Integrated BIM and UAV-Based Oblique Photogrammetry for High-Precision Earthwork Volume Calculation and Verification: A Case Study of the Dawang Mountain Snow World Project

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Abstract: In large-scale projects with complex geological conditions and harsh site environments, traditional earthwork data collection methods suffer from low accuracy, poor efficiency, and inadequate safety. Taking the Changsha Dawang Mountain Ice and Snow World project as a case study, this paper investigates the synergistic application of Building Information Modeling (BIM) and Unmanned Aerial Vehicle (UAV) oblique photogrammetry technology. By streamlining the technical process and establishing a collaborative path of "data collection-model fusion-dynamic optimization," three key technical characteristics are identified: parametricity, visualization, and collaboration. The integration of these technologies highlights the primary advantages of precision and digitalization in achieving deep integration of data and scenarios, while the high efficiency and improved coordination lead to substantial economic benefits. Practical results demonstrate that BIM + UAV surveying technology can control elevation measurement errors within ±0.1m in pit terrain, with planar coordinate errors as low as 0.08m. Efficiency surpasses traditional methods by over 80%. This approach proposes comprehensive optimization for industry-standardized collaborative management and urgent technical challenges. This technology significantly enhances measurement accuracy in complex terrain earthwork data collection, thereby reducing result errors and boosting data acquisition efficiency. It provides both theoretical contributions and practical case studies for the collaborative advancement of BIM technology.

Keywords: BIM; UAV Oblique Photogrammetry; Earthwork Data Collection; Changsha Dawang Mountain Snow World

1. Introduction

The integration of digital technology with the construction industry has brought significant transformation to the sector. Since 2011, the Ministry of Housing and Urban-Rural Development has repeatedly advocated for the vigorous promotion of intelligent construction and the deep application of BIM technology in the construction field to enhance the modernization level of the industrial chain[1]. This underscores that intelligent construction and technological innovation are inevitable choices for achieving high-quality development in the construction sector[2], driving the emergence and advancement of new tools such as BIM, drones, and artificial intelligence. Traditional methods for field data collection and office-based earthwork calculations suffer from low measurement efficiency and accuracy, failing to meet the demands of modern development.

In recent years, both BIM technology and UAV oblique photogrammetry have experienced rapid development and widespread application. Song Xiaogang et al.[3] utilized BIM technology to optimize design and achieve green intelligent construction management; He Yuanrong et al.[4] applied UAV oblique photogrammetry combined with 3D laser scanning for the 3D reconstruction of ancient buildings; Li Bo and Xu Jinghai[5] employed UAVs for earthwork calculations, effectively streamlining workflows and enhancing computational accuracy. It is evident that the integration of BIM and UAV technology encompasses research domains including smart construction site systems, ancient building preservation and model reconstruction, and road earthwork calculations. However, theoretical research and practical summaries on their collaborative pathways remain scarce, while industry-standardized collaborative management and technical challenges demand urgent resolution. Compared to traditional earthwork data collection methods, “BIM + UAV” technology offers significant advantages. By applying theoretical methods for BIM + UAV collaboration through project case studies, practical challenges in real-world projects can be effectively addressed.

2. Development History and Current Research Status of BIM and UAV Oblique Photogrammetry Technology

2.1 The Evolution of BIM and UAV Oblique Photogrammetry Technology

The development of “BIM + UAV” technology has evolved from its early stages—when technical limitations and high costs confined its use to rudimentary documentation—to become a low-cost, high-precision oblique photogrammetry and data acquisition technique. Through continuous optimization in recent years, it now supports automated site recognition, real-time modeling, and technical collaboration, meeting diverse application demands[6]. The advent of computer-aided design laid the foundation for digital modeling in the construction industry. From the formal introduction of the “BIM” concept over three decades ago and the launch of Revit software, to today's deep integration with drones achieving hardware-software compatibility, the convergence of drones with Building Information Modeling (BIM) and construction automation has grown increasingly tight[7].

2.2 Current Research Status of BIM and UAV Oblique Photogrammetry Technology

The “BIM + UAV” technology leverages its outstanding advantages in digitalization and automation, finding primary application throughout the entire construction process—including architectural planning and design, construction engineering, and the preservation of architectural heritage. In architectural planning and design, this technology facilitates parametric modeling, design analysis, and data collection, significantly enhancing work efficiency and digitalization levels, with particularly notable advantages during the early design stages[8]. Construction processes involve unpredictability and substantial challenges[9], where operating drones enables tasks such as progress monitoring and surveying complex terrains.

3. Fundamental Principles and Technical Pathways of BIM and UAV Oblique Photogrammetry Technology

3.1 Fundamental Principles of BIM and UAV Oblique Photogrammetry Technology

3.1.1 Fundamental Principles of UAV Oblique Photogrammetry

UAV oblique photogrammetry employs five sensors mounted on the airframe (one vertical and four oblique lenses) integrated with a POS system to synchronize imagery and data. With a field of view spanning 45°–60°, it captures multi-angle positional data of ground objects, effectively resolving texture gaps on building facades and transforming traditional surveying's “point-to-surface” approach. The UAV automatically acquires continuous ground imagery along a preset flight path (Figure 1), primarily employing array flight patterns supplemented by circular flight patterns (Figure 2)[6]. By integrating collected texture data with survey imagery and undergoing geometric correction, UAV oblique photogrammetry generates 3D models that restore physical site environments and enable digital measurement.

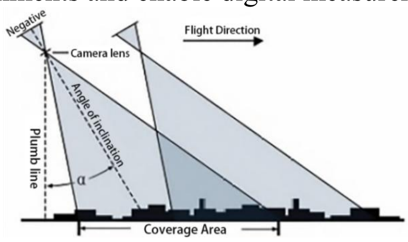

Figure 1. Principle Diagram of Oblique Photogrammetry

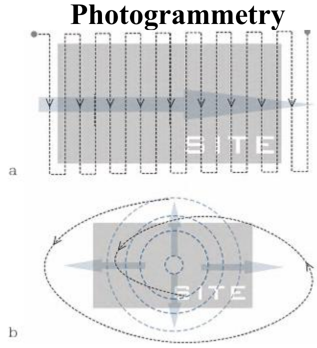

Figure 2. Flight Trajectory Diagram (a: Array Flight, b: Orbiting Flight)

3.1.2 Fundamental Principles of Building Information Modeling (BIM)

BIM refers to the use of digital technology to create structured information models throughout the entire lifecycle of building planning, design, construction, operation, and maintenance (Figure 3), enabling information exchange and sharing[10]. By establishing digital models to virtually present projects, BIM facilitates expressions ranging from three-dimensional to five-dimensional representations. This promotes collaboration among multiple stakeholders—including design and construction firms, owners, and government departments—enabling efficient project coordination and refined management.

Figure 3. BIM Structured Information Model

3.2 Technical Pathways for Integrating BIM with UAV Oblique Photogrammetry Technology

"BIM + UAV" establishes a data-driven collaborative management platform to enable real-time interaction and sharing between building information models and field data[11]. UAV oblique photogrammetry provides precise data for site analysis, being primarily employed for complex terrain surveying and data acquisition; BIM focuses on parametric modeling to deliver comprehensive lifecycle information for target structures. By integrating surrounding environmental conditions with internal structural data, this approach enables comprehensive oversight of construction processes.

Prior to earthwork data collection, a technical plan must be developed based on the project's topographical characteristics. Core project metrics are defined, UAV equipment parameters are determined, and collection areas are delineated. Using the BIM model's site boundaries, flight parameters such as altitude and overlap are preset through UAV flight path planning. Design drawings are imported into Revit software to create terrain models and construct the BIM framework.

Drone-based oblique photogrammetry captures multidimensional data, providing realistic, high-density raw data for earthwork calculations. A "multi-rotor drone + LiDAR + five-lens camera" system collects three types of data: tilted imagery, laser point clouds, and POS data. The field data collected by UAVs is converted into a form compatible with the BIM model. Simultaneously, data preprocessing generates a Digital Surface Model (DSM) and a Digital Elevation Model (DEM). The DEM data is imported into the BIM software to automatically generate the existing terrain surface model. The "coordinate alignment" function of the BIM software is utilized to complete model calibration. The workflow summary is shown in Figure 4.

BIM software calculates the "total earthwork volume = total excavation volume - total backfill volume" using the polyhedron method based on the volume difference between the designed terrain and the existing terrain. For complex terrains such as mine pit slopes, the slope inclines are extracted from the BIM model, and the slope earthwork volume is calculated as "slope area × average excavation thickness." Subsequent dynamic monitoring throughout the entire project cycle is achieved through regular drone re-surveys and dynamic updates to the BIM model.

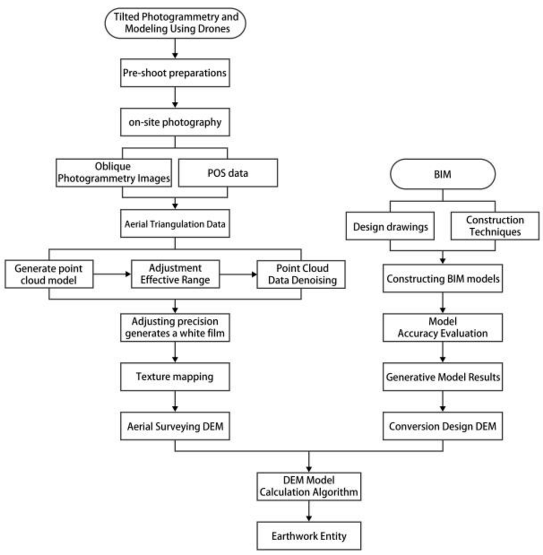

Figure 4. Summary of the "BIM + UAV" Technology Workflow

4. Characteristics, Advantages, and Challenges of BIM and UAV Oblique Photogrammetry Technology

4.1 Characteristics of BIM and UAV Oblique Photogrammetry Technology

4.1.1 Parametric

The core of BIM technology lies in parametric modeling techniques[12]. UAV oblique photogrammetry data offers high precision and a high degree of automation in post-processing, accurately reflecting site conditions. Combined with multi-source data collected through acquisition, both can be used to create three-dimensional models based on data association technology.

4.1.2 Visualization

Compared to traditional two-dimensional drawings, three-dimensional models offer more intuitive visualization, supporting engineering technicians in comparing and modifying construction plans[13]. UAV oblique photogrammetry provides flexible operation and rapid delivery of visual image data, while BIM models enable visual representation of equipment and facilities across construction phases, as well as the phased progress of main building structures.

4.1.3 Synergy

Coordination plays a vital role in the construction industry, involving the collaborative efforts of all project stakeholders. The integration of BIM and drone technology enables seamless coordination across project phases, minimizing communication gaps. Post-construction operations and maintenance management leverages comprehensive 3D models, integrating model data with O&M systems to achieve efficient asset information sharing and management[1].

4.2 Advantages of BIM and UAV Oblique Photogrammetry Technology

4.2.1 Technical advantages are becoming increasingly evident

The collaborative visualization and parametric characteristics of “BIM + UAV” technology effectively enhance the precision and digitization of photogrammetry and model creation. On the one hand, visualization achieves deep integration between data and scenes. Drones accurately capture dimensional data and location information for elements like buildings and roads. High-resolution site information recognition significantly reduces errors and improves measurement accuracy. On the other hand, BIM technology converts collected point cloud data into parametric models, enabling real-time updates and adjustments to form a dynamic optimization system. Compared to traditional surveying methods, this approach offers substantial technical advantages.

4.2.2 Enhanced Economic Benefits

The integration of BIM and drone technology effectively reduces repetitive tasks, saves working hours, and boosts efficiency. The resulting high efficiency and coordination translate into greater economic benefits. Traditional earthwork surveying relies on manual rock climbing or setting up survey stations, where harsh working conditions are not only time-consuming and labor-intensive but also carry high risk factors, exposing personnel to greater challenges. In recent years, with the widespread adoption of drone technology and the rapid development of civilian drones, the cost of drone equipment has trended downward, significantly enhancing its economic advantages.

4.3 Challenges in BIM and UAV Oblique Photogrammetry Technology

Currently, academic research on “BIM + UAV” technology in China's construction industry has yielded significant results. However, several critical issues remain to be addressed regarding the application of digital technologies.

(1) Insufficient standardized collaborative management. Incompatibilities between file formats across different software platforms may lead to partial information loss, impeding data exchange. During the full-process digital transformation, project operations lack centralized management [10] and other issues.

(2) High software and hardware requirements. During the import and conversion of point cloud data collected by UAVs into Revit software, minor data loss may occur in local textures and detailed information, affecting the rendering quality of 3D models and scenes. Software used for BIM model conversion must possess significant processing power to minimize data import failures, model lag, and software crashes. This highlights the high demands digital technology places on the precision of UAV equipment and the computational power of BIM software.

(3) Adverse environmental impacts. Adverse natural conditions---such as insufficient lighting,

inclement weather, or natural disasters---can hinder preliminary photogrammetric surveys and data collection, potentially leading to inaccurate measurements or blurred imagery and resulting in measurement errors. Therefore, UAV survey flights should ideally be scheduled during bright, cloudy weather or around noon [14]. Additionally, complex field conditions demand high levels of technical expertise and practical operational skills from personnel.

5. Case Study Application: The Changsha Dawangshan Ice and Snow World Project

This project is located within the Dawang Mountain Tourism Resort in Changsha City. The site was formerly occupied by the Changsha Xinsheng Cement Factory, where over fifty years of mining operations resulted in abandoned quarry pits (Figure 5). The overall layout ingeniously utilizes the existing topography, seamlessly integrating the disused quarry pits with natural cliff walls to create an ice and snow wonderland that appears to float above the quarry (Figure 6).

Figure 5. Project Topography and Landforms

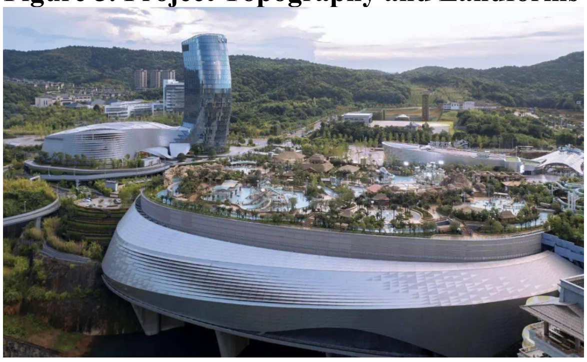

Figure 6. Final Construction Effect of Dawang Mountain Tourism Resort

This project primarily relies on the collaborative use of UAV oblique photogrammetry and BIM technology to complete earthwork data collection. The total project area spans 90.13 km², with a pit depth of 100 m, length of 440 m, width of 350 m, and an upper opening area of approximately 180,000 m². The site environment is harsh, posing significant challenges for data acquisition. Traditional surveying methods such as grid sampling, cross-sectioning, and contour mapping proved inadequate for accurately capturing on-site imagery. These approaches failed to meet the project's requirements for precise digital terrain parameters during main construction phases. Consequently, UAVs were deployed to survey the site and its surroundings, enabling rapid and efficient measurement of earthworks while ensuring accurate acquisition of point cloud data.

UAV aerial surveys capture high-resolution imagery and geographic data of the site. Aerial imagery and POS data undergo geometric correction and dense matching for data preprocessing. DSM data extracted from the 3D model is processed to derive DEM information [15]. The measured data is imported into BIM software, where computer-reconstructed terrain surfaces enable earthwork calculations, laying the foundation for subsequent construction phases. For earthwork site leveling, GPS RTK equipment is used to collect on-site topographic data. Comparing these calculations with UAV earthwork volume estimation methods reveals that smaller grid sizes yield more precise results that closely align with UAV-calculated earthwork volumes (Figure 7).

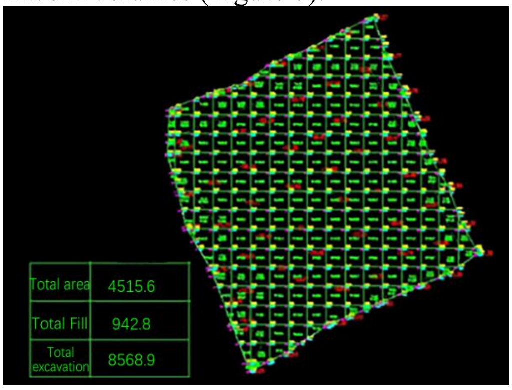

Figure 7. Traditional Grid Quantity Takeoff

Field data collection was conducted using the DJI Matrice 300 RTK equipped with a Zenmuse P1 camera. Post-processing involved triangulation and 3D mesh model generation using DJI Terra software. ArcGIS was employed for data analysis. For the 100-meter-deep pit at the Dawang Mountain project, layered aerial surveying was implemented alongside oblique-angle flight paths. The tilt angles of the lenses were adjusted to avoid data gaps caused by obstructions Specific UAV aerial survey parameters: Three flight passes completed scanning of an 180,000-square-meter site, yielding 2,300 images and 120 million point cloud data points. Flight path overlap reached

80%, with side overlap at 85%. Parameters for the layered aerial survey of the mine pit are detailed in Table 1.

Table 1. Aerial Survey Parameters for Mine Pit Stratification

Stratification	Depth range (meters/m)	Flight altitude (meters/m)	Flight Speed (m/s)	Course Overlap (%)	Lateral Overlap (%)
TOP	0-30	150	12	70	75
MIDDLE	30-70	100	8	75	80
BOTTM	70-100	80	5	80	85

The “BIM + UAV” technology lays the foundation for achieving synchronized project construction. Building upon earthwork surveys conducted during the project's initial phase, engineers can overlay BIM 3D models with real-world site models to visually monitor construction progress and identify structural-rock wall collision risks (Figure 8). During the project's early stages, accuracy rates for traditional 2D surveying tools and 3D BIM surveying methods were 50% and 75%, respectively, while the combined UAV-BIM approach achieved 100% accuracy [8]. Traditional RTK surveying for a mining site required three personnel over seven days, with an additional two days for in-house data processing. In contrast, UAV oblique photogrammetry surveying required only one person for two hours, followed by six hours of in-house data processing and modeling, resulting in an overall efficiency improvement of 80% (Figure 9). In summary, the application of BIM and UAV oblique photogrammetry in earthwork data collection for complex terrains demonstrates excellent adaptability, effectively enhancing measurement precision and digital information modeling.

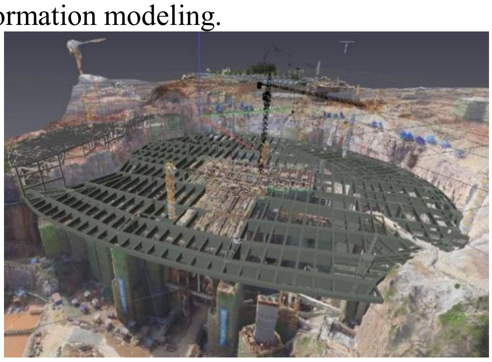

Figure 8. Actual Site + BIM Progress Visualization

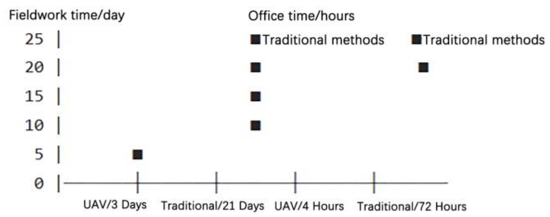

Figure 9. Efficiency Comparison Bar Chart

6. Summary

The rapid development and widespread application of BIM and UAV oblique photogrammetry technology have significantly enhanced the efficiency and accuracy of earthwork data collection. In special environments characterized by complex geological conditions, extremely harsh site environments, and large upper openings, traditional earthwork data collection methods suffer from poor adaptability to pit topography, low accuracy in rock surface surveying leading to substantial measurement errors, and low measurement efficiency. Consequently, they fail to meet project requirements. This paper first conducts a visual analysis of the collaborative technical pathways and workflow of “BIM + UAV” technology, summarizing its three key characteristics: parametric nature, visualization, and collaborative capability. The integration of these technologies prominently demonstrates precision and digitalization, achieving deep integration of data and scenarios. The primary advantages lie in the transformation of high efficiency and coordination into economic benefits. However, it also highlights pressing issues requiring resolution, such as standardized collaborative management within the industry and technical barriers. Finally, a case study examines the application of “BIM+UAV” technology in earthwork data collection for the Dawang Mountain Tourist Resort project. It demonstrates how this technology effectively enhances measurement accuracy, reduces result errors, improves earthwork data collection efficiency, and exhibits strong adaptability to complex terrains. This provides both theoretical contributions and practical case evidence for the collaborative development of BIM technology.

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