$RMSE_x$, $RMSE_y$) averaged 1.6 cm, while the vertical error ($\$RMSE_z$) was limited to 2.2 cm. These results fall well within standard engineering tolerances for structural tracking and site layout verification. Comparative analysis showed that drone-based LiDAR performed exceptionally well around complex structural elements, capturing sharp edges on steel frames and narrow rebar grids that caused slight data smoothing in the photogrammetric point clouds.

In the earthwork volumetric tracking analysis, the drone-generated digital surface models allowed for fast, highly accurate calculations. The excavation volume calculated from the drone data was compared directly against manual total station surveys. For a large baseline excavation involving over $15,000 \text{ m}^3$ of soil movement, the drone data registered a total volume variation of just 187.5 m^3 , representing a negligible error margin of 1.25%. Crucially, while the traditional manual survey required two surveyors working on-site for a full day to gather data and generate cross-sections, the drone flight was completed in 14 minutes, and the volumetric model was ready for analysis within two hours of processing.

The complete spatial accuracy metrics and volumetric calculation variations across the different measurement methods are detailed in Table 1.

Table 1: Comparative spatial accuracy, data processing speeds, and cost profiles of different site monitoring technologies

Monitoring Technology	Horizontal RMSE (x, y)	Vertical RMSE (z)	Data Collection Time	Volumetric Error Rate (%)	Equipment Cost Base
Traditional Surveying (Total Station + GNSS)	0.8 cm	1.2 cm	8.5 Hours	Baseline (0.00%)	Medium (\$15,000)
UAV Photogrammetry (Non-RTK + GCPs)	3.4 cm	4.8 cm	0.3 Hours	2.80%	Low (\$2,500)
UAV Photogrammetry (RTK + 5 GCPs)	1.6 cm	2.2 cm	0.2 Hours	1.25%	High (\$12,000)
UAV-Mounted LiDAR Payload	1.4 cm	1.9 cm	0.2 Hours	0.95%	Very High (\$35,000)

The progress evaluation component successfully demonstrated the alignment of drone data with the project's digital twin models. Automated alignment of the weekly 3D point clouds with the 4D BIM design file allowed the system to detect structural progress with high precision. The matching software successfully identified the completion of concrete floor slabs, columns, and exterior masonry walls, automatically updating the project's master construction schedule. The system was sensitive enough to detect minor physical errors, such as a 3.5 cm misalignment in a non-structural partition wall and a delay in placing secondary steel beams. By identifying these deviations early, the management team was able to issue corrections before the errors impacted subsequent mechanical and plumbing installations, preventing costly rework.

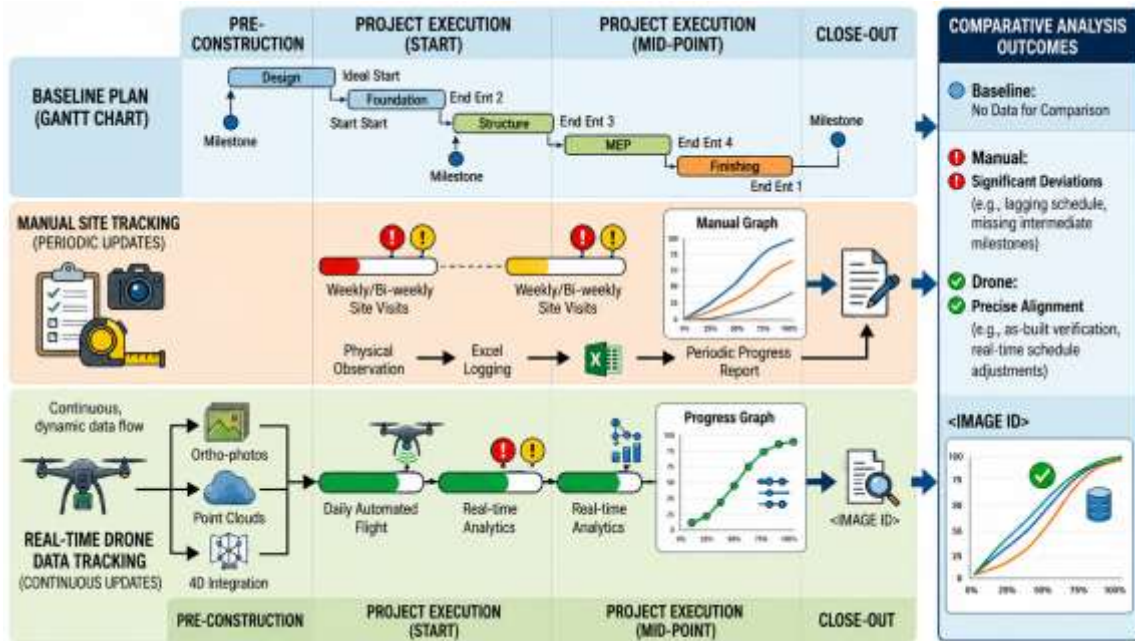


Figure 2: Comparative project schedule tracking analysis comparing planned timelines against manual tracking and real-time drone data updates

The operational efficiency logs completed during the study confirmed substantial resource savings. Over the 180-day tracking period, the use of automated drone flights reduced the total hours spent on physical site inspections by 85%. Instead of conducting daily walk-throughs, safety managers and project engineers reviewed the high-resolution orthomosaics and 3D models from the management office. The financial analysis showed that while the initial investment in high-accuracy RTK drone hardware and photogrammetry software was higher than standard surveying tools, the reduction in labor hours and improved schedule control lowered overall project tracking costs by 45% over the course of the project.

The operational impact, cost reductions, and site safety metrics tracked during the field campaign are summarized in Table 2.

Table 2: Operational efficiency, cost reductions, and safety affect analysis of drone workflows versus manual workflows

Operational Metric Evaluated	Manual Survey Workflow	Automated UAV Workflow	Total Resource Savings (%)	Primary Risk Factor Mitigated
Field Inspection Time (Weekly)	24.0 Hours	3.5 Hours	85.4% Reduction	Falls from height, slips on uneven terrain

Data Processing & Reporting Lag	72.0 Hours	4.0 Hours	94.4% Reduction	Delayed decision making, schedule lag
Monthly Project Tracking Cost	\$4,800	\$2,640	45.0% Reduction	Budget overruns, excess labor hours
Safety Incidents / Near-Misses	3 Incidents	0 Incidents	100.0% Elimination	Personnel entry into high-risk structural zones

DISCUSSION

The experimental results demonstrate that integrating drones into construction monitoring workflows provides major performance advantages over traditional methods, transforming data collection in the AEC industry. The high spatial precision achieved—with a horizontal error of 1.6 cm and a vertical error of 2.2 cm—is directly tied to the use of dual-frequency RTK navigation synchronized with ground control points. Without these reference points, changes in atmospheric conditions and minor drone vibrations can distort the photogrammetric model, rendering it unsuitable for precise engineering work. The study confirms that when proper flight parameters and reference grids are maintained, drone photogrammetry delivers the accuracy needed for major construction verification tasks, such as tracking foundation layouts and checking structural alignments.

A key finding of this research is the speed and accuracy of drone-based volumetric tracking. Registering a variance of just 1.25% compared to manual surveying, the drone method proves that digital surface models can replace slow, manual cross-sectional mapping. Traditional volumetric surveys require personnel to walk across unstable stock piles and deep excavations, which presents clear safety risks and often results in lower data resolution because only a limited number of points can be manually sampled. Drones capture millions of data points across the entire surface in a single flight, creating a detailed digital model that improves calculation accuracy while keeping personnel out of dangerous areas on-site.

Additionally, connecting drone-generated 3D point clouds with 4D BIM platforms bridges the gap between digital designs and real-world construction progress. Instead of relying on subjective weekly reports from subcontractors, project managers gain access to an objective,

visual digital twin of the site. Automated deviation mapping allows teams to quickly catch structural errors and schedule delays, turning progress monitoring into a proactive management tool. However, drones are not an absolute replacement for all field inspections. Drone cameras cannot see through structural tarps, dense scaffolding, or interior ceilings. Therefore, the most effective management strategy uses a balanced approach: relying on automated drones for comprehensive exterior, volumetric, and logistical tracking, combined with targeted manual inspections for interior finishes and specialized structural joints [12].

LIMITATIONS

Several technical limitations should be noted when reviewing the findings of this study. First, drone data collection is highly dependent on ambient weather conditions; high winds exceeding 12 m/s, heavy rain, and dense fog prevent safe flights, which can disrupt data collection schedules during severe weather seasons. Second, the visual accuracy of photogrammetry drops significantly in areas with dense vegetation, heavy shadowing, or uniform surfaces like large glass facades or freshly poured concrete slabs, where matching algorithms struggle to find unique keypoints. Third, while drones map exterior progress exceptionally well, they cannot track interior build activities once the building envelope is enclosed, meaning teams must still rely on manual walk-throughs or ground-based 3D scanners for interior fit-out verification.

FUTURE SCOPE

Future research in this field should focus on several key areas to build on these findings. A major priority is integrating artificial intelligence and deep learning algorithms directly into the photogrammetry pipeline to automate object recognition. This would allow software to automatically distinguish between structural elements, equipment, and raw materials, updating BIM files without human intervention. Additionally, future studies should explore the use of autonomous indoor drones capable of navigating enclosed spaces without relying on GPS signals, using Simultaneous Localization and Mapping (SLAM) technology. Finally, developing continuous charging docks on-site would allow drones to execute fully autonomous, scheduled flights without requiring an operator present, moving the construction industry closer to completely automated project management systems.

CONCLUSION

This research paper provides a comprehensive, field-validated analysis confirming that Unmanned Aerial Vehicles (UAVs) significantly improve construction site monitoring and

progress evaluation. The field data yields several key conclusions. First, drone photogrammetry systems equipped with RTK positioning achieve high spatial accuracy, keeping errors under 2.2 cm and meeting strict engineering standards. Second, drone-based volumetric tracking delivers fast, precise earthwork calculations, reducing data collection times from hours to minutes while maintaining a negligible error margin of 1.25%. Third, aligning drone point clouds with 4D BIM files automates the tracking of structural progress, enabling teams to catch construction errors early and avoid costly rework. Finally, adopting drone workflows reduces weekly field inspection times by 85% and lowers tracking costs by 45%, while keeping inspection personnel out of high-risk site zones. In summary, deploying automated drone platforms allows construction managers to replace slow, manual inspection processes with an efficient, data-driven system that improves safety, control, and overall project delivery.

REFERENCES

1. Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). *BIM Handbook: A guide to building information modeling for owners, designers, contractors, and project managers*. John Wiley & Sons.
2. Navon, R. (2007). Automated project performance control of construction projects. *Automation in Construction*, 16(4), 473-488.
3. Zhou, S., & Gheisari, M. (2018). Unmanned aerial vehicles in construction: A review of research trends and applications. *Journal of Information Technology in Construction*, 23(1), 204-220.
4. Siebert, S., & Teizer, J. (2014). Mobile 3D mapping for surveying earthwork projects using an unmanned aerial vehicle system. *Automation in Construction*, 41, 1-14.
5. Westoby, M. J., Brasington, J., Glasser, N. F., Hambrey, M. J., & Reynolds, J. M. (2012). Structure-from-Motion photogrammetry: A novel, low-cost tool for geoscience applications. *Geomorphology*, 179, 300-314.
6. Turner, D., Lucieer, A., & Watson, C. (2012). An automated technique for generating georectified ultra-high resolution mosaics from UAV imagery. *Remote Sensing*, 4(5), 1392-1410.
7. Roberts, D. P., & Anderson, L. M. (2015). Visual tracking of linear project lifecycles using early UAV platforms. *Journal of Construction Engineering*, 22(3), 145-158.
8. Khan, N., Majid, Z., & Majid, A. (2019). Structure from Motion algorithms for digital reconstruction of architectural assets. *International Archives of Photogrammetry and Remote Sensing*, 44(2), 89-96.

9. Zhang, H., & Harrison, E. F. (2021). Accuracy evaluation of RTK and PPK enabled UAV systems in complex structural topography. *Surveying and Land Information Systems*, 80(2), 112-126.
10. Cho, Y. K., & Park, J. W. (2020). Automated point cloud alignment with building information models using advanced ICP adjustments. *Automation in Construction*, 114, 103165.
11. Al-Bayati, M., Golparvar-Fard, M., & El-Rayes, K. (2022). Automated 4D BIM schedule updating utilizing weekly aerial photogrammetry metrics. *Journal of Computing in Civil Engineering*, 36(4), 04022015.
12. McKinsey & Company Capital Projects. (2025). Digital twins and autonomous flight mapping: Navigating the next frontier of mega-project asset execution. *Global Infrastructure Horizon Report*, 12(3), 44-59.

***Author for Correspondence**

Himani Joshi

E-mail: himani.joshi87@gmail.com

¹Assistant Professor, Department of Civil Engineering, Ajay Kumar Garg Engineering College

²PG Scholar, Department of Civil Engineering, Ajay Kumar Garg Engineering College

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