

## Utilizing UAV Technology for Monitoring and Management of Road Construction Projects

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### ABSTRACT

Unmanned Aerial Vehicles (UAVs) have emerged as an effective tool for spatial data acquisition in construction projects, offering high-resolution information suitable for monitoring earthwork operations and construction progress. The objectives of this study are to quantitatively assess the applicability and accuracy of UAV-based photogrammetry for monitoring the cut-and-fill activities in road construction projects in real-world conditions. A UAV survey was performed at an active urban road construction site with a multicopter platform featuring a high resolution RGB camera. The Structure from Motion (SfM) approach was used for photogrammetric processing to create dense point clouds, digital elevation models (DEMs) and Ortho mosaics. The geometric accuracy of geospatial products was ensured by collecting ground control points with Real-Time Kinematic Global Navigation Satellite System (RTK-GNSS). The created surface models were subsequently used in a civil engineering design environment to calculate cut-and-fill volumes and measure the construction progress. The findings showed that the UAV generated photogrammetric products could provide geometric accuracy of up to centimeters, when compared with the RTK-GNSS control, and provide a reliable estimation of earthworks volumes. The methodology suggested can be applied to make an objective comparison between the as-built and design surfaces, identifying substantial fill needs in the road corridor analyzed. The study contribution lies in the corridor-specific, design-integrated validation of UAV-derived cut-and-fill volumes against RTK-GNSS measurements along a continuous road alignment under active construction conditions. The findings indicate that UAV-based photogrammetry can provide an efficient and cost-effective complement to conventional surveying methods for earthwork volume estimation and progress monitoring in road construction projects, with geometric accuracy validated against RTK-GNSS control at the studied site.

**Keywords:** Unmanned Aerial Vehicle (UAV), SfM-Photogrammetry, Road construction, 3D point clouds, Earthworks.

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## 1. INTRODUCTION

Since time immemorial, accurate topographic measurements have been a vital part of any science or industrial application that requires such surveys to be carried out quickly and precisely (**Deliry and Avdan, 2024**). In this context, photogrammetry is one of the most widely used techniques in the field of surveying and has proved useful in the acquisition of spatial information from images. It has been used in a wide range of applications, including geology, environment, structural engineering and biology (**Westoby et al., 2012**). It has seen dramatic improvements in its outputs, due to the use of advanced imaging technologies and increased computing power (**Eltner et al., 2016**).

The use of UAVs for photogrammetry has proved to be an effective method for collecting high-resolution spatial data for engineering uses. Accurate and timely estimation of earthwork volume and progress is one of the key elements in road construction projects for controlling the cost, scheduling, and quality assurance (**Pajares, 2015; Mohsan et al., 2022**). The UAV-photogrammetry has been used in various civilian applications, including surveillance and mapping, traffic surveillance and monitoring, and environmental inspection (**Singhal et al., 2018; AL-Dosari et al., 2023; Choi et al., 2023**). The use of UAVs in the collection of spatial information has drastically changed the way this type of information is being collected, especially in surveying, civil engineering, construction management, and safety and security monitoring. (**Eisenbeiß, 2009; Tatum and Liu, 2017; Sestras et al., 2023**). UAVs can be applied at all stages of a construction project, from preliminary works to final inspections after completion (**Siebert and Teizer, 2014**). At the pre-construction stage, drones are used for topographic mapping and site analysis. During construction, UAVs help track progress, conduct inspections, and identify potential hazards (**Kaamin et al., 2023**). Moreover, UAV data can be used to create dense point clouds, Digital Surface Models (DSMs), and orthomosaics, which provide full three-dimensional spatial information useful for terrain analysis and volumetric computation (**Colomina and Molina, 2014; Nex and Remondino, 2014**). Accurate and timely spatial information is critical in planning, designing, and implementing road construction projects because correct measurements of alignment, elevation, and earthwork volumes determine construction quality, cost effectiveness, and adherence to design requirements.

Ground-based volume estimation and monitoring of earthworks in road construction projects, using UAV-based photogrammetry, has increasingly been investigated in recent years as a viable technique for efficiently managing such volume. Aerial imagery was used to create high-resolution surface models that can be accurate up to RTK-GNSS measurements. The work carried out by (**Julge et al., 2019**) on monitoring road construction earthworks using UAV photogrammetry is suitable for cut and fill calculations in linear infrastructure. In a similar fashion, (**Chonpatathip et al., 2023**) tested the UAV data on an actual road construction project and showed that the estimates for volume using the UAV were within a relatively small difference from the conventional methods, and that the conventionally applied methods required a considerable amount of field time and operating costs. In support of this, (**Lee et al., 2022; Al-Tahir and Barran, 2020**) found that the models generated using UAVs are able to deliver accurate volume calculations in a range of construction scenarios and thus are suitable for earthwork applications in engineering. In civil engineering projects, earthwork volume estimation is a crucial process that can be improved by analyzing the traditional 2D and software-based 3D methods, as conducted by (**Ansari and Agrawal, 2019**), who showed that 3D DTM and BIM-based approaches are more time-efficient, cost-effective, and accurate. Furthermore, integration of



UAV photogrammetry with TLS has been explored by **(Muhammed and Abed, 2025)** to demonstrate that although UAV data accuracy limitations are common due to co-registration issues, it introduces accurate and cost-effective volume estimates, and combining TLS with UAV data results in a high level of surface detail and completeness.

In addition to static volume estimation, more recent studies have also explored progress monitoring in road construction scenarios. **(Lo et al., 2022)** showed that the 3D reconstruction by photogrammetry is a powerful way to quantify the construction progress over time, which would be more objective than the traditional way of reporting construction progress. Although tremendous progress has been made, there are still some key challenges that need to be addressed when using UAV-photogrammetry in road corridors. Road construction projects are usually elongated and narrow in geometry, making it difficult to obtain images with complete or accurate construction from occlusions created by construction machinery, steep slopes and vegetation along roadsides. The effect of occlusions on volumetric analysis has been directly pointed out by **(Ersoz and Pekcan, 2025)**, who demonstrated that occlusions markedly affect the volumetric analysis and suggested automatic techniques to reduce the effects of the occlusion. Moreover, **(Ferrer-González et al., 2020)** noted that where roads are situated on terrain with a high percentage of elevation change, the accuracy of UAVs is significantly affected by terrain complexity, flight configuration, and how the ground control points are distributed.

In the engineering sector, products obtained from UAVs have been demonstrated to be capable of centimeter-level precision with well-distributed ground control points **(Shahbazi et al., 2015; Agüera-Vega et al., 2017)**. The literature has validated how to use low-altitude UAV imaging and RTK-GNSS control to capture accurate surface models at a fraction of the time and cost of traditional surveying methods **(Heeto Abdulrahman et al., 2020; Athirah et al., 2025)**. **(Eyoh et al., 2019; Kim et al., 2022)** noted that the UAV-based methods for earthwork and volume estimation were found to be more efficient and accurate than conventional volume-estimation methods like average end-area and prismatic methods. The innovative volumetric accuracy studies have additionally given an extra boost of confidence in the UAV-based volumetric analysis: dam applications and stockpile applications have reported volumetric accuracy higher than 99% with a significant reduction in safety and efficiency risks **(Tucci et al., 2019; Idrees and Heeto, 2020; Mohsan and Aduah, 2021)**. Meanwhile, combining UAV photogrammetry with digital construction-management systems like BIM and time-series surface models has also facilitated data-driven progress monitoring and decision making in infrastructure projects **(Cho et al., 2021; Sentosa et al., 2023)**. Furthermore, Photogrammetry provides the whole coverage of the site and can be used to gather information other than that of traditional photographs, that include quantitative information about the volume and topography of the site **(Remondino et al., 2011)**. This information helps to provide more precise estimating of earthwork and better management of resources. Due to the ongoing technological development, UAVs are projected to be utilized more and more in the construction sector, but also across other industries, including agriculture, environmental monitoring, mining, disaster management, transportation infrastructure inspection, and others **(Hassanalian and Abdelkefi, 2017; Molina et al., 2023; Gholami, 2024)**.

Although various developments have been made, the literature mostly focuses on isolated sites, stockpiles, or average earthwork projects in the open, while little is known about linear road-corridor projects in real construction conditions. In addition, the impact of corridor-specific constraints, occlusion and workflow limitations is not addressed enough. It is



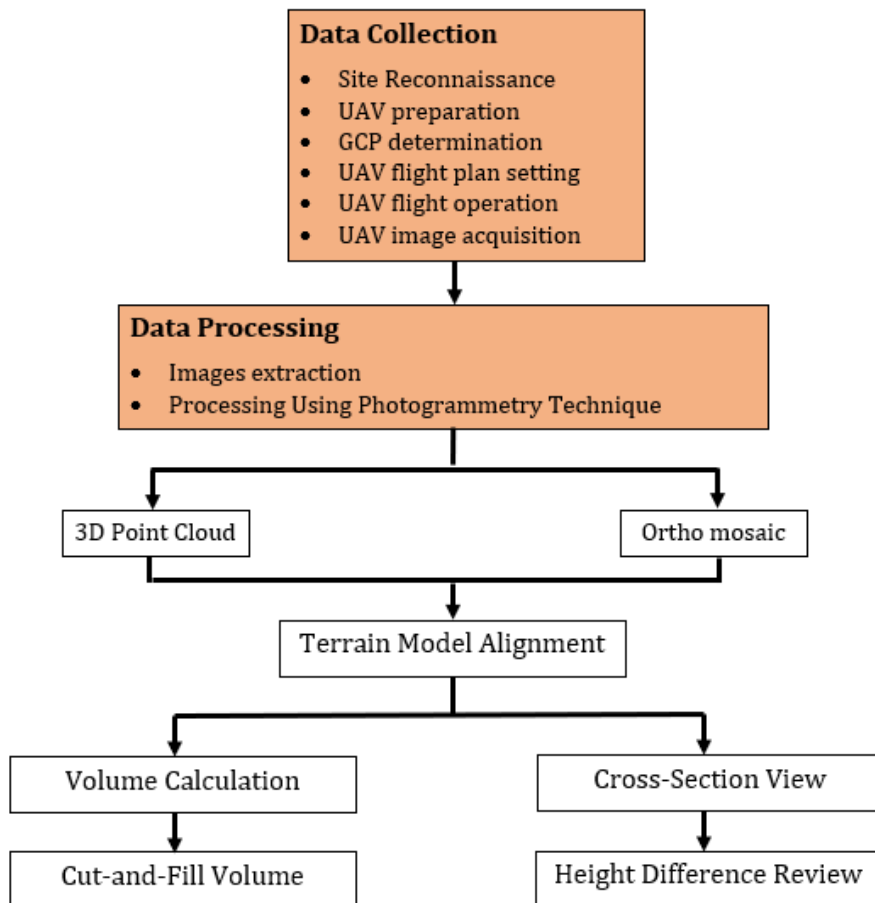
therefore imperative that a more specific investigation of UAV-based methods be undertaken to reliably aid in earthworks volume estimation and progress monitoring in real-world road construction settings.

This forms the gap in knowledge, which is filled by the present study. For this purpose, this research compares the accuracy and applicability of UAV photogrammetry for volume estimation and progress monitoring of earthwork in a linear road construction project. The work brings together products from UAV photogrammetry, RTK-GNSS validation, and civil engineering design pipeline to offer a quantitative and scalable solution for monitoring cut-and-fill earthworks. Specific objectives include: (1) to create accurate surface models of the corridor; (2) to estimate the earthwork volumes for the road alignment; and (3) to evaluate construction progress by comparing the as-built and design surfaces.

## 2. METHODOLOGY

### 2.1 Overview

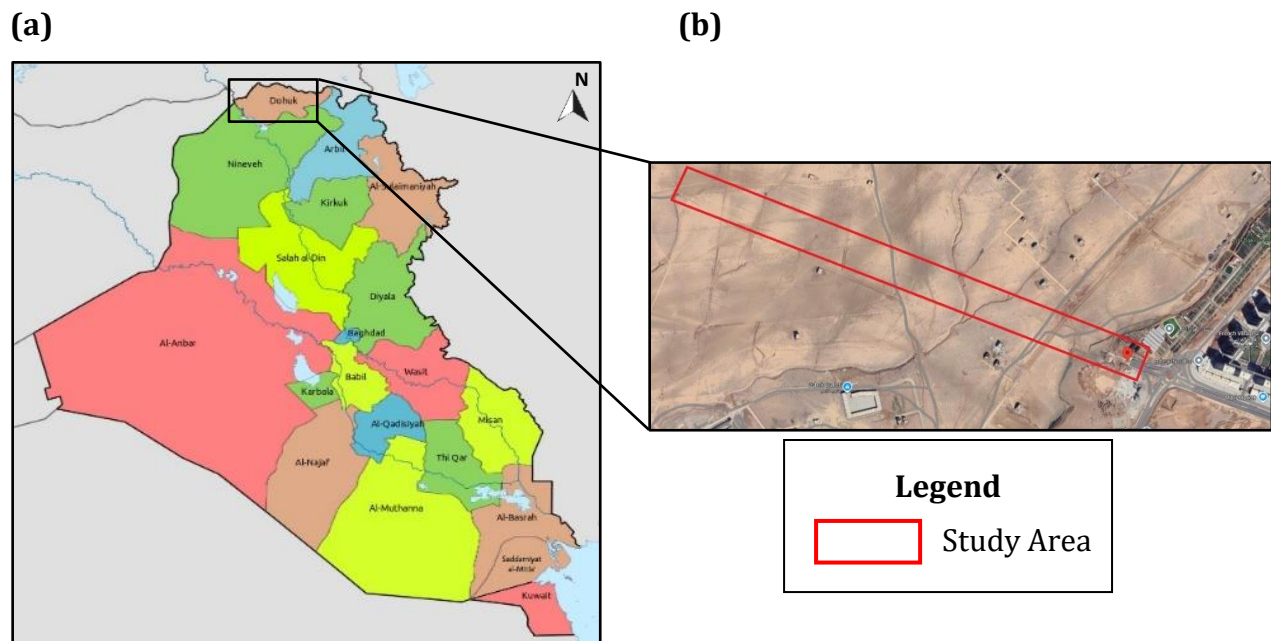
This study proposes a framework for the earthwork monitoring of road construction sites based on UAVs, as shown in **Fig.1**. The framework consists of three stages: (1) data collection, (2) data processing, and (3) data analysis.



**Figure 1.** Flowchart of the proposed methodology for UAV-based earthwork management.

## 2.2 Study Area Description

The proposed research site is in the Duhok Governorate, North Iraq, on the urban boundary of Tanahi district, as shown in **Fig. 2**. **Fig. 2a** shows the regional setting of Iraq and the location of the Duhok Governorate. The specific location of the chosen road construction site is presented in **Fig. 2b**, which is located at  $36^{\circ}52'58.5''\text{N}$   $42^{\circ}53'60.0''\text{E}$ . The study area can be described as generally semi-flat, with some areas varying due to excavation and embankment work related to the construction of the roads.



**Figure 2.** Location map of the study area: (a) Iraq, Duhok Governorate, and (b) Tanahi district (SAS Planet).

The site is an active urban road construction project with a newly developed, predominantly straight alignment. These geometric characteristics make the site particularly suitable for testing UAV-based photogrammetry in linear infrastructure surveys, where corridor continuity and geometry are critical.

## 2.3 Data Collection

An RTK-GNSS survey was conducted to evaluate the geometric accuracy of the UAV-derived products and to collect valid ground reference data. The accuracy of the E-Survey E600 receiver is nominally  $\pm 8$  mm horizontally and  $\pm 15$  mm vertically, respectively. The geometric accuracy of the aerial images and, consequently, the photogrammetric models, can be greatly improved by the use of ground control points (GCPs) that provide a strong reference framework for the alignment of the aerial images with the ground (**Agüera-Vega et al., 2017; Martínez-Carricondo et al., 2018**).

For this study, six GCPs were set up and measured with the RTK-GNSS method. The six GCPs were chosen to provide geometric control and balance of effort in the field for a corridor of this length. In linear corridors, the distribution of control points is more important than the number of points: control points should be placed near both ends of the

alignment, but spaced out along both sides to prevent the geometry of the block from being overly constrained and to avoid systematic vertical 'doming' from near-parallel image strips and camera self-calibration (James et al., 2017). To this end, the six points were placed alternately on both sides of the corridor (total length ~300 m) with an average space between control points of ~50–60 m. The study area starts at 0+000 and ends in about 300 m distance, which is a total area of about 9000 m<sup>2</sup>. Ground control points were scattered around the site before the flight of the UAV, as seen in Fig. 3.

The GCP targets were systematically distributed across the study site. These GCP targets were marked using red spray paint in an 'X' configuration, with an approximate span of 1.0–1.2 m and line width of 5–10 cm, ensuring sufficient visibility in UAV imagery. And each center was surveyed using a RTK-GNSS, and its coordinates were recorded. Fig. 4 illustrates the spatial distribution and placement of the GCP targets across the study area.



Figure 3. Ground control points (GCPs).

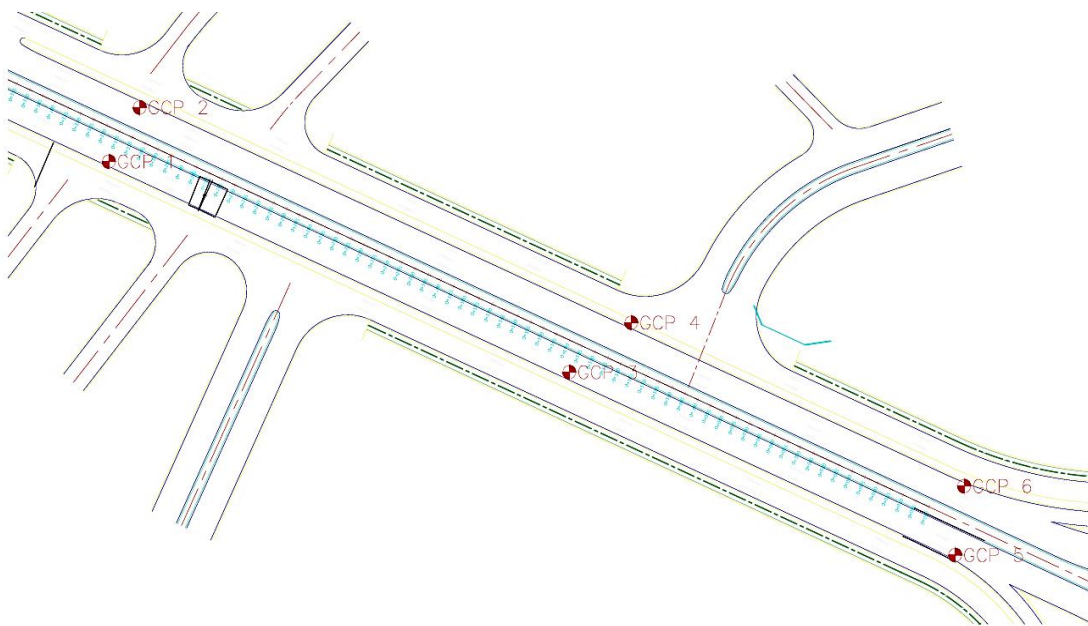


Figure 4. Location and distribution of ground control targets.

The UAV system used in this study was a quadcopter multirotor UAV, named Phantom 4 Pro, manufactured by DJI. In this study, the UAV system was the DJI Phantom 4 Pro, a 20 MP high-resolution RGB camera with a 1-inch CMOS sensor installed in a quadcopter multirotor UAV. The flight planning parameters and camera settings are displayed on **Fig. 5**. The flight mission was conducted on [18/12/2025] [2:30 PM]. To minimize image distortion and achieve the highest possible photogrammetric quality, the flight mission was carried out in the following weather conditions: low wind speed, good visibility and stable illumination. The images were captured with 80% of frontal overlap and 80% of side overlap, which is needed for the photogrammetric reconstruction process to ensure good image redundancy for better feature matching. The altitude of 75 m above ground level and the maximum speed of 5 m/s were chosen to provide the best compromise between image resolution, coverage efficiency and motion stability. The entire mission resulted in 220 images that covered the region well for modeling and volumetric analysis.



**Figure 5.** The UAV flight plan showing flight settings.

## 2.4 Data Processing

Following the completion of the UAV mission and configuration of the flight plan in the 3D Survey Pilot software, the captured images were imported into Agisoft Metashape Professional (version 2.1.2 build 18204) for photogrammetric processing, as illustrated in **Fig. 6**.

This software performs automated three-dimensional reconstruction based on the SfM approach, enabling the generation of accurate and cost-effective 3D spatial data from overlapping RGB images. The software is developed by Agisoft LLC and is widely used in photogrammetric applications for geospatial data processing. More details about the software can be found on the official website: <https://www.agisoft.com/>

In this study, the 220 images from a single representative flight dataset were processed in one chunk. Image alignment was performed at High accuracy, with a key-point limit of 40,000 and a tie-point limit of 4,000, producing 75,025 tie points across a fully connected camera network. Six GCPs measured with the E-Survey E600 RTK-GNSS receiver were imported and manually marked on the corresponding images. The following **Tables 1 and 2** show Coordinates of the GCPs based on the WGS 84 central origin (EPSG:4326) and the error parameters relating to the GCPs.

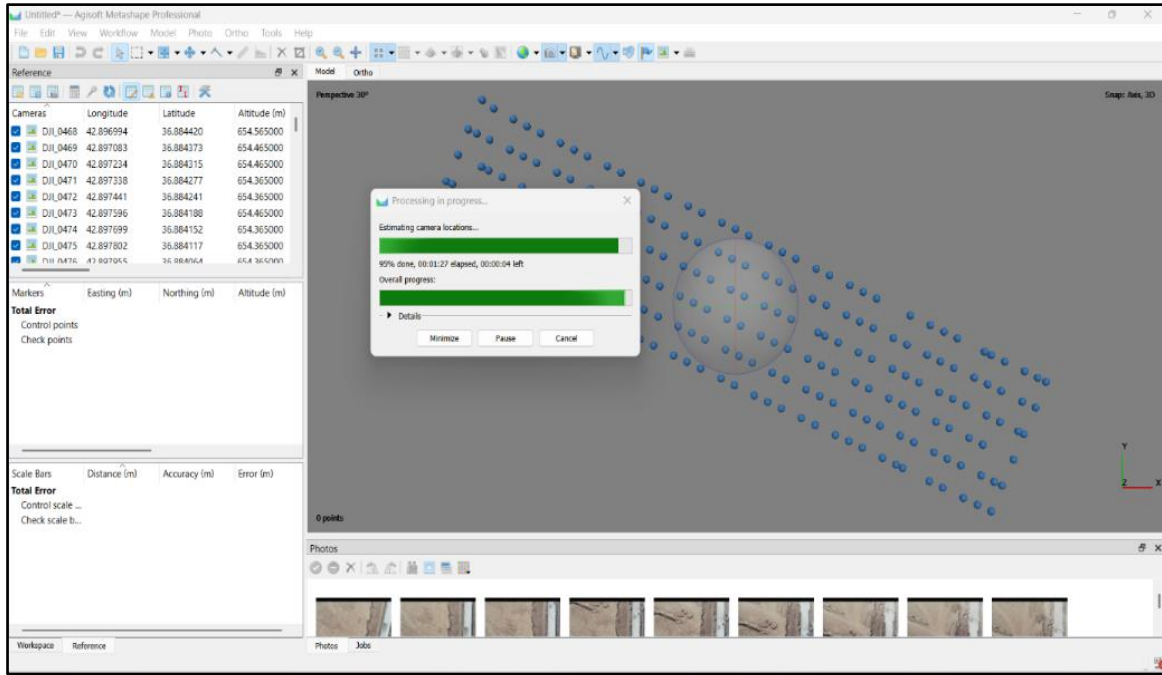


Figure 6. Images added to Agisoft Metashape.

Table 1. Coordinates of the ground control points.

GCPs	X (m)	Y (m)	Z (m)
1	312581.006	4084054.119	542.077
2	312591.968	4084072.605	542.083
3	312744.624	4083982.147	540.167
4	312766.643	4083999.057	540.452
5	312881.774	4083919.659	542.985
6	312884.966	4083943.22	542.864

Table 2. GCP errors.

Label	X error (mm)	Y error (mm)	Z error (mm)	Total (mm)	Image (pix)
1	-2.13209	0.833875	-1.92874	2.99353	0.451 (9)
2	-1.25556	2.09102	2.6018	3.56625	0.462 (9)
3	-1.49256	-1.48463	1.87703	2.82048	0.392 (9)
4	8.11924	-5.6562	-0.755266	9.92397	0.344 (9)
5	-0.301394	4.1323	1.19386	4.31185	0.292 (9)
6	-2.84174	0.108916	-0.393272	2.87089	0.397 (9)
<b>Total</b>	<b>3.70671</b>	<b>3.06464</b>	<b>1.64129</b>	<b>5.08189</b>	<b>0.394</b>

Following GCP integration and camera optimization, the standard SfM workflow was completed in Agisoft Metashape. A sparse point cloud was first generated through feature matching and initial camera orientation. The reprojection error (the planar distance, in pixels, between the measured image position of a tie point and the position obtained by re-projecting its reconstructed 3D coordinate onto the image) was minimized by bundle

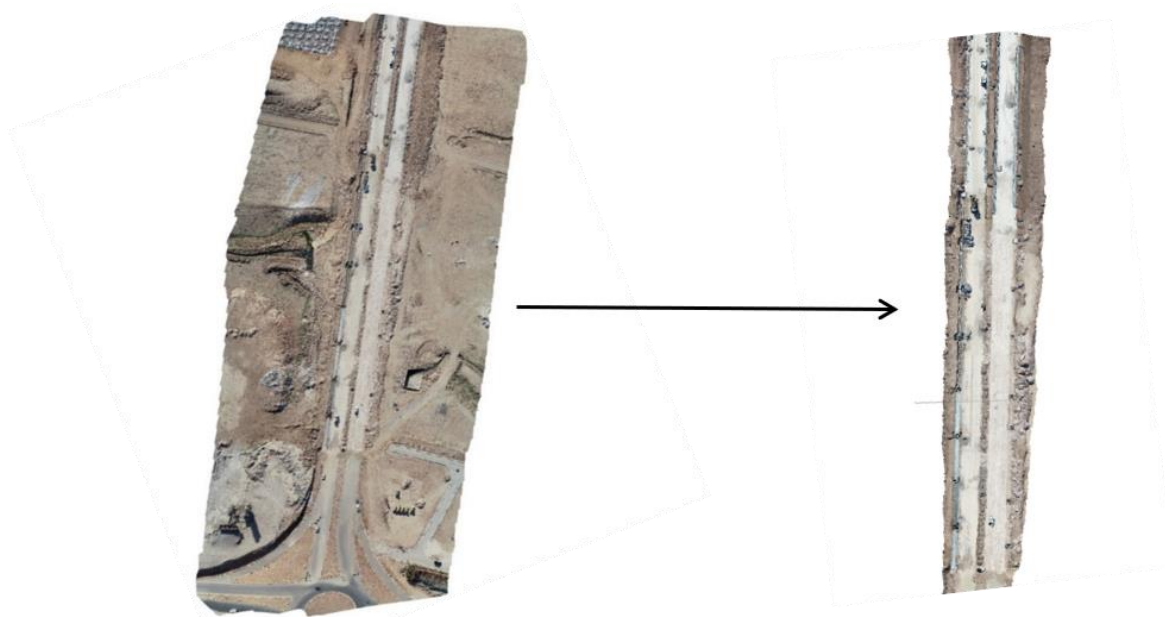
adjustment. The bundle adjustment minimizes the total reprojection error  $E$  defined by the formula below:

$$E = \sum_i \sum_j \| x_{ij} - \pi(K_i, R_i, t_i, X_j) \|^2 \quad (1)$$

where  $x_{ij}$  is the observed image coordinate of 3D point  $X_j$  in image  $i$ ,  $\pi(\cdot)$  is the perspective projection function,  $K_i$  is the camera interior-orientation (calibration) matrix, and  $R_i$  and  $t_i$  are the rotation matrix and translation vector describing the exterior orientation of image  $i$ . This non-linear least-squares problem is solved iteratively (Levenberg–Marquardt algorithm) to obtain the optimal camera parameters and 3D point coordinates (**Szeliski, 2010**).

Dense image matching was then performed to reconstruct a high-density 3D representation of the study area. The resulting dense point cloud comprised approximately 6,066,207 points (corresponding to an average density of about [674.023/m<sup>2</sup> from the Metashape report] over the  $\approx 9,000$  m<sup>2</sup> study area), providing detailed surface geometry suitable for engineering analysis. During alignment, all images returned an image-quality estimate greater than 0.8 (Agisoft Metashape's normalized image-sharpness index, where 1.0 denotes an ideally sharp image and values below 0.5 are recommended for rejection); accordingly, no images were discarded.

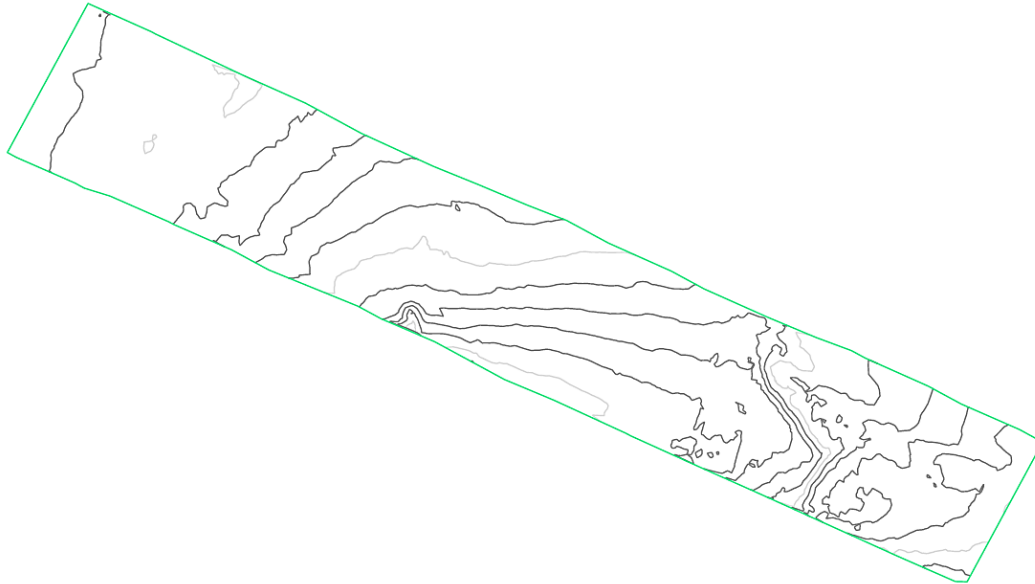
The registration of multiple partial point clouds from individual photographs produces duplicate points that do not improve surface quality but increase processing time; these were removed during point-cloud clean-up. **Fig.7** shows the point-cloud clean-up result. Once finalized, the point cloud was exported to Autodesk Civil 3D for further processing and volume calculation.



**Figure 7.** 3D Point clouds clean-up results.

After generating the dense point cloud, DEMs, contour maps and orthomosaic images were created with the help of Agisoft Metashape Professional (Version 2.1.2 build 18204). The resulting dense point cloud was, on average, 674.023 points/m<sup>2</sup>, which is a detailed representation of the surface of the terrain. The ground sampling distance (GSD) of the input images was 1.71 cm/pixel. Next, the DEMs were created with a spatial resolution of 3.42

cm/pixel and exported to be analyzed in spatial, cut-and-fill and profile extraction programs, including Autodesk Civil 3D (Version 13.5.131.0 Autodesk Civil 3D 2023). The filtered point cloud data was then imported into Autodesk Civil 3D to reconstruct the surface and analyze the terrain. A triangulated irregular network (TIN) surface model was then created to characterize the topographic features of the study area and facilitate quantitative and volumetric analyses. The processed surface model was used to create the contour map shown in **Fig. 8**.



**Figure 8.** Contour map.

### 3. RESULTS AND DISCUSSION

The project progress assessment was conducted to quantitatively evaluate the completed excavation and backfilling activities along the road construction corridor. Photogrammetric surveying techniques were employed to generate high-resolution topographic maps and DEMs, which were subsequently utilized for earthwork quantity estimation and terrain analysis. Following point cloud filtering and terrain extraction, a Triangulated Irregular Network (TIN) surface was generated using Autodesk Civil 3D to represent the existing ground surface conditions of the study area. The processed terrain data were further used to derive contour maps, longitudinal profiles, and cross-sectional geometries required for volumetric computations. The earthwork analysis focused on estimating cut-and-fill quantities along the designed road alignment. Initially, the road centerline alignment was established, followed by the generation of a longitudinal profile and the development of a corridor model based on the proposed road geometry and assembly parameters. Subsequently, cross-sections were automatically generated at regular station intervals to facilitate accurate earthwork computations. The cut-and-fill volumes between adjacent cross-sections were calculated using the Average End Area (AEA) method (**Ghilani and Wolf, 2012**) according to:

$$V = \frac{A_1 + A_2}{2} \times L \quad (2)$$

where  $V$  represents the earthwork volume between two consecutive cross-sections ( $m^3$ ),  $A_1$  and  $A_2$  denote the cross-sectional areas ( $m^2$ ), and  $L$  represents the distance between adjacent sections ( $m$ ).



In addition, the elevation difference between the proposed design surface and the existing ground surface was determined using:

$$\Delta h = Z_p - Z_e \tag{3}$$

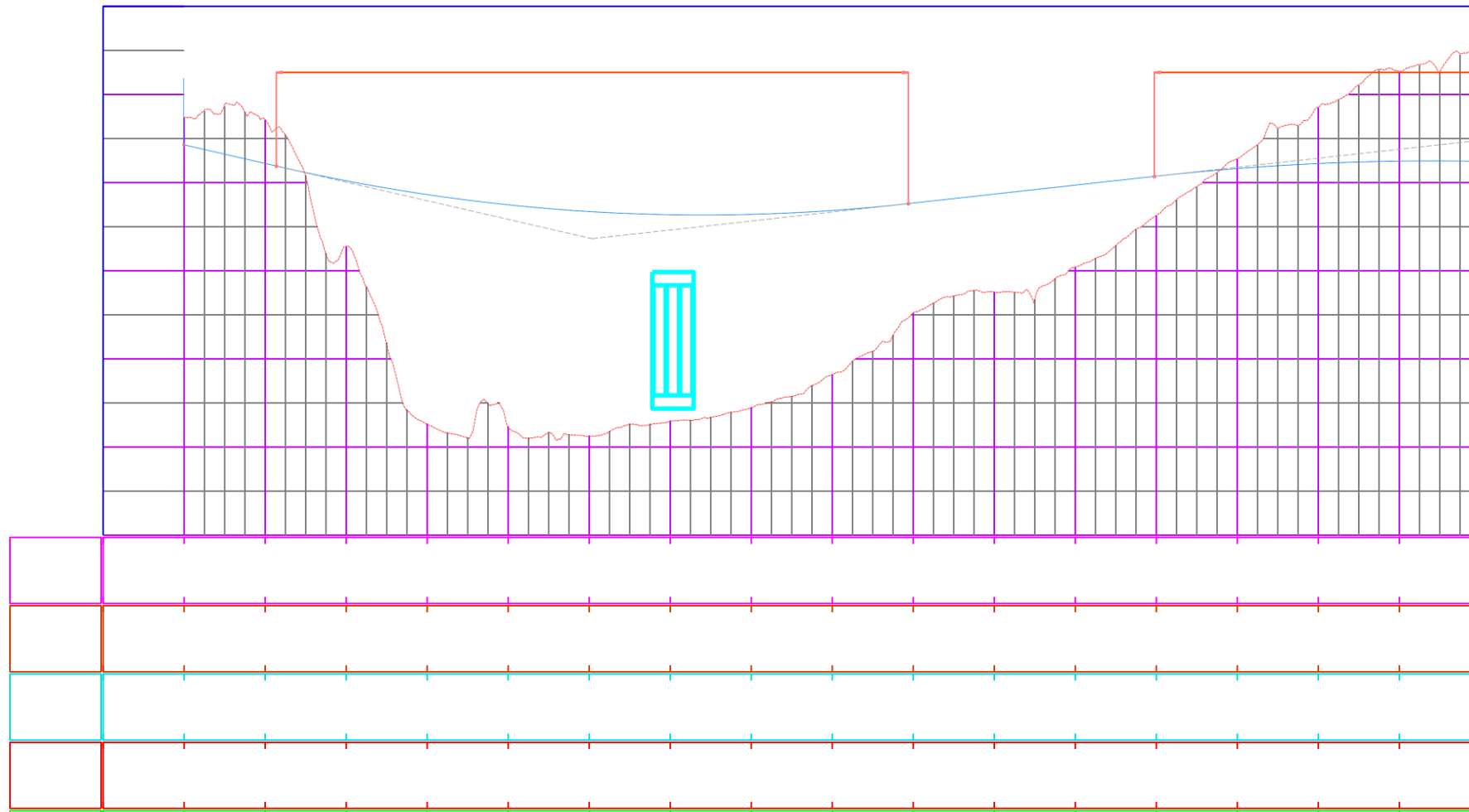
where  $\Delta h$  is the elevation difference,  $Z_p$  is the proposed surface elevation, and  $Z_e$  is the existing ground elevation. Positive values indicate embankment (fill) volumes, whereas negative values represent excavation (cut) volumes. Based on these geometric and elevation parameters, the software automatically generated detailed reports of excavation and embankment quantities. **Figs. 9 and 10** demonstrate the workflow adopted in the analysis, while **Table 3** summarizes the calculated earthwork quantities for the investigated road project.

**Table 3.** Earthwork quantities for the Road Project.

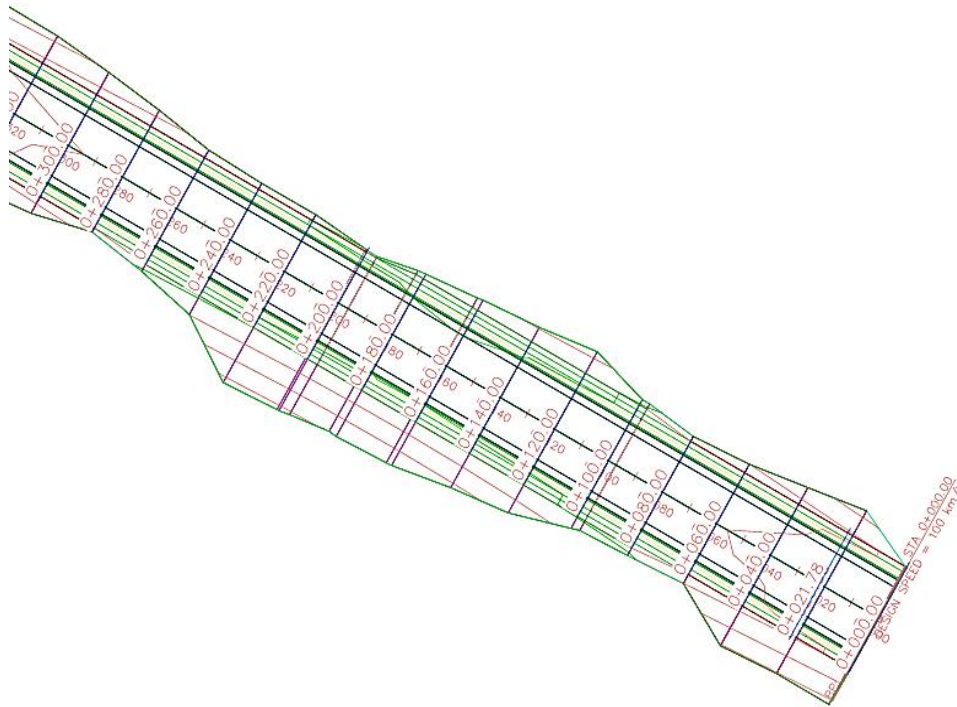
Station	Cut Area (m <sup>2</sup> )	Cut Volume (m <sup>3</sup> )	Reusable Volume (m <sup>3</sup> )	Fill Area (m <sup>2</sup> )	Fill Volume (m <sup>3</sup> )	Cumulative Cut Volume (m <sup>3</sup> )	Cumulative Reusable Volume (m <sup>3</sup> )	Cumulative Fill Volume (m <sup>3</sup> )	Cumulative Net Volume (m <sup>3</sup> )
0+000.00	0	0	0	0	0	0	0	0	0
0+020.00	99.13	991.27	991.27	0	0	991.27	0	0	991.27
0+040.00	70.43	1,523.89	1,523.89	0	0	2,689.82	0	0	2,689.82
0+060.00	53.71	1,241.37	1,241.37	0	0	3,931.19	0	0	3,931.19
0+080.00	0.56	542.65	542.65	96.27	962.69	4,473.85	962.69	962.69	3,511.16
0+100.00	0	5.56	5.56	174.55	2,708.14	4,479.40	3,670.83	3,670.83	808.57
0+120.00	0	0	0	167.84	3,423.83	4,479.40	7,094.65	7,094.65	-2,615.25
0+140.00	0	0	0	162.79	3,306.31	4,479.40	10,400.97	10,400.97	-5,921.57
0+160.00	0	0	0	150.62	3,134.15	4,479.40	13,535.12	13,535.12	-9,055.71
0+180.00	0	0	0	128.84	2,794.60	4,479.40	16,329.72	16,329.72	-11,850.31
0+200.00	0.25	2.51	2.51	91.73	2,205.71	4,481.91	18,535.42	18,535.42	-14,053.51
0+220.00	2.17	24.23	24.23	54.19	1,459.19	4,506.14	19,994.62	19,994.62	-15,488.48
0+240.00	1.83	40.05	40.05	42.95	971.37	4,546.19	20,965.99	20,965.99	-16,419.80
0+260.00	4.86	66.92	66.92	21.65	645.99	4,613.11	21,611.97	21,611.97	-16,998.87
0+280.00	21.13	259.88	259.88	0	216.5	4,872.99	21,828.48	21,828.48	-16,955.49
0+300.00	69.76	908.9	908.9	0	0	5,781.89	21,828.48	21,828.48	-16,046.59

The earthwork analysis presented in **Table 3** consists of three major parameters: cut volume, fill volume, and cumulative net volume. The volume of material to be removed to meet the proposed design elevations is the cut volume, while the volume of material to be added to the design elevations is the fill volume. These two are interdependent; some of the material excavated can be used as fill, thus decreasing the need for borrow materials from other sources. The cumulative net volume is a difference between the total volume of excavation and filling along the analyzed stations, it means how much more or less material is used in each part of the alignment.

The total fill volume from STA 0+00 to STA 3+00 is 21,828.48 m<sup>3</sup> and the total cut volume is 5,781.89 m<sup>3</sup>. The net deficit of 16,046.59 m<sup>3</sup> has been observed after balancing the cut and fill quantities, which shows that the amount of excavated materials available is not enough to meet the embankment volumes. Therefore, more borrowed material needs to be imported in order to meet the design requirements, and this will directly affect the cost of the project and material logistics. This imbalance also underscores the critical need for optimized haulage planning, such as borrow pit selection, haulage routing and stockpiling materials.



**Figure 9.** longitudinal profile of the proposed road alignment illustrating terrain elevation variations used in the earthwork assessment process.



**Figure 10.** Developed corridor model representing the proposed roadway geometry employed for automated cross-section generation and volumetric analysis.

The early detection of these deficiencies allows for better utilization of equipment and scheduling throughout the project. Sustainability is restricted by the fact that only a small amount of reusable cut material is available which limits on-site material recycling. The higher the portion of excavated material that can be reused, the greater the amount of material that can be transported without hauling. The greater the percentage of excavated material that can be reused, the less material will need to be hauled, which will reduce the distances and fuel consumption and environmental impacts from material hauling.

Input parameters like GCP distribution, image resolution, and terrain complexity affect the volumetric results derived from surface modeling using photogrammetry. Photogrammetric methods offer higher spatial resolution and quicker data collection than traditional surveying techniques like GNSS measurements, but they can still produce some error, caused by occlusions, surface reflectivity changes, and reconstruction errors in dense vegetation or steep terrain. The observed cumulative net volume trend is clear and shows that along the corridor, the number of cuts was decreasing while the number of fills was increasing, reflecting the geometric nature of the proposed alignment. These trends are crucial to setting up earthworks and to minimizing off-site material movement in the implementation of the project.

In addition, GIS-based spatial analysis systems can be linked to the photogrammetric products, thus improving the capabilities of decision making, by giving the possibility of spatial visualization of the distribution of cut-and-fill. These data sets can be added to spatial databases and used for infrastructure management, progress monitoring and future optimization of design. The primary benefits of using photogrammetry are its efficiency, repeatability and dense surface reconstruction, however there are drawbacks with regard to environmental sensitivity and dependency on data quality. The challenges can be reduced by a hybrid surveying system that uses UAV photogrammetry and ground-based control surveys to enhance the accuracy of the UAV survey.



#### 4. CONCLUSIONS

By combining these UAV-generated photogrammetric data with the dense point cloud processing, digital 3D models of construction sites can be accurately generated. In this context, the geospatial parameters are the X, Y, Z coordinates and the elevation values determined from the DEM, GCPs and the coordinate transformation parameters used to guarantee the spatial accuracy and consistency of the reconstructed surface models. These parameters are used to make reliable topographic maps and volumetric computations. The proposed methodology will improve construction monitoring by offering a consistent framework and measurement that will allow to assess the progress of earthwork construction in space. Point cloud data with georeferenced data from UAVs helps to guarantee the reliability of the construction records by ensuring accurate spatial referencing of the point cloud with the true ground coordinate system. For the purposes of this study, only excavation and embankment (cut and fill) operations were considered. The results show a total material deficit of 16,046.59 m<sup>3</sup> is present in the analyzed section, with the available excavated material being less than the volume to be filled. This result, however, is not included in the overall project completion, because it's an evaluation for a particular corridor segment and time interval. To achieve full alignment coverage, multi-temporal datasets would be required to complete the evaluation of project progress. Overall, the study is successful in showing that the use of an UAV platform for photogrammetry is a reliable method for estimating and monitoring earthworks quantity in an infrastructure project. It is especially useful for cut and fill analysis, and can be further enhanced by multi-temporal monitoring, full project coverage and linkage with construction scheduling systems to provide a more comprehensive project control.

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#### Credit Authorship Contribution Statement

Farsat Heeto Abdulrahman: Conceived the proposed idea, created the theory, verified the analytical procedures, and oversaw the findings of this study. Noor Yousif Ahmed: did the computations, analyzed the data, and authored the manuscript. All authors discussed the findings and contributed to the final text.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## استخدام تقنية الطائرات بدون طيار لمراقبة وإدارة مشاريع بناء الطرق

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### الخلاصة

برزت المركبات الجوية غير المأهولة (UAVs) كأداة فعّالة لجمع البيانات المكانية في مشاريع البناء، إذ توفر معلومات عالية الدقة مناسبة لرصد عمليات الحفر والردم وتقدم أعمال البناء. تهدف هذه الدراسة إلى التقييم الكمي لمدى ملاءمة ودقة التصوير المساحي الجوي باستخدام المركبات الجوية غير المأهولة لرصد أنشطة الحفر والردم في مشاريع بناء الطرق في ظروف واقعية. أُجري مسح جوي باستخدام طائرة متعددة المراوح مزودة بكاميرا RGB عالية الدقة فوق موقع بناء طرق حضري نشط. استُخدمت معالجة التصوير المساحي الجوي القائمة على تقنية إعادة بناء الهيكل من الحركة (SfM) لإنشاء سحب نقاط كثيفة، ونماذج ارتفاع رقمية (DEMs)، وصور فسيفسائية مُصححة. استُخدمت نقاط تحكم أرضية تم قياسها باستخدام نظام RTK-GNSS لضمان الدقة الهندسية. دُمجت نماذج السطح المنشأة في بيئة تصميم هندسي لإجراء حسابات تفصيلية لحجم الحفر والردم وتقييم تقدم أعمال البناء. تُظهر النتائج أن منتجات التصوير المساحي الجوي المُستمد من الطائرات بدون طيار توفر دقة هندسية عالية، وتُمكن من تقدير كميات أعمال الحفر والردم بشكل موثوق. تسمح المنهجية المقترحة بإجراء مقارنة موضوعية بين الأسطح المنفذة والأسطح التصميمية، مما يكشف عن كميات كبيرة متبقية من مواد الردم ضمن حرم الطريق المدروس. تكمن جدة هذه الدراسة في التكامل المنهجي للتصوير المساحي الجوي باستخدام الطائرات بدون طيار مع التحقق من صحة نظام تحديد المواقع العالمي RTK-GNSS لمراقبة أعمال الحفر والردم في بيئة إنشاء الطرق الخطية، مما يوفر إطارًا عمليًا وقابلًا للتطوير لإدارة الإنشاءات. تؤكد النتائج أن التصوير المساحي الجوي باستخدام الطائرات بدون طيار يُمثل بديلًا دقيقًا وفعالًا واقتصاديًا لأساليب المسح التقليدية لتقدير كميات أعمال الحفر والردم ومراقبة التقدم في مشاريع إنشاء الطرق.

**الكلمات المفتاحية:** المركبات الجوية غير المأهولة، التصوير المساحي، مشاريع البناء، السحب النقطية، الصور الفسيفسائية المتعامدة، أعمال الحفر.