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Estimation of the Physical Progress of Work Using UAV and BIM in Construction Projects

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Abstract

The delay in the physical progress of construction creates additional costs, missed deadlines, and quality issues. The research aimed to estimate the physical progress of the project by using unmanned aerial vehicles (UAVs) and building information modeling (BIM). The methodology comprised capturing 848 high-resolution images of the Civil Engineering Laboratory construction site at the National University of Jaen, Cajamarca, Peru, using the Phantom 4 RTK drone. The photographs were processed using Agisoft 2.0.1 software, resulting in a point cloud. This was then imported into ReCap Pro 2023 software, which was used to assess the quality of the points. The Revit 2023 software was subsequently utilized to establish the phase parameters, linking the BIM model with the point cloud, filtering the model, and eventually exporting it to the Power BI 2023 software. The work's estimated progress utilizing the proposed methodology was 42.82%, which was not statistically significant compared to the Public Works Information System (INFOBRAS) of 43.14%. This allows for the automation of customary processes, the identification of crucial issues, and prompt decision-making. The study's originality lies in the suggestion of integrating aerial imagery with drones and BIM modeling for the real-time and precise estimation of work progression. This method provides a precise and effective substitute for traditional techniques for gauging the tangible advancement of projects.

Keywords: BIM; Construction Automation; Construction Progress; Project Management; UAV.

1. Introduction

The construction industry plays a pivotal role in the global economy. It is responsible for planning, designing, constructing, and maintaining infrastructure and buildings [1]. Additionally, it promotes economic growth and enhances the quality of life of citizens [2]. From constructing residential and commercial buildings to developing transport and energy infrastructure [3], this industry is dynamic and constantly evolving due to technological advancements and changes in market demands [4]. It is projected that the industry will reach a value of $15 trillion by 2025, indicating a 70% increase from its value in 2013 [5]. Nonetheless, the industry is constantly confronted with challenges in effectively managing projects, such as deficient visibility and control over physical progress, coordination, proper planning, and efficient team communication. Delayed progress and design changes have a direct impact on resource and labor planning, as well as the allocation of materials and equipment. This can lead to delays, conflicts, poor time management, and additional costs [6].

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Construction progress is a crucial metric in project management. To ensure deadlines and project goals are achieved, it is crucial to have accurate and timely updates on work progress. Additionally, having precise and comprehensive design data that aligns with the intended construction plan is essential [7]. Traditionally, designs have been created in two dimensions, and construction progress has been monitored through visual inspections and manual measurements. These methods are time-consuming and can result in inaccuracies. Project managers without an appropriate tracking tool may face difficulties in identifying and addressing issues promptly, which can lead to missed deadlines and delayed work delivery. However, recent advancements in construction technology have led to the development of more effective and precise techniques for tracking progress [8].

One of the technologies that has revolutionized the monitoring of construction progress in the construction industry is the application of unmanned aerial vehicles (UAVs) [9], which are valuable tools in different industries within the framework of Industry 4.0 [10]. UAVs are equipped with cameras and sensors that capture accurate images and data from different angles and heights [11, 12], making them ideal for monitoring the progress of work [13]. They use photogrammetry and laser scanning to generate three-dimensional models that are used to perform calculations of areas, volumes, and distances [14]. In addition, they have proven to be an effective tool for estimating the physical progress of construction projects, as they fly over the site at regular intervals and capture images and video of the current state [13]. However, despite the growing interest in UAVs in construction, there is a lack of scientific information on the methods and specific applications in this field [15]. For this reason, researchers recommend performing integration with Building Information Modeling (BIM) to generate complex models that emulate the construction state [16].

The implementation of BIM yields a more precise analysis of construction development by generating 3D models that encompass relevant infrastructure data, including materials, structures, electrical systems, plumbing, and architecture, among other components [17]. These technologies enable activities to be planned and scheduled, scenarios to be simulated and analyzed, information to be visualized, and designs to be made accurate and robust to changes, as well as coordinate construction activities. This encourages the early detection of problems, design optimization, and decision-making, which can help reduce costs and delays in construction [18, 19]. The utilization of Building Information Modeling (BIM) within the construction industry results in enhanced project efficiency and quality, as it enables reduced costs, optimization of construction processes, and collaboration among various project specialists [20].

The integration of BIM and UAVs has been extensively studied due to their ability to provide construction teams with a fast, accurate, and secure method for collecting data on construction progress, enabling informed decision-making [21]. For instance, Melo et al. [22] explored the feasibility of utilizing UAVs for safety inspections during construction and discovered that the visual assets gathered by UAVs can enhance job site safety inspections. In this context, Ellenberge et al. [23] proposed an automatic method for UAV image recognition to detect structural damage on bridges. Similarly, Huang et al. [24] conducted deformation monitoring on steep slopes in mountainous regions through the use of remote sensing by UAVs, while Rengaraju et al. [25] and Jones [26] investigated the use of UAVs in smart grid inspections.

The estimation of physical progress has been evaluated using various methods, but gaps have been identified. Wei et al. [27] point out that there is a lack of research on the development of real-time progress monitoring systems with other digital construction technologies, such as Building Information Modeling for foundation construction in different environments and weather conditions. Kamari and Ham [28] mention that there is a lack of studies using daily construction images, building information modeling, and morphological image processing techniques to monitor and evaluate the progress and degree of clutter on construction sites. According to Zhang et al. [29], existing image-to-BIM registration methods require high-precision GPS data, which is only available for UAV RTK, or rely on matching specific textural and geometric features, which are generally absent on building facades. Accurately recording images collected by UAVs is necessary for building facade inspection in BIM. According to Song et al. [8], there is insufficient focus on integrating laser scanning data and route planning for complex structure inspection. Sheikhkhoshkar et al. [19] do not address explicitly how BIM models can be integrated with other real-time monitoring systems, like sensors at the construction site, to enhance concrete pour planning.

Jia et al. [30] focus solely on the application of their proposed methodology in the construction of a specific stadium without addressing its generalization for other types of buildings or architectural structures. They also fail to comprehensively address the use of technologies such as terrestrial laser scanning (TLS) and photogrammetry for point cloud modeling in construction environments or the integration of point cloud information with BIM for construction information management and progress monitoring. Pan and Zhang [6] highlight the importance of process mining in construction project management using event log data but do not specifically address how the integration of BIM with process mining can affect real-time decision-making during project execution. Meyer et al. [17] focus on verifying BIM to a certain level of accuracy using TLS point clouds. However, he does not explicitly address how this approach could be integrated with Geospatial Information Systems (GIS) for more complete verification and effective updating of BIM models. Kiriiak [21] mentions that comparisons between photogrammetry and laser scanning are not detailed in terms of accuracy, cost, and specific limitations in the context of nuclear power plant construction. Reja et al. [18] point out that computer vision does not have an integrated framework that addresses in detail the data acquisition processes in construction progress estimation and that research is needed to improve the accuracy and efficiency of data acquisition, 3D reconstruction, and modeling techniques. Han et al. [31] recommend that the integration of project schedules and budgets should be explored to improve the accuracy of construction progress.

This study has filled gaps in the literature on constructing progress monitoring systems by proposing a cutting-edge methodology that incorporates the simultaneous use of UAV and BIM. This integration estimates the physical progress of the construction in real time with precision. Due to the rarity of research involving construction site images captured daily, alongside building information models and image processing techniques, the collection of high-resolution images has been automated. This was achieved by employing BIM models and processing the images with Agisoft 2.0.1 software, which utilizes Python-based image processing techniques. The limitation of current techniques, which necessitate high-precision GPS information, was addressed by utilizing the Phantom 4 RTK drone. Its built-in GNSS (Global Navigation Satellite System) module permits it to acquire accurate positional and orientational information via satellite signals. The absence of emphasis on information integration was tackled and resolved through the utilization of Power BI software, which examines the BIM models' database via an automated connection. The constraints of incorporating BIM models with other real-time monitoring systems were addressed via interoperable UAV and BIM technologies that exchange information without forfeiting any data in the process. Furthermore, literature cases have been identified that solely focus on the application of specific works without addressing the generalization of this methodology to other types of infrastructure. This issue can be resolved by applying a generalized methodology that is self-adaptable and applicable to different types of structures. This method aims to address the challenges inherent in assessing the actual advancement of a construction project. It proposes a novel approach that combines various UAV and BIM technologies using image analysis and data mining with Power BI to improve the precision and productivity of work monitoring.

The objective of the research was to estimate the physical work progress using UAV and BIM in construction projects, integrating BIM software, image processing, and data analysis with Power BI to improve construction monitoring as an alternative to traditional methods that are manual, laborious, error-prone, and provide an incomplete view of the construction work.

The contribution of the research is to propose a methodology that integrates UAV and BIM to estimate the progress of work as a sustainable, efficient, and cost-effective solution. This automates project tracking by linking the processing phases, allowing project engineers to have a workflow that can be applied in different engineering works.

The remaining sections of this study are organized as follows. Section 2 presents the literature review. Section 3 describes the materials and methods used. Section 4 presents the results with a detailed description. Section 5 discusses the results obtained with the proposed methodology. Section 6 presents the declarations of contribution, data availability, funding, and conflict of interest. Finally, Section 7 presents conclusions, recommendations, and future work.

2. Literature Review

Methods to create digital models utilizing UAVs and BIM have been examined by researchers to estimate construction progress. These technologies have also found applications in other fields of civil engineering. Wei et al. [27] used UAVs and BIM to objectively monitor China's campus foundation progress. Images captured from multiple angles provided a detailed and concise view of construction, while the SOLOv2 algorithm estimated progress with 90.90% accuracy. Finally, the actual progress was integrated into a BIM model using self-adaptive grid-based mapping. Kamari and Ham [28] assessed windblown debris hazards at construction sites by utilizing UAVs to create digital models. They captured aerial images of the study area to reconstruct 3D digital models, then conducted image segmentation to identify windblown debris and projected their findings on the digital model. Their approach provides a comprehensive evaluation of windblown debris hazards at construction sites.

Zhang et al. [29] proposed an approach to registering UAV images into a BIM model in three phases: (1) extract positional and optical parameters from UAV images to set up virtual cameras in the BIM and generate template images; (2) use an enhanced generalized Hough transform to extract building facade components with arbitrary shapes; and (3) project UAV images onto an orthophoto and incorporate them into 2D and 3D views. A Dynamo prototype was developed to automate this process. Computer simulations and field experiments have shown that this approach has an average image-to-BIM registration error of less than 21 mm, demonstrating its potential for facilitating UAV facade inspection. Song et al. [8] integrated BIM and UAV technology for the inspection of building system components by developing advanced probabilistic mapping techniques, scan coverage planning, and efficient trajectory generation, and validated the methodology through simulations in virtual environments and real flights. They concluded that the integration of BIM and UAVs for the inspection of mechanical, electrical, and plumbing systems enables the automation of inspection processes in the construction industry.

Sheikhkhoshkar et al. [19] developed a software prototype using BIM to automate the scheduling of concrete joints in construction projects. They used a combination of Revit, Dynamo, Microsoft Excel, and MATLAB software to schedule concrete pouring and manage critical points in the structure. The prototype was validated through a case study on a three-story educational building and demonstrated benefits such as reduced waste and improved structural integrity compared to traditional manual methods. Jia et al. [30], proposed a bi-directional interaction mechanism between BIM and construction processes using a point cloud model enabled for geospatial data from multiple sources. In the interaction, they obtained parametric BIM models by providing detailed construction information, this strategy allowed them to create an accurate 3D model that reflected the actual construction state. The proposed method was applied to the construction of the main stadium facade of the Chengdu 2022 World University Summer Games and compared with four other methods, demonstrating the effectiveness of the interaction between the BIM model and the actual states throughout the construction cycle.

Pan & Zhang [6], applied process mining techniques to event logs derived from BIM models to analyze and visualize the flow of activities in a construction project. They performed compliance, frequency, and bottleneck analysis, as well as social network analysis to identify collaboration patterns. The results showed that BIM-based process mining can detect deviations, inefficiencies, and collaboration patterns. In addition, by integrating IoT with BIM, they were able to obtain real-time information on construction progress to make tactical decisions. Meyer et al. [17], rely on the fusion of 3D laser scanning data and BIM models using Dempster-Shafer theory to verify and evaluate construction changes. Using a voxel-based change detection approach to improve process automation and efficiency. They concluded that the approach provides a solution for verifying and evaluating construction changes using 3D laser scanning and BIM models. Table 1 shows the research that has been conducted using UAV and BIM to estimate construction progress.

Table 1. Recent studies on the use of UAV and BIM in construction

Reference	Focus of study	Method	Software	Application
Wei et al. [27]	Automation and monitoring of foundation construction progress	BIM	SOLOv2	Computer vision-based study for automated monitoring of progress in foundation construction
Kamari & Ham [28]	Assessment of windblown debris on construction sites	UAV + Deep learning	Keras Python	Identification and analysis of the characteristics and impacts of windborne debris at construction sites
Zhang et al. [29]	Image registration of a building façade in BIM models	UAV + BIM	Revit 2023 and Dynamo	BIM-based image management for building façade inspection using UAVs
Song et al. [8]	Exploration and planning of UAV movement with LiDAR in the context of the construction industry	UAV + BIM	Revit, Cloud Compare, and MATLAB	BIM-assisted map construction, collision-free shortest path planning, trajectory generation, and feedback-based flight control.
Sheikhkhoshkar et al. [19]	Developed an automated program for concrete scheduling using BIM	BIM	Autodesk Revit, Dynamo, Microsoft Excel, and MATLAB	Employed BIM to plan construction joints and improve the efficiency of on-site activities affected by several variables
Jia et al. [30]	Accurately model the curtain wall construction process using point clouds	UAV + BIM	Grasshopper and Rhino	Bidirectional interaction mechanism between BIM, construction, and point cloud modeling with geospatial data from multiple sources
Pan & Zhang [6]	Explore and analyze BIM data to improve intelligent project management using process mining techniques	BIM	Revit, AutoCAD, and Navisworks	Intelligent management of construction projects by using process mining techniques on BIM record data
Meyer et al. [17]	Evaluation of construction progress using 3D point clouds	BIM	-	Automation and efficiency of construction progress monitoring and evaluation using TLS and BIM
Kiriiak [21]	3D scanning, and Multi-View Stereo, to identify deviations in construction and compare 3-D models with the project	UAV	Bentley and Context Capture	Application of Structure from Motion algorithm and 3D scanning for digital support of nuclear power plant construction
Han et al. [31]	Representation of construction sequencing and accuracy of construction progress monitoring with the BIM model	UAV + BIM	Prototype	Tracking the progress of construction projects by visually detecting BIM project elements

3. Material and Methods

3.1. Methodology

The study employed UAV and BIM to measure the physical progress of work using various software, including Agisoft 2.0.1, Revit 2023, ReCap Pro 2023, and Power BI. The construction site of the Civil Engineering Laboratory at the National University of Jaen, Cajamarca, Peru, was selected as the study area. A 3D flight plan was created using the Phantom 4 RTK drone, which captured high-quality images that were imported into Agisoft software for processing and the generation of a point cloud. Next, the point cloud was imported into RepCap Pro software for quality control. Next, the BIM model for the project was generated in Revit software. The point cloud was then imported and utilized as a filter to select the physical progress of the work based on the Revit phase parameter. The model database was ultimately imported into Power BI software, which automatically computed the work progress (see Figure 1).

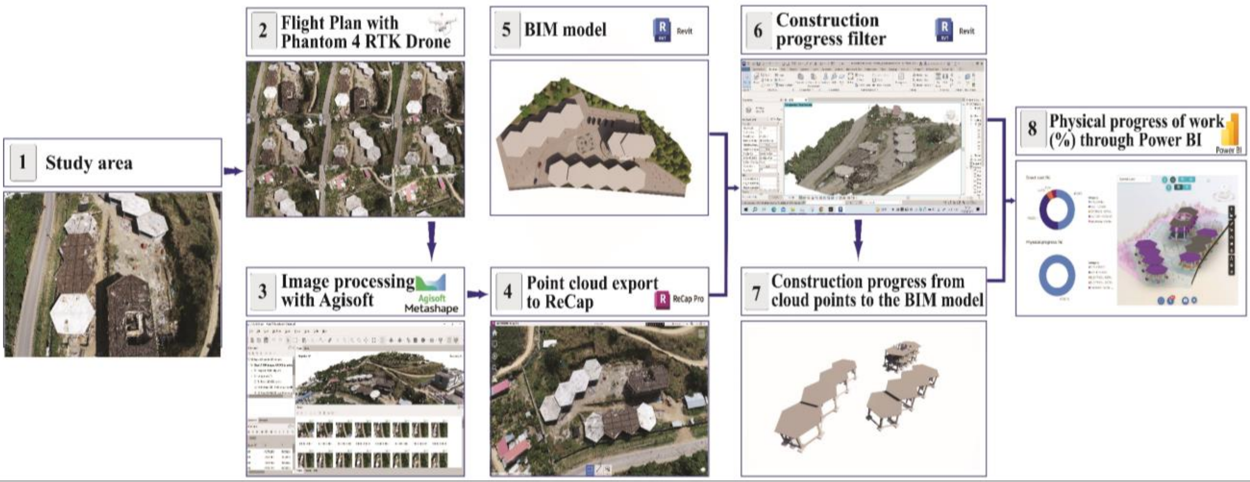


Figure 1. Methodology flowchart

3.2. Phantom 4 RTK

It is a DJI drone designed for high-precision surveying and mapping applications. It has a real-time positioning (RTK) system that uses satellite navigation technology to obtain accurate position data. In addition, they are equipped with a high-resolution camera and advanced sensors to capture high-quality images and geospatial data. They are widely used in mapping, infrastructure inspection, and precision agriculture projects, among others [15]. It is equipped with a 20-megapixel camera that captures high-resolution images and videos, and a built-in GNSS (Global Navigation Satellite System) receiver for precise positioning [32].

Figure 2 illustrates the basic components of the drone: propellers, which are designed to provide stability and maneuverability. There are four, two counterclockwise and two clockwise, with opposing black and red colors. The motors are highly efficient, while the vision system is located at the front, back, and bottom of each drone. The infrared sensing system includes three stereo-vision sensors and two ultrasonic sensors to prevent collisions during flight. The battery is lithium and provides approximately 30 minutes of flight time. (6) The drone is equipped with a micro-USB port and a microSD card slot for the camera. (7) It includes a gimbal and a camera that uses a 1-inch CMOS sensor with 20 million effective pixels and a 24mm wide-angle lens. (8) The drone also has an antenna that transmits frequency signals to the controller. (9) A remote control allows the operator to control the drone and view real-time data. (10) In addition, a tripod is available to stabilize the RTK base. (11) The RTK base helps improve the accuracy of the drone's positioning and navigation, enabling reliable flight planning.

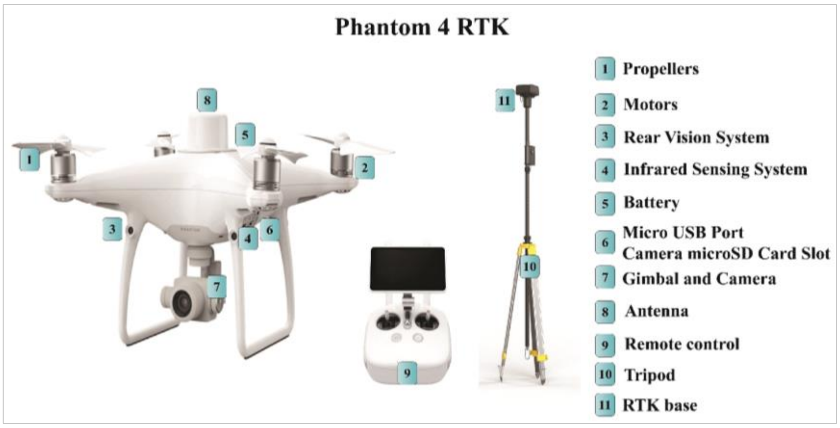


Figure 2. Parts of the Phantom 4 RTK Drone

3.3. BIM

The methodology for creating and managing digital project models involves physically and functionally characterizing a 3D model with information on geometry, spatial relationships, materials, and more [7]. It enables visualization and comparison of work progress with the planned schedule, efficiently identifying deviations through collaboration and coordination among the parties involved in designing, constructing, and operating a project. The shared model integrates various disciplines, including architects, engineers, contractors, and owners [21]. Furthermore, the software allows for visualizing, analyzing, detecting conflicts, estimating costs, and planning, resulting in decreased errors, enhanced consistency, and improved efficiency throughout the entire project. These features aid in identifying and resolving potential issues before they arise on the construction site, ultimately leading to time and cost savings [33].

3.4. Study Area

Construction of the Civil Engineering Laboratory of the National University of Jaen, located in the district of Jaen, province of Jaen, in the region of Cajamarca, Peru, at coordinates 5°40'34.45"S 78°46'45.27"W. Access is via the Jaen-San Ignacio highway, 12 minutes from downtown. The project is divided into several blocks with a total construction area of 6,400 m^2, including academic and administrative areas and laboratories. Block 1 (MD-01) has an area of 614.35 m^2, Block 2 (MD-02) has an area of 1056.55 m^2 and Block 3 (MD-03) has an area of 1315.30 m^2. The rooms are divided into three blocks to optimize space and facilitate access to the different areas. The climate is warm, and moderately rainy, with moderate thermal amplitude, and the average annual maximum and minimum temperatures are 30.2°C and 19.8°C, respectively. Figure 3 shows the location of the study area on a satellite map.

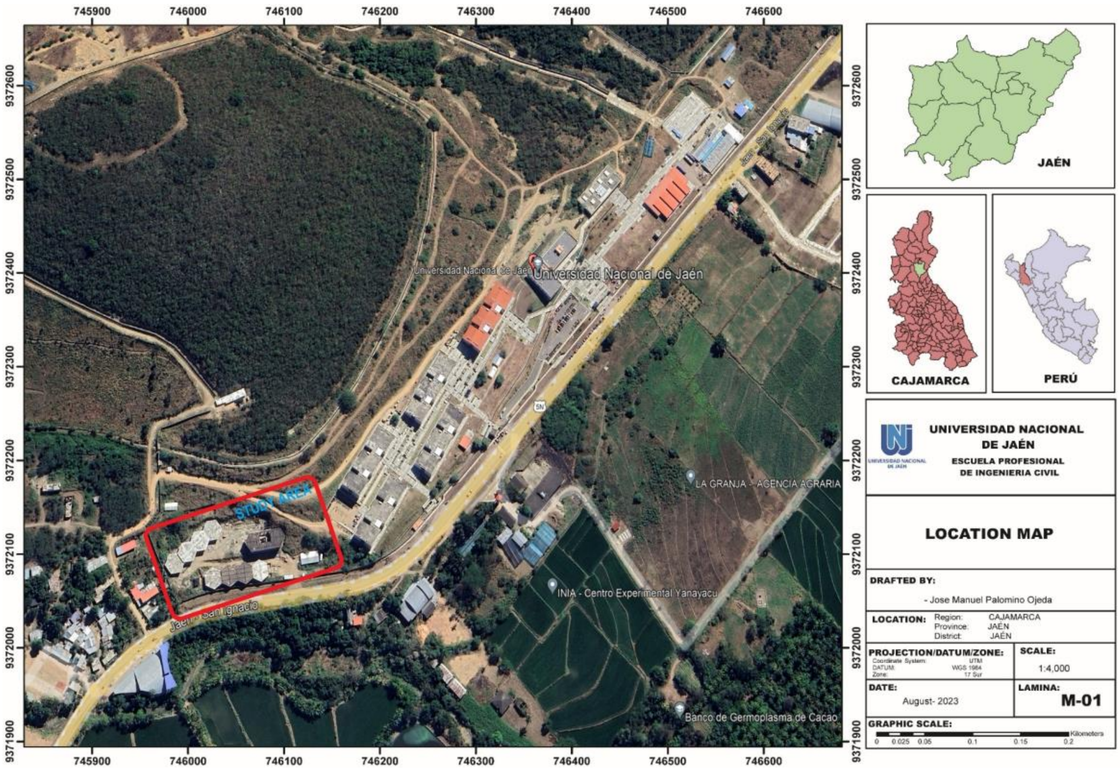


Figure 3. Location of the study area in Jaen, Cajamarca, Peru

3.5. Phantom 4 RTK Flight Plan

Route planning is an essential task in the configuration of the UAV flight plan; the best route must be determined to efficiently complete its mission. In addition, routing protocols are critical to ensuring network connectivity and efficient data transmission between the UAV and ground stations [34]. The flight plan is a document that details the route and procedures that an aircraft will follow during its flight, including information such as departure point, arrival point, air routes to be followed, flight altitudes, speeds, and any restrictions or special instructions [35].

The flight planning was done in several steps: (1) the mission was planned with the remote control by logging into the DJI application using the 3D planimetry option and uploading the flight polygon of 1.2 ha^2 in KML format to the microSD folder, (2) identified a wide and obstacle-free launch area, (3) assembled the equipment, making sure that the propellers were securely attached, (3) verified that the drone and remote control batteries were charged, (4) turned on the remote control and drone, (5) verified the connection between the drone and the remote control, and (6) verified that the drone and the remote control were working properly, (5) verified the connection between the remote control and the drone using the DJI Go application, (6) verified that the number of satellites was sufficient for takeoff, (7) set the remote control to P mode, (8) performed the flyover at an altitude of 30 m, specifying the camera tilt and overlap rate, and (9) finally downloaded the images and verified their sharpness and position. Figure 4 shows the configuration and positioning of the equipment for the flight plan, the RTK base was placed in a stable place near the study area, and the equipment was positioned in front with the controller executing the flight file, then the drone received the commands and performed the flight in 12 minutes. At the end, it returned to the registered starting point.

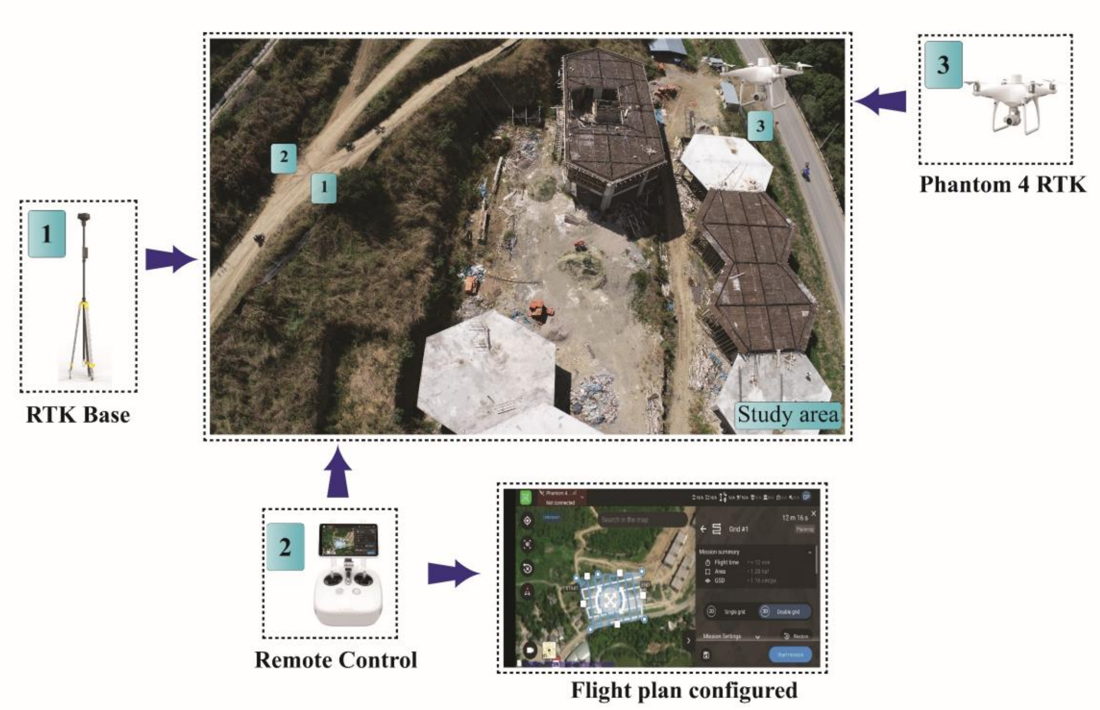


Figure 4. Diagram of the flight plan in the study area

3.6. Data Collection

Figure 5 shows some high-resolution images taken at 11:00 a.m., from different angles at a height of 30 m, of the double-mesh route of the drone in the study area, which is a suitable schedule that does not generate critical shadows that affect the collection of information. Each image contains geospatial information on the current state of the site, showing the accesses, modules, and topography of the terrain. In addition, they share information for linking and georeferencing during the creation of the point cloud.

Figure 5. High-quality images were taken by the Phantom 4 RTK

3.7. Image Processing

It was performed in several steps using the Agisoft software workflow, this application is used for 3D reconstruction from multiple 2D images. The software is used in the field of photogrammetry and allows users to align photographs, estimate camera positions, and generate dense point clouds and 3D models, and has been used in various studies and applications such as cultural heritage reconstruction, ship hull modeling, and smartphone-based 3D reconstruction. It provides a user-friendly interface and a set of tools for processing and analyzing image data [36]. The point cloud is a three-dimensional representation of an object or physical environment obtained by laser scanning or photogrammetry techniques. It consists of a set of points in space that represent the three-dimensional coordinates of the points of interest of the scanned object or environment. These points may contain additional information such as the color or intensity of the scanned surface. The point cloud is used in various applications such as reverse engineering, architectural visualization, quality inspection, and documentation of historical sites [31].

Figure 6 shows the flowchart used: (1) Image loading, once the images have been captured, the folder has been loaded, (2) Image alignment, the software uses advanced algorithms to align the images and determine the position and orientation of each camera about the structure, (3) Control point generation, control points are generated on the images to help the software determine the 3D position of each point on the structure, (4) Mesh creation, once the control points have been generated, the Agisoft software uses triangulation techniques to determine the 3D position of each point on the structure. Then the software creates a mesh using these points and the surfaces that connect them, (5) texturing after the mesh is created, the software applies textures to the mesh to give it a more realistic appearance, (6) finally the point cloud is created, which was used to analyze and measure the construction, identify problem areas and detect changes, (7) the model was exported in the LAS format for use in construction control applications.

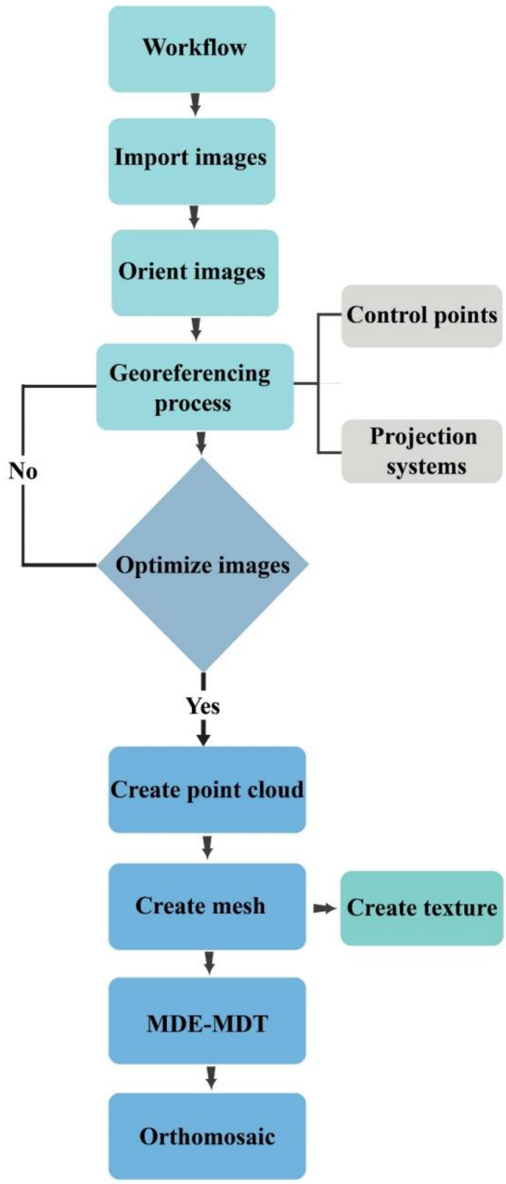


Figure 6. Image processing flowchart in Agisoft software

Figure 7 shows the Agisoft software interface, where the 848 images were processed by executing the different phases of the workflow until obtaining the point cloud, all the generated files are displayed in the workspace. The program is made up of the menu bar, located at the top of the interface, which contains various options for opening, saving, and exporting projects, as well as accessing different tools and settings; the toolbar is located below the menu window and contains buttons for accessing image alignment, mesh generation, and texturing tools. The Viewer window displays the images loaded into the software and allows 2D or 3D visualization; the Timeline window is used to adjust the position and orientation of the cameras over the object or scene being edited; the Properties window is used to adjust the tool settings and view detailed information about the edited objects and scenes.

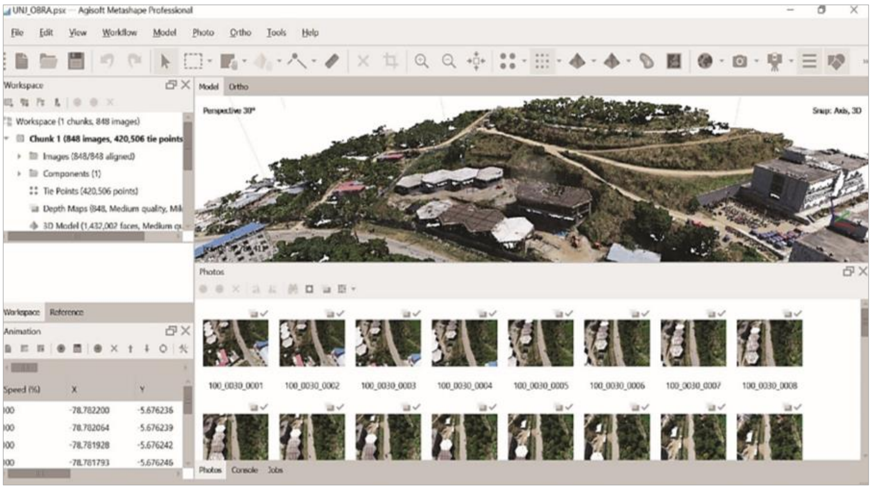


Figure 7. Image processing in the Agisoft 2.0.1 interface

3.8. BIM Model

For BIM modeling, the Revit 2023 software was utilized as it grants access to all project components and is compatible with other Autodesk programs. The technical drawings from the Seace 3.0 (Electronic System of State Contracting) were downloaded for this purpose, and different subprojects were used to model each specialty, with metrics being extracted accordingly. Figure 8 depicts the modeling process flowchart. The drawings in DWG format were imported into the Revit 2023 software. The project was created utilizing a template configured with International System Units. Reference grids and planes were established in the interface. Subsequently, the structure, architecture, plumbing, electrical installations, and external works were modeled. Furthermore, separate files were created for MD-01, MD-02, and MD-03, which feature different specialties. Afterward, the subprojects were linked to the central model using common coordinates. Following the completion of the modeling process, planning tables were created for architectural, structural, electrical, plumbing, and external works categories, with each element assigned a unit cost via type parameter.

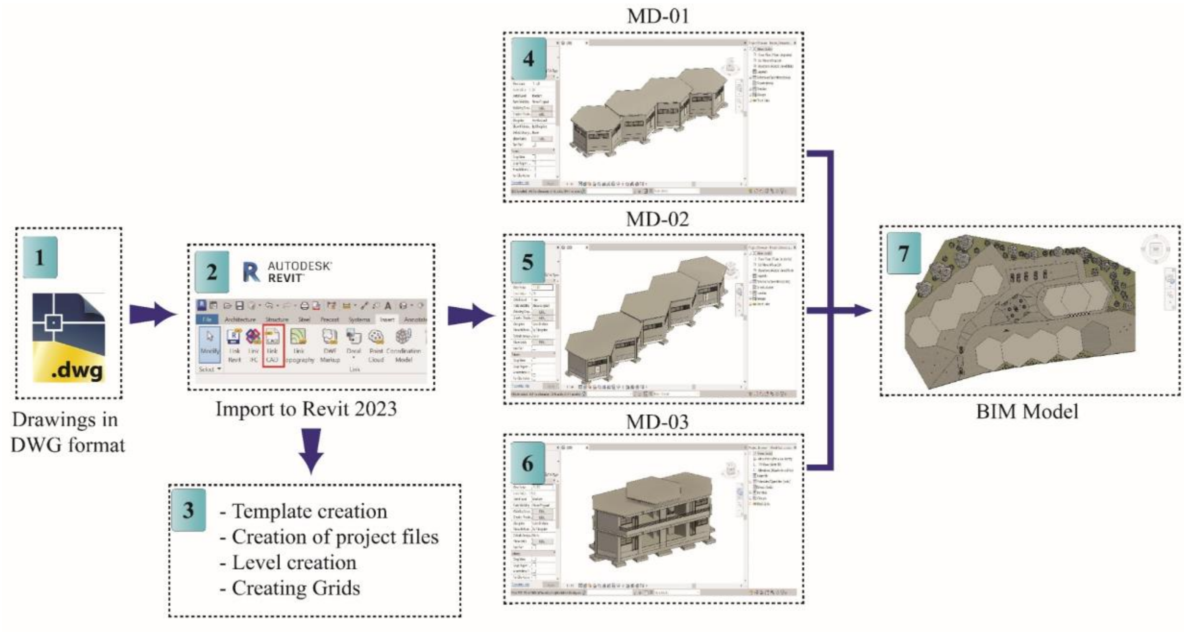


Figure 8. BIM model flow diagram of the civil engineering laboratory

The architectural distribution of blocks MD-01, MD-02, and MD-03 was executed by the National Building Code (Peru). Standards E.020 (Loads), E.030 (Seismic design), E.050 (Soils and foundations), E.060 (Reinforced concrete), and E.070 (Masonry) were utilized for structuring, structural analysis, and seismic design. The distribution of areas in Block MD-01 is detailed in Table 2. The first level of Block MD-01 consists of four laboratories. Materials testing and strength covers an area of 210.25 m^2, while Concrete Technology occupies 212.69 m^2. Pavement Technology has an area of 211.86 m^2, and Soils and Geotechnics covers 210.55 m^2. The facility also features a 5.19 m^2 space for disabled restrooms.

Table 2. Surface areas of the spaces of block MD-01

Level	Distribution	Area (m^2)
First	Materials testing and strength laboratory	210.25
	Concrete technology laboratory	212.69
	Pavement technology laboratory	211.86
	Soil and geotechnical laboratory	210.55
	Toilet facilities Disabled	5.19

Table 3 displays the areas of rooms designated to the MD-02 block, arranged by level. The first level encompasses seismic resistance, reinforced concrete, masonry, and structural analysis laboratories, with a total area of 391.29 m^2, along with the fluid mechanics and hydraulics laboratory, covering an area of 283.36 m^2. The facility includes a space reserved for hydraulic models measuring 107.11 m^2, and restrooms for women, men, and individuals with disabilities occupying a total of 52.38, 37.15, and 6.85 m^2, respectively. Additionally, there is a solid waste area covering 29.70 m^2, two warehouses (I and II) with sizes of 35.99 m^2 and 62.54 m^2, a cleaning room spanning 7.00 m^2, and a 37.19 m^2 hall.

Table 3. Areas of spaces in Block MD-02

Level	Distribution	Area (m^2)
First	Seismic resistance, reinforced concrete, masonry, and structural analysis laboratory	391.29
	Fluid mechanics and hydraulics laboratory	283.36
	Area for hydraulic models	107.11
	Ladies' restrooms	52.38
	Men's restrooms	37.15
	Disabled restrooms	6.85
	Solid waste area	29.70
	Warehouse I	35.99
	Warehouse II	62.54
	Cleaning room	7.00
	Hall	37.19

Table 4 shows the floor areas of Block MD-03 on the first level. The area of Infrastructure, Resources, and Sanitation Laboratory is 137.38 m^2, Topography, and Roads Laboratory is 33.50 m^2, Women's Toilet, Men's Toilet, and Disabled Toilet are 16.37 m^2, 23.75 $m^{2,}$ and 5.19 m^2 respectively. The storage room is 13.49 m^2, the equipment room is 75.26 m^2, the hall is 105.77 m^2, and the secretary's office is 12.25 m^2. On the second floor, there are several laboratories, including drawing, architecture, cost, and budget, which have a total area of 276.18 m^2. There is also a staff office of 22.96 m^2 and a printing and plotting area of 17.85 m^2. There is also a warehouse with an area of 26.98 m^2 and a hall with an area of 77.67 m^2.

Table 4. Areas of spaces in Block MD-03

Level	Distribution	Area (m^2)
First	Infrastructure, resources, and sanitation laboratory	137.38
	Topography and roads laboratory	33.50
	Toilets Ladies	16.37
	Men's restrooms	23.75
	Toilet facilities Disabled	5.19
	Deposit	13.49
	Equipment area	75.26
	Hall	105.77
	Secretary	12.25

Second	Drawing, architecture, and costing and budgeting laboratories	276.18
	Staff office	22.96
	Printers and plotters area	17.85
	Warehouse	26.98
	Hall	77.67

3.9. Physical Progress of Work

It is the estimate of the execution of a construction project in terms of work completed as planned, expressed as a percentage, and used to evaluate the progress of the project according to the budgeted and established deadline. To measure it, a detailed plan of activities, tasks, and resources for the work performed is established to determine the percentage of progress. It is also an important tool in construction project management, allowing managers and contractors to evaluate project progress and make timely decisions to avoid delays and additional costs. To estimate the physical progress of the work, the 4D information from the BIM model and the point cloud linked to the same data environment were used. This was done using Power BI software, a data analytics tool developed by Microsoft that enables project management through dashboards that show the status of progress, costs, and work schedules from initial budget to actual spending. Table 5 shows that the direct cost of the project was $1,722,872.11, of which 49.02% was for structures, 40.32% for architecture, 4.60% for plumbing, 5.23% for electrical, and 0.83% for electrical, mechanical, and specialty equipment.

Table 5. Construction budget

Category	Direct Cost (US)
Structures	844,326.42
Architecture	694,623.78
Sanitary installations	792,14.02
Electrical installations	903,52.07
Electrical, mechanical, and special equipment	143,55.82

Figure 9 shows the BIM model data extraction flowchart. An application was created in the Autodesk API and the token key was used to connect to the VCAD platform, then the system was configured by entering the credentials and the BIM model was uploaded in RVT format, waiting for the file to be processed in the cloud and the template was downloaded in PBIX format. A project was then created in Power BI and the file was imported to connect to the VCAD server. All the information generated in the template, such as metrics, budgets, and project phases, is visualized in the Power BI interface using interactive graphics and 3D models. Finally, the data environment tables were configured and the progress of the point cloud model was compared to the central model through a pie chart showing the physical progress of the work for each specialty in percentage terms.

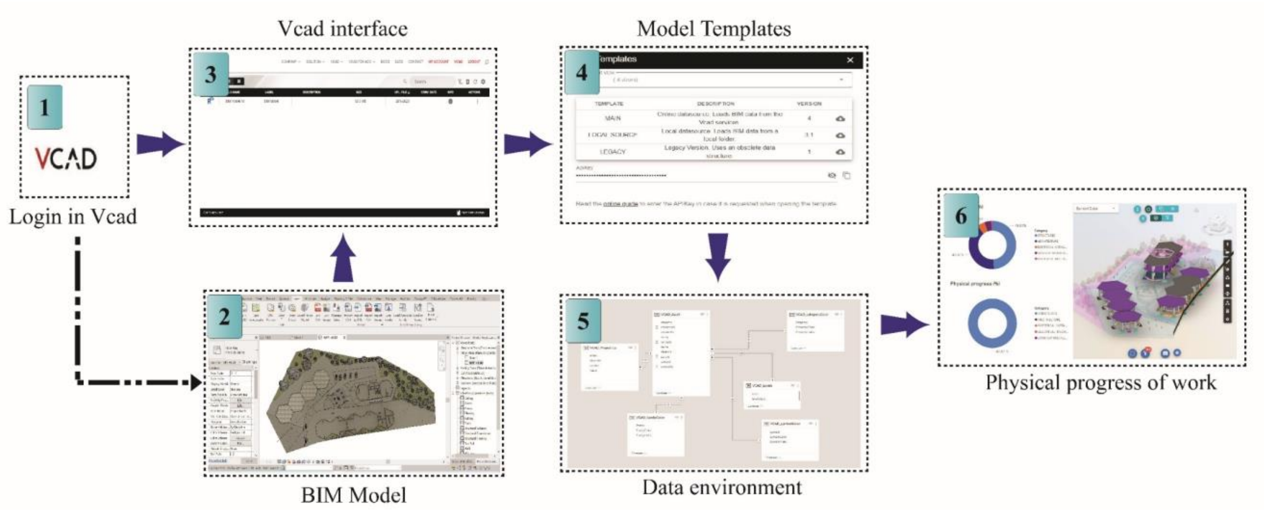


Figure 9. Orthophoto of the study area

4. Results

4.1. Data Collection and Processing

After processing the images in Agisoft 2.0.1 software, the digital elevation model and the point cloud of the construction of the civil engineering laboratory were generated. The generation process was performed using 885 images with a ground resolution of 1.63 cm/pixel, covering a convergence area of 0.0284 km^2, 848 camera stations, 420,506 tie points, and 2,039,341 projections. Figure 10 shows the calibration of the images taken by the drone equipped with an FC6310R camera of 5472 × 3648 resolution, 8.8 mm focal length, and 2.41 × 2.41 µm pixel size during processing. Table 6 shows the calibration coefficients and correlation matrix used to calibrate the imaging system. The first column lists the calibrated parameters, including the focal length (F), the coordinates of the principal points (Cx and Cy), and various distortion coefficients (K1, K2, K3, P1, P2). The second column shows the corresponding values of these parameters, and the third column shows the corresponding errors. The correlation matrix, which runs from the fourth to the last column, shows the pairwise correlations between the calibrated parameters. The matrix provides information to assess the accuracy and reliability of the camera calibration, which is crucial to ensure accuracy in data processing and analysis.

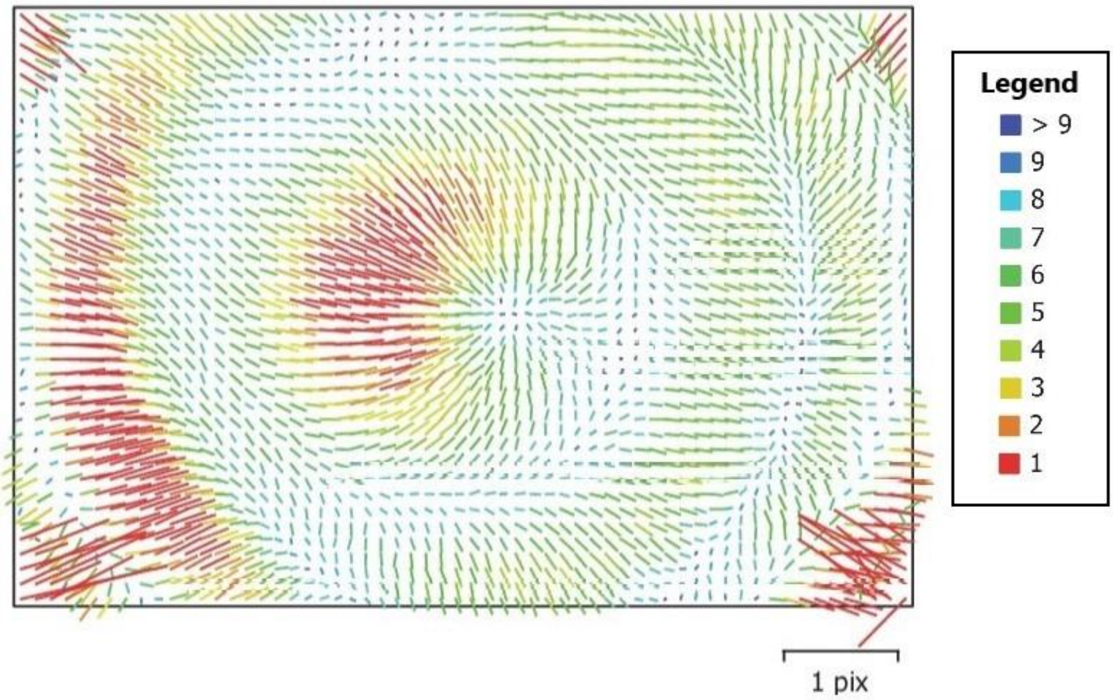


Figure 10. Image residuals for FC6310R (8.8mm)

Table 6. Calibration coefficients and correlation matrix

	Value	Error	F	Cx	Cy	K1	K2	K3	P1	P2
F	3706.34	0.036	1.00	0.02	-0.88	-0.33	0.22	-0.20	0.06	0.65
Cx	-3.8377	0.019		1.00	-0.02	-0.00	0.00	0.00	0.19	0.00
Cy	-44.2218	0.038			1.00	0.09	-0.04	0.04	-0.03	-0.50
K1	-0.281679	1.2e-05				1.00	-0.96	0.91	-0.04	-0.21
K2	0.119584	2.4e-05					1.00	-0.98	0.02	0.11
K3	-0.0314157	1.4e-05						1.00	-0.02	-0.11
P1	-0.00012652	3.7e-07							1.00	0.08
P2	0.000248505	8.3e-07								1.00

The camera locations and estimated errors are shown in Figure 11, representing longitude (X), latitude (Y), and elevation (Z). The error in Z is indicated by the color of the ellipse (from red to blue) and the X, and Y errors represent the ellipse shape with minimum distances of -6 cm and maximum distances of 6 cm, the estimated camera locations are marked with a black dot. Table 7 shows the average camera position error, expressed in centimeters, broken down into different dimensions. Each column reflects a specific category of error, while the rows show the corresponding values for each dimension. The results show that the total error was 0.43 cm at X = 0.22 cm, Y = 0.16 cm, and Z = 0.33 cm.

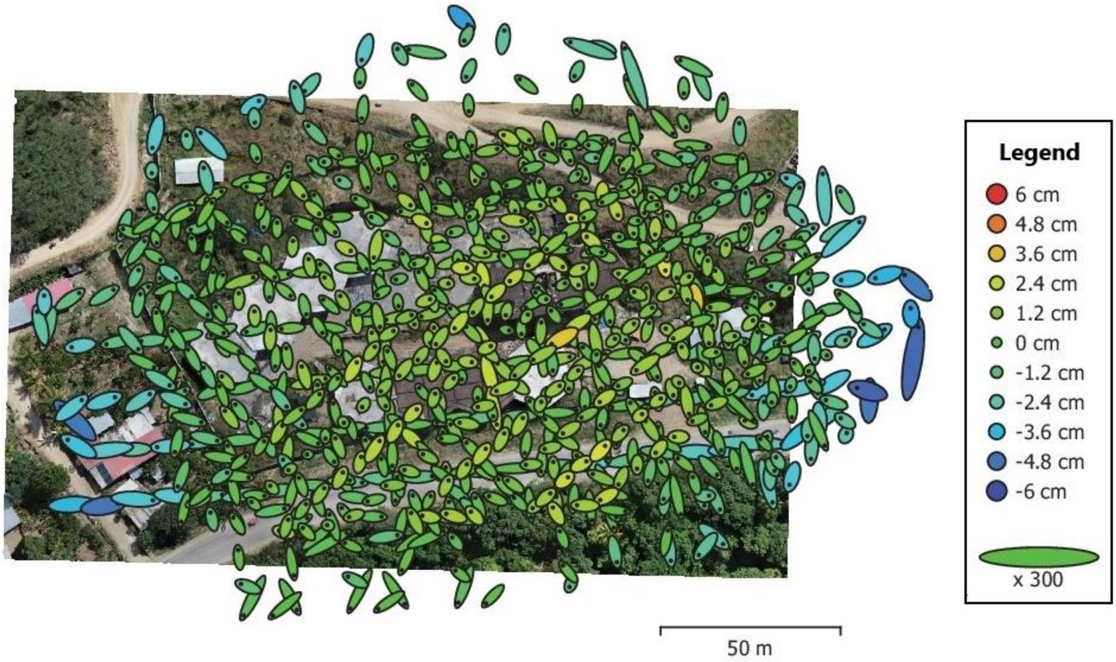


Figure 11. Camera locations and error estimation

Table 7. Average camera location error

X error (cm)	Y error (cm)	Z error (cm)	XY error (cm)	Total error (cm)
0.22	0.16	0.33	0.27	0.43

After processing the images according to the flowchart in Agisoft 2.0.1, the digital elevation model was obtained, which allows for obtaining information on the terrain characteristics with a resolution of 5.12 cm/pix, through a spectrum of colors that represent the different heights, the minimum elevation is 646 m and maximum 685 m (see Figure 12), which indicates a topography with a moderate slope, the main access to the area is through the Jaen-San Ignacio road, which presents a gentle slope. These results are fundamental to understanding the configuration of the terrain and its accessibility, which can influence the planning and execution of the project in the study area, serving as a basis for the generation of the point cloud.

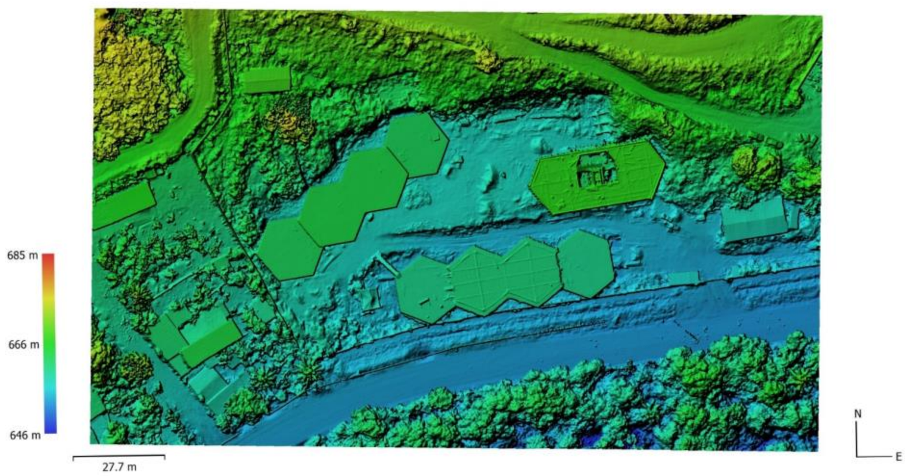


Figure 12. Digital elevation model

The point cloud model consisted of 37,786,411 points with a minimum error of 0.43 cm compared to the actual construction. This high-resolution three-dimensional model of the study area (Figure 13) includes the three modules, the accesses, and the topography, providing detailed information on the construction progress, georeferenced with the WGS 84 system, which guarantees spatial accuracy. The process of obtaining this model required a processing time of 3 hours, a memory of 5.49 GB, and generated a file with a size of 499.33 MB. This level of detail and accuracy in the cloud model obtained is critical for construction planning and monitoring. The high resolution and georeferencing to a global coordinate system such as WGS 84 allows for accurate measurement of construction progress and representation of the environment. In addition, the size and complexity of the model, with nearly 38 million points, indicate the completeness of the data collection and the ability to accurately represent the reality of the site.

Figure 13. Real 3D model of the study area in Agisoft 2.0.1

After the point cloud model was created, it was exported to the ReCap Pro 2023 software in LAS format. Figure 14 clearly shows the import of the model with the identification of the points. It is important to emphasize that during the analysis, rigorous quality control was carried out, eliminating the points that were considered anomalous or that could introduce biases in the results; after this quality control process, the final model was exported to Revit 2023 in RCP format. The need for this transition is due to the direct incompatibility of the Agisoft 2.0.1 format with Revit. This additional step is of paramount importance as it allows for a quality check of the points before they are processed in Revit. Performing this pre-check is a critical aspect as it significantly improves the quality of the measurements and ultimately minimizes potential errors in the representation of the 3D model in the Revit environment. This proactive approach to data management ensures greater accuracy and reliability in the project phases, thus consolidating the integrity of the results obtained.

Figure 14. Point cloud exported to ReCap

4.2. BIM Modeling

The 3D and 4D BIM models were created using CAD drawings and unit cost analysis extracted from the technical file. The tool used was Revit 2023 software. Modules MD-01, MD-02, and MD-03 were modeled individually and then integrated into a single consolidated model. This approach allowed for a comprehensive and detailed representation of the structure, facilitating the analysis and management of the project. Figure 15 shows the model as rendered by Enscape 3.3, providing a comprehensive and realistic visualization of the structures and their components. The individual views of each module are presented, providing detailed information on the metrics corresponding to the different specialties and the unit prices associated with each activity of the project. Also included is the representation of the external works, such as access, parking, parking, and green areas, contributing to a holistic understanding of the project's environment. A highlight of this process is the import of the point cloud that reflects the progress of the project. By applying phase parameters, it was possible to extract the metrics recorded in the BIM model. This approach not only enriches the three-dimensional representation of the project but also provides a solid basis for monitoring and evaluating the progress of the work, supporting decision-making in the phases of the project.

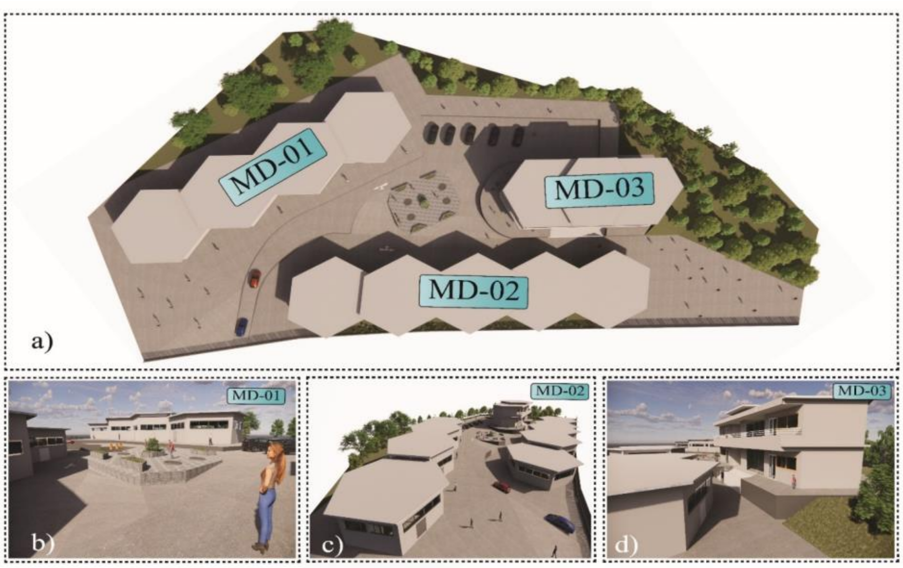


Figure 15. a) BIM model of the civil engineering laboratory, b) MD-01, c) MD-02, and d) MD-03.

4.3. Data analysis in Power BI

After obtaining the 4D BIM model, it was exported to the cloud-based VCAD platform. Next, the template was downloaded in PBIT format, and a view was created using the Power BI 2023 software, following the pre-established goals. Figure 16 presents a comprehensive display of information extracted from the BIM model, including categories, families, symbols, metrics, element properties, unit prices, and a three-dimensional depiction. The data is structured in tables that are automatically updated in the event of any changes made to the central model. The template created not only presents a thorough and structured visualization of the BIM model information but also provides interactive features through the utilization of Power BI. The model can be interacted with through the use of various tools, such as filters, categorized selection, model segmentation, plan visualization, and a search engine for element property analysis. These tools not only improve accessibility and understanding of the information but also assist in decision-making by enabling detailed and specific exploration of model elements. This integrated approach to visualization and analysis represents a significant contribution to project management, enabling project stakeholders to efficiently access and evaluate key information and make decisions based on accurate and timely data. The synergy between the 4D BIM model and the Power BI platform stands out as a tool to optimize the management and execution of construction projects.

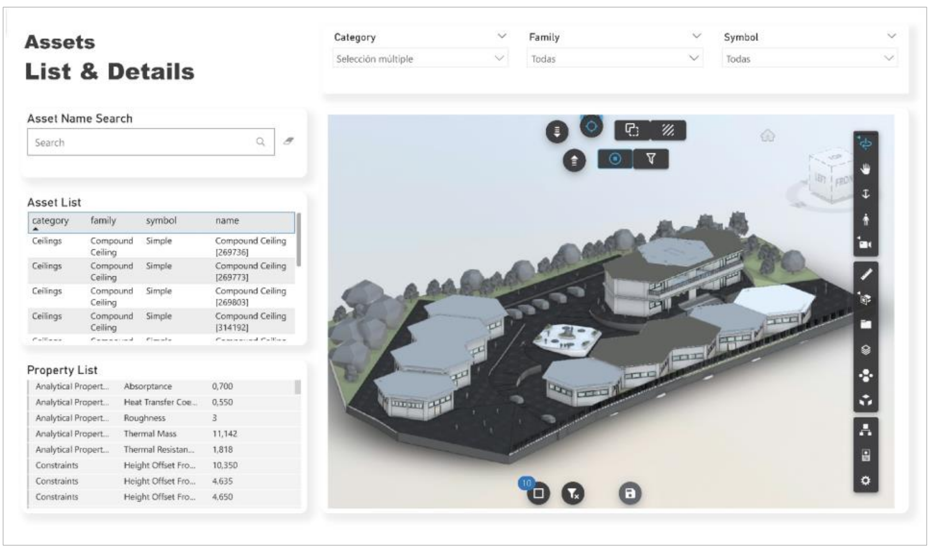


Figure 16. BIM Model List and Details in PowerBI

The work progress was presented through a customized workspace in Power BI that included data from the BIM model. Figure 17 displays the project's direct cost across various categories and visualizes the physical progress through pie charts depicting percentage values and a 3D model sourced from the point cloud. In addition, structures account for 49.02%, architecture 40.32%, electrical installations 5.23%, sanitary installations 4.60%, and electrical, mechanical, and special equipment 0.83% of the total direct cost of the project.

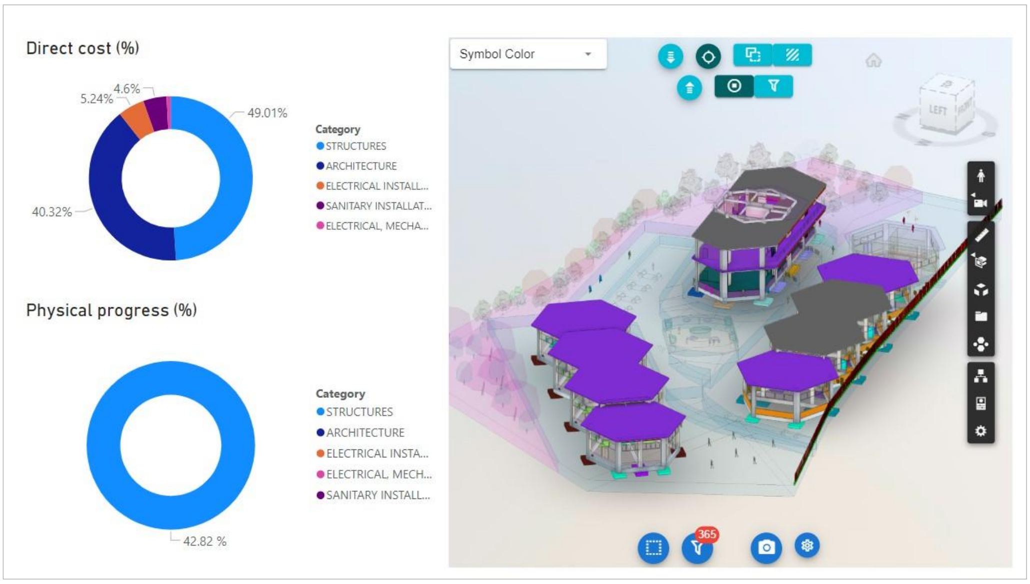
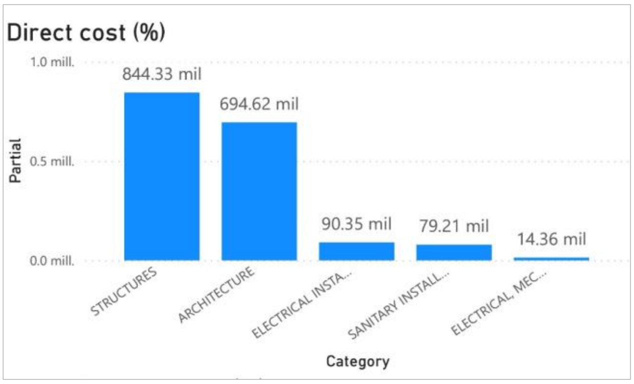


Figure 17. 3D physical progress of the construction site in PowerBI

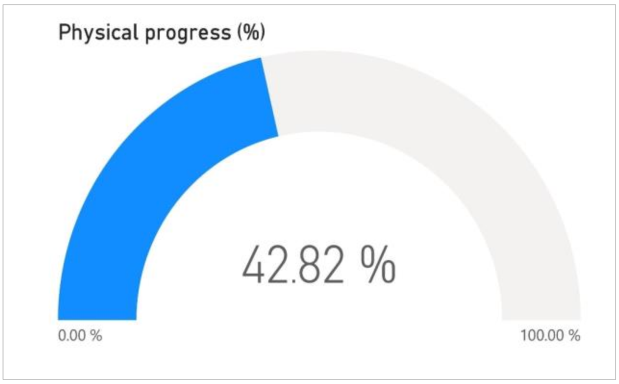
4.4. Estimate of the Physical Progress of the Work

The project has achieved an estimated 42.82% physical work progress, as depicted in Figure 18b. Out of all the phases involved, Structures have displayed the highest level of progress. This analysis has a direct correlation with the direct cost of the project, which is presented in Figure 18a. Structures have received the most significant investment out of all other categories, amounting to $844,326.42, followed by Architecture with a cost of $694,623.78. Other categories include Sanitary Installations costing $79,214.02, Electrical Installations costing $90,352.07, and Electrical, Mechanical, and Special Equipment costing $14,355.82. The comparison of physical progress and direct costs indicates a consistent correlation between the progression through the various phases of construction and the associated economic expenditures. This thorough analysis offers a comprehensive comprehension of the financial and operational dynamics of the project, thereby informing management decisions.

The progress of construction work, as reported by the public works information system (INFOBRAS), was 43.14%, with a difference of 0.32% from the proposed methodology. However, this difference was not statistically significant, thus reinforcing the reliability and accuracy of the proposed methodology for estimating progress. The demonstrated consistency and replicability of the proposed methodology suggest its utility across diverse contexts. The substantial agreement between the outcomes and official oversight confirms the appropriateness of this method as a dependable and precise instrument for assessing comparable construction projects' advancement.



a)



b)

Figure 18. a) Direct project cost and b) Estimated physical progress of work in PowerBI

5. Discussion

The research was carried out in the province of Jaen, Peru; because most of the works are paralyzed due to a deficient planning and quantification of the work progress, generating that the public entities observe their monthly evaluations that do not correspond to the physical progress in situ. Given this situation, a methodology that combines UAVs and BIM for the estimation of physical progress has been proposed, studies use Kamari & Ham methodologies [28], integrate UAV + Deep Learning, using Python Keras, Sheikhkhoshkar et al. [19], uses only BIM with Autodesk Revit, Dynamo, Microsoft Excel and MATLAB software and Jia et al. [30], uses UAV + BIM with Grasshopper and Rhino, in the research were used software such as Agisoft 2.0.1, ReCap Pro, Revit 2023 and Power Bi, which are different and more efficient than those used by other researchers. Table 8 shows the methodologies, the software used, and the proposed software that differs in the application of other collaborative programs, demonstrating the diversity of approaches and tools used in the physical progress of construction, which highlights the importance of adapting methods to the specific needs of each project. In addition, there is a growing interest in the combination of UAV and BIM, suggesting an emerging trend in the construction industry. These findings provide a solid foundation for future research and practical applications in this area.

Table 8. Methodologies and software used in the physical progress of construction

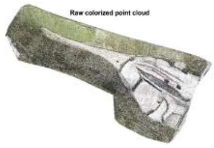
Method	Software	Reference
UAV + Deep learning	Keras Python	Kamari & Ham [28]
BIM	Autodesk Revit, Dynamo, Microsoft Excel, and MATLAB	Sheikhkhoshkar et al. [19]
UAV + BIM	Grasshopper and Rhino	Jia et al. [30]
UAV + BIM	Agisoft 2.0.1, ReCap Pro 2023, Revit 2023, and Power BI 2023	Present study

The images captured by the UAV and processed in Agisoft 2.0.1 software have minimal error because the FC6310R camera with 5472 × 3648 resolution, 8.8 mm focal length, and JPG photos of the Drone Phantom 4 RTK were calibrated with different coefficients to ensure the reliability of the data, Melo et al. [22], uses a DJI Phantom 3 drone, with a Sony EXMOR ½0.30" camera, 12.76 pixels resolution, 4000×3000 image size, creating photos in JPEG format, which calibrates the camera with different coefficients to avoid errors in image acquisition. The estimation error of the cameras processed in the software was minimal, specifically 0.43 cm, which guarantees high precision in the measurements of the construction progress, Ham et al. [37], recommend this type of camera since they use RGB-D, combining color and depth information, offering a higher precision in the estimation of three-dimensional measurements compared to traditional RGB cameras. The digital elevation model of the study area with a resolution of 5.12 cm/pixel and point density of 236 points/m², shows the elevation spectrum of the study area and provides an accurate representation of the terrain in three dimensions, suitable for generating 4D models, according to Huang et al. [24], recommends that an average resolution of 5 cm/pixel should be used to obtain greater resolution and clarity of the image, suitable for evaluating landslides, construction progress, among others.

The point cloud consisted of 37,786,711 points, WGS 84 coordinate system, processed in 3 hours, and used a memory of 5.49 GB, these data demonstrate the ability of this technique to capture and process large amounts of spatial information quickly and efficiently. Jiang et al. [3], recommend the use of this method for modeling, since it is a cheaper and faster alternative compared to other real-time data acquisition techniques, such as 3D laser scanning, because the image processing and geometry of multiple views allow determining the spatial location of a point covered by at least two photos, reducing the cost and time of data collection.

Table 9 presents a comprehensive analysis of research that examines the implementation of point clouds in various settings. The analysis examines factors such as point cloud model, specific application, data acquisition device, image resolution, image processing software, and post-processing errors. Han et al. [38] are noteworthy for their use of automatic bridge alignment extraction using point cloud data acquired with UAVs and TLS. They also used the FPS algorithm in conjunction with high-resolution images (5184 × 3888), resulting in a minimum error of 0.105 cm. Bori et al. [36] focused on developing 3D models with low-cost tools, integrating UAV and Google Earth data, and using Agisoft PhotoScan. They were able to achieve an error of 0.900 cm with an image resolution of 1166 × 874. Other studies, including those by Siebert et al. [9] and Kiriiak [21], investigate the use of UAVs and various image processing tools in earthworks, excavations, and the design of 2D and 3D models of structures. In contrast, the objective of our research is to evaluate the work progress in construction projects using UAVs, incorporating high-resolution images (5472 × 3648) and Agisoft 2.0.1 software. Our results show a negligible margin of error of 0.43 cm. This analysis highlights the range of methods and applications of point cloud technology and emphasizes the need to consider factors such as image resolution and processing software to achieve results in different research settings.

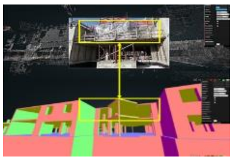
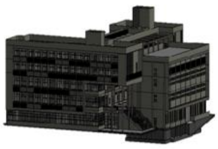
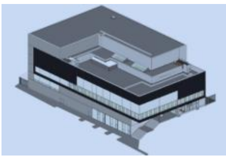
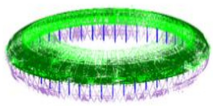
Table 9. Comparison of point cloud, image resolution, and error obtained after processing

Reference	Point cloud model	Application	Data collection instrument	Image resolution	Image processing software	Error (cm)
Han et al. [38]		Automatic extraction of bridge alignments from point cloud data	UAV + TLS	5184 × 3888	FPS algorithm	0.105
Bori et al. [36]		Creation of 3D models with low-cost tools	UAV + Google Earth	1166 × 874	Agisoft PhotoScan	0.900
Siebert et al. [9]		Excavations and earthworks	UAV	2000 × 1600	Agisoft PhotoScan	2.000
Kiriiak [21]		Creation of 3D and 2D models of buildings	UAV	3264 × 2448	Bentley Context Capture	3.000
Present study		Estimate of construction progress in construction projects	UAV	5472 × 3648	Agisoft 2.0.1	0.43

The Revit 2023 Software was utilized to develop a comprehensive 3D and 4D BIM model of the study area, incorporating information from all project specialties. The effectiveness of this methodology is evidenced by Li et al. [4], Fonseca et al. [1], and Tan et al. [39], who also employed a virtual model and essential building data to support planning, design, construction, and operation. Planning components encompass site surveying, cost budgeting, and modeling of the existing conditions. During the design stage, various evaluations and analyses were conducted, including modeling evaluations, cost accounting, structural analysis, performance analysis, resource analysis, energy analysis, and piping integration. Jeelani et al. [40] also utilized this approach, as it enhances project coordination, communication, and efficiency, resulting in improved safety, productivity, and profitability.

Table 10 presents a comparison of studies that explore the integration of BIM models with different technologies and approaches applied to construction. Han et al. [31] use the combination of BIM and UAV in a 3D dimension to advance the construction site using an ontological methodology and classification mechanisms with BIM. Meyer et al. [16] use the same combination of BIM + UAV in 3D for geometric verification of indoor BIM models, incorporating imagery and managing uncertainty. Tan et al. [39] chose 3D BIM + UAV for the inspection of exterior walls in high-rise buildings. Rahimian et al. [41] introduce deep learning in 3D BIM + Deep Learning integration, focusing on building construction inspection and monitoring. The other studies also explore various applications, ranging from indoor drone wayfinding to concrete joint location planning in construction projects. The present study applied BIM + UAV integration in a 4D dimension, highlighting the consideration of the time factor in estimating work progress in construction projects. This analysis shows the variety of approaches and applications that address different aspects of construction by integrating BIM with emerging technologies, contributing to the understanding and improvement of processes in the sector.

Table 10. Comparison of models and methods of integration with BIM

Reference	BIM models	Integration	Dimension	Application
Han et al. [31]		BIM + UAV	3D	Work progress using ontological methodology and classification mechanisms with BIM
Meyer et al. [16]		BIM + UAV	3D	Geometric verification of indoor BIM models using images and uncertainty management.
Tan et al. [39]		BIM + Dynamo	3D	Inspection of exterior walls of high-rise buildings
Rahimian et al. [41]		BIM + Deep Learning	3D	Building construction inspection and supervision
Chen et al. [15]		BIM + UAV	3D	Indoor drone path finding
Jia et al. [30]		BIM + UAV	3D	Construction of the curtain wall of the main stadium of the 31st World University Summer Games Chengdu 2022
Zhang et al. [29]		BIM + UAV	3D	Inspection of building facades with unmanned aerial vehicles (UAVs)
Sheikhkhoshkar et al. [19]		BIIM+ Dynamo	3D	Planning the location of concrete joints in construction projects
Present study		BIM +UAV	4D	Estimate of construction progress in construction projects

The estimated work progress of the Civil Engineering Laboratory of the National University of Jaen, through the application of UAV and BIM, was 42.82%, similar to that obtained by INFOBRAS of 43.14%, constituting this effective methodology that integrates BIM software and data analysis to determine the progress of work in construction. Dupont et al. [32] stated that the integration of these technologies improves productivity in construction due to the integration of data collected by UAVs with BIM models, a major challenge since most projects are focused on developing separate BIM software environments. The implementation of these methods creates a bridge between the collected data and BIM models. Freimuth et al. [42] are precise that the application of these methods in open spaces is reliable and accurate because it enables the BIM 4D workflow, where inspection data is stored in a structured manner by BIM 4D. Chen et al. [15] mention that the BIM methodology is effective for automatic indoor drone navigation in progress monitoring from inside the construction, generating efficient paths in the evaluation walkthrough. Siebert et al. [9] recommend the use of UAVs, which allow a greater number of points to be recorded and measured compared to the conventional method, which means that a detailed and accurate representation of the terrain can be obtained, which is crucial in the planning and design of construction projects.

To address the gaps in the literature, it is recommended to promote interdisciplinarity in research projects by encouraging the participation of experts in BIM, UAV, and related technologies. This will allow for a more holistic understanding of the integration of these technologies in the construction sector. In addition, collaborative platforms and research networks should be established to facilitate communication and knowledge sharing between researchers and practitioners from different fields related to construction and emerging technologies. The creation of shared databases and repositories that house relevant data, models, and research results is also recommended. This will not only facilitate access to critical information but also promote the replicability and verifiability of studies. In addition, the implementation of training and education programs that cover both technical and methodological aspects of these technologies is recommended. This will ensure that professionals and research teams are properly equipped to take full advantage of the tools available.

Research has identified gaps in the literature, yet there remain substantial gaps in the construction industry that could lead to severe ramifications for both operational efficiency and project quality. Insufficient integration of technology in construction could lead to underutilization of its potential advantages, which would limit process optimization, accuracy in estimating progress, and early problem detection during construction. Less efficient projects with higher costs and a greater risk of delay may ensue if strategies are not implemented to address potential consequences. It is recommended that best practices for the interoperability of BIM, UAV, TLS, and Deep Learning technologies be investigated to evaluate their impact on construction project efficiency and quality. Furthermore, it may be worthwhile to explore the adoption of standardized regulations and frameworks to enhance integration and collaboration within the construction industry.

6. Conclusion

The study addresses the problem of construction stoppages in Jaen, Peru, due to poor planning and inadequate quantification of project progress. A new methodology that integrates UAV and BIM technology is proposed to estimate construction progress, using as a case study the construction of the Civil Engineering Laboratory of the National University of Jaén. A Phantom 4 RTK drone was used to acquire 885 high-resolution images, which were processed with Agisoft 2.0.1 software to generate a digital elevation model and a point cloud. The lab was modeled in Revit 2023, incorporating cost information, metrics, and a point cloud-based construction progress phase. Data analysis was performed in Power BI, yielding project progress of 42.82% compared to 43.14% recorded in INFOBRAS, a difference of less than 1%. The efficient use of UAVs facilitated data collection, while BIM enabled accurate integration and analysis of the information. The automated methodology improved the visualization and systematization of construction activities, enabling early detection of problems and timely decisions. The research highlights the importance of effective data integration between UAVs and BIM, underscoring its usefulness for estimating construction progress and conducting efficient inspections. This approach contributes significantly to improving the planning and execution of construction projects, highlighting the overall relevance of the research in solving challenges in the construction sector.

7. Declarations

7.1. Author Contributions

Conceptualization, J.M.P.O.; methodology, L.Q.H. and J.M.P.O.; software, J.M.P.O.; investigation, J.M.P.O.; writing—original draft preparation, J.M.P.O. and L.Q.H.; writing—review and editing, M.E.M.P. and B.A.C.C.; supervision, J.L.P.T. and CZAP. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available in the article.

7.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.4. Conflicts of Interest

The authors declare no conflict of interest.

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