# Improving Cut and Fill Operations in Construction using Drone Technology and Aerial Analytics

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**Abstract.** The construction industry is always looking for new, creative ways to increase the effectiveness and precision of its operations. The use of drones for cut-and-fill operations in construction is one area where great progress has been made. Construction sites are now being surveyed by drones in order to gather data for analysis and decision-making. In this paper, we examine the usage of drones for cut and fill operations in construction and how they might be used in conjunction with aerial analytics technologies to produce better outcomes. We present a case study in which a construction site was surveyed by drones in order to gather topographic and elevational data. To create detailed maps and 3D models of the location, this data was analyzed using a suite of aerial analytics technologies. The article's findings demonstrate that traditional surveying techniques can be greatly sped up and cost-effectively replaced by drones in cut and fill construction operations. Additionally, using aerial analytics technologies enables a more precise and in-depth analysis of the collected data. As a result, we draw the conclusion that the application of drone technology and aerial analytics has the potential to transform the construction sector and boost project productivity.

**Keywords:** Construction industry; Innovation; Drones; Construction cut and fill operations; Surveying; Aerial analytics tools; Topography

## 1. Introduction

Many construction projects include cut-and-fill operations as essential elements. These procedures include the removal of soil from one location, referred to as the cut, and the placing of that soil in another area, referred to as the fill. The accuracy of the earthwork quantities and the effective management of the excavated materials are essential to the success of cut and fill operations. Drone technology and aerial analytics have recently been recognized as promising methods to increase the precision and effectiveness of cut and fill operations. In-depth 3D maps, models, and volumetric measurements can be produced using aerial analytics software by processing data on the topography and geographical features of construction sites that is swiftly and accurately captured by drones with high-resolution cameras and sensors.

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It is essential to have a trustworthy approach that can analyze, anticipate, monitor, and record the outcomes in order to survey earthwork topography properly, effectively, and simply. The total station (TS) and the Global Positioning System (GPS), as well as Drone or unmanned aerial vehicle (UAV) photogrammetry and laser scanning, are two common techniques used to survey topographical data. TS represents the area-based strategy, whereas drone represents the point-based method. A drone or unmanned aerial vehicle (UAV) is an aircraft that doesn't have a human pilot on board. UAVs can be configured to fly independently using predefined routes and instructions, or they can generally be commanded remotely by a pilot on the ground. UAVs are available in a range of sizes, from compact portable devices to massive military-grade drones.

## 2. Literature Review

A thorough analysis of rotorcraft UAV advances and prospective applications in civil engineering is given by [12]. It covers a range of rotorcraft UAV parts, technological breakthroughs related to UAVs, sensor payloads, and communication systems. Additionally, it explores the possible uses of rotorcraft unmanned aerial vehicles (UAVs) in civil engineering, including topographic mapping, site inspection, structural health monitoring, and disaster assessment. [13] look into the viability of using UAS to inspect construction sites for safety. The study examined the benefits and drawbacks of UAS in comparison to conventional inspection techniques and assessed the efficiency of UAS in locating safety risks. In especially for dangerous or difficult-to-reach places, the authors found that UAS technology offers a safer and more effective method for safety checks. A thorough analysis of UAV applications in civil infrastructure was carried out by [20]. The document gives a general overview of the main UAV models, as well as their sensors and data processing capabilities. It talks about how to use them for building, monitoring, and inspecting infrastructure. The authors concluded that the use of unmanned aerial vehicles (UAVs) might change the field of civil infrastructure by introducing safer, more effective, and affordable techniques for inspection and monitoring. The findings of a study on the potential of UAS for applications in construction safety were presented by [11]. The authors looked at how UAS technology can be used to spot potential safety risks on building sites and assessed how well UAS work to increase safety in the construction sector. The study discovered that by supplying real-time monitoring and identifying potential safety issues, UAS technology has the ability to greatly improve safety on construction sites. [18] carried out a thorough analysis of UAS applications in the construction industry. In the study, many uses of UAS technology in the building industry were found, including site surveying, progress monitoring, quality control, safety management, and asset management. The authors concluded that UAS technology has the ability to greatly enhance productivity, security, and quality in the building sector. In open-pit mines, [15] showed how to conduct topographic surveys using a fixed-wing UAV. The study contrasted the drone-based surveying methodology with conventional surveying techniques and found that the drone-based surveying technique offered equivalent accuracy while being quicker and more economical. The slope local length of auto-correlation (SLLAC), a novel landscape metric introduced by [5], can be used to identify terraced sites. In a case study of terraced landscapes in Italy, the authors showed how to apply SLLAC and contrasted it with other landscape metrics frequently used for terraced landscape analysis. The findings demonstrated that SLLAC was superior to other metrics in detecting terraced locations and accurately representing terraced landscapes. To produce digital magnetic-elevation maps, [6] describe a collaborative method utilising little autonomous airborne robots. The robots can fly together to map the magnetic and altitude fields of a target area since they are outfitted with magnetometers and altimeters. Applications for the resultant maps include monitoring topographic changes and mining exploration. The accuracy of two DEMs, one created using UAV photogrammetry and the other by conventional terrestrial surveying, is compared by [1]. The investigation, which was conducted in a quarry in Slovakia, revealed that the root means square error (RMSE) of the DEM produced from UAVs was marginally lower than that of the DEM derived from terrestrial sources. The authors draw attention to the potential of inexpensive UAVs and photogrammetry for precise and effective terrain mapping, particularly in challenging-to-access places. They also go through how crucial it is to choose the right UAV platforms, cameras, and photogrammetric software in order to get high-quality data. The accuracy of topographic surveying findings acquired with a fixed-wing and rotary-wing UAV is compared by [14]. Two field tests were undertaken by the authors in a limestone mine and a granite quarry, and the resulting DEMs were compared to those produced using conventional surveying techniques. According to the study, the fixed-wing UAV produced DEMs with lower absolute and relative errors than the rotary-wing UAV. The authors conclude that the specific characteristics of the survey region and the necessary precision of the DEM should be taken into consideration when choosing a UAV platform. In order to study the terrain of a post-mining site during leaf-off conditions, [19] compare a commercial and a home-assembled fixed-wing UAV in great detail. The accuracy and precision of the two UAV systems were analysed by the authors, who considered a number of factors including flight length, image resolution, and data processing speed. The study discovered that while both systems produced results with similar precision, the commercial UAV fared better than the home-assembled one in terms of accuracy and data processing time. The accuracy of employing drones and photogrammetry to study the topography of sandy beaches is examined in [4]. The authors discovered that the results of drone-based surveys were more accurate, especially in places with considerable relief, when compared to conventional GPS-based surveys. The constraints of utilising drones for beach surveying are also covered in the research, including the necessity for high-resolution cameras and how the wind affects the drone's stability. [7] investigates how to measure topographic changes in overhanging sea cliffs using small unmanned aerial vehicles (UAVs). A small UAV with a digital camera and GPS is used in the study to collect data and photographs, which are then processed to create precise 3D models of the cliff surface. The benefits of deploying UAVs over conventional surveying methods for such applications are highlighted in the article, including better safety, improved accuracy, and decreased survey time and costs. The study's findings show how UAV-based surveying has a lot of potential for tracking and comprehending the dynamic changes in coastal landscapes. A case study of the application of close-range photogrammetry and unmanned aerial vehicles (UAVs) in geomechanically analysis for the management of road safety is provided by [3]. The Vallone d'Elva route in the Italian Alps, which is distinguished by its steep slopes and frequent rockfall events, is the subject of the study. A high-precision digital elevation model (DEM) and orthophoto are produced by the authors using photogrammetric software after aerial imagery is collected using a fixed-wing UAV outfitted with a high-resolution camera. The resulting information is used to evaluate the stability of the slope and pinpoint any potential rockfall dangers near the road. The study emphasises the potential for geomechanically analysis in road safety management using UAV-based photogrammetry as a low-cost and effective technique. [8] examine the most recent developments in unmanned aerial systems (UAS) for photogrammetry and remote sensing applications. The authors give a summary of the UAS's operating parts, including the sensors, platforms, and control systems. The following section of the study looks at the benefits of UAS over conventional surveying techniques, including their speed and efficiency in capturing high-resolution data as well as their safety and adaptability in data collecting. The authors also go into UAS restrictions, including those related to data processing, flight rules, and weather. [16] paper presents a comparative analysis of stockpile volume estimation using both unmanned aerial vehicles (UAVs) and GPS techniques. The authors carried out a case study at a construction site in Ghana, where they collected data using both UAVs and GPS methods. The data was then processed using photogrammetric software and compared to estimate the volume of the stockpile. The study found that UAV-based surveys were more accurate and efficient than GPS-based surveys, with the UAV-based method achieving an accuracy of 97% compared to 80% for the GPS-based method. The paper highlights the potential of using UAVs for stockpile volume estimation, which can aid in optimizing earthwork quantities, reducing project timelines, and improving site safety. [2] investigate the use of softcopy photogrammetry and unmanned aerial vehicles (UAVs) to execute earthwork volumetric. The study takes pictures of a construction site with a tiny UAV fitted with a digital camera. These pictures are then analysed with photogrammetric software to produce a high-precision digital elevation model (DEM) and orthomosaic. The results of the UAV-based survey were found to be faster and more cost-effective while still maintaining a high degree of accuracy when the authors compared them to traditional surveying methods. The study emphasises the potential for UAV-based photogrammetry to increase the precision and efficacy of construction projects as well as the possibilities for earthwork volumetric. [9] propose a case study of the application of photogrammetry and unmanned aerial systems (UAS) for the digitization of large-scale earthwork progress on a building site. In order to create a succession of 3D models at various stages of the project, the authors employ a UAS fitted with a high-resolution camera to take pictures of the construction site. These pictures are then processed using photogrammetric software. The article goes over the advantages of combining UAS and photogrammetry to monitor the progress of earthworks, including increased precision, efficacy, and safety. The possibility for automating the detection and monitoring of earthwork progress using the generated 3D models is also highlighted by the authors. This study shows how UAS-based photogrammetry has the potential to be an effective tool for digitalizing and automating construction progress monitoring. In order to create digital terrain models (DTMs), [10] examined the precision and effectiveness of four different surveying techniques: analytical aerial photogrammetry, laser scanning, total station, and global positioning system (GPS) surveys. While all four approaches could create precise DTMs, the study discovered that depending on the surveying technique and the topographical features of the survey area, accuracy and efficiency varied. For flat terrain, analytical aerial photogrammetry was shown to be the most effective technique for creating DTMs, but laser scanning was found to be more accurate in high relief locations. The study emphasises how crucial it is to choose the best surveying technique depending on the features of the survey region and the required level of accuracy.

## 3. Research Design

**3.1. Introduction to Earthwork Operations and Role of drones:** Any construction project must begin with the essential earthwork phase, which entails measuring and surveying the soil and creating a strategy for earthmoving. During this phase, contractors do site clearance, excavation, grading, compaction, and backfilling work using heavy equipment such dozers, excavators, graders, rollers, and dump trucks. Monitoring the earthwork procedure is crucial to preventing expensive mistakes that could cause project delays and increased costs. The earthwork is carried out precisely and effectively thanks to ongoing documentation and progress monitoring. At a construction site, there are several important phases of earthwork:

1.) Site preparation involves cleaning the construction site of any existing structures, vegetation, and debris as well as grading the earth to make a flat surface for constructing on.
2.) Excavation consists of creating trenches for foundations, utilities, and other building materials. Either fill material is made from the excavated dirt, or it is taken off-site.
3.) Grading is the process of removing or adding soil using heavy machinery to level the site to create the proper height and slope for the project.
4.) Compaction is the process of utilizing heavy rollers and other equipment to increase the soil's stability and density, which is essential for creating road and building foundations.
5.) Backfilling entails using the excavated soil to fill in any residual craters or trenches. The earth is then compacted for stability after the construction is finished.

A digital visualization of the surface of the Earth or any other terrain is known as a digital surface model (DSM). It offers a thorough 3D picture of the topography, complete with both natural and artificial characteristics including structures, vegetation, and elevations of the land. Data from remote sensing techniques, such as satellite imaging, aerial photography, or UAVs, is frequently used to produce DSMs.
DSMs are used extensively in many disciplines, including disaster management, environmental evaluation, civil engineering, and urban planning. They are useful resources for landscape analysis, spotting possible dangers or hazards, and assisting in decision-making. Creating Digital Surface Models (DSMs) of the Area of Interest plays a significant role in the verification and design checks of earthwork. However, generation of a high-density 3D model of large areas of interests using traditional technologies such as TS & GPS is a time-consuming and labor-intensive task as it requires workers to actively move on field. Variations in topography increases difficulty in data collection and runs a risk of inaccuracy of data collection. Another popular method of creating high-density 3D point cloud is by using laser scanning technology such as LIDAR, the data collection is relatively faster but requires more time and skill for data processing. Errors can occur in the produced terrain surface due to occlusions caused by slope crests or other objects, which is a common issue with laser scanning. In comparison to the above-mentioned technologies, UAVs provide a more robust and comprehensive solution for data collection for generating 3D models of an area of interest in a given topography. Adoption of UAVs at construction is scaling up in recent period as a result of favorable government policies and affordable costs. UAVs have become increasingly popular in the field of earthwork due to their ability to provide high-resolution aerial imagery and survey data. Some of the roles that UAVs can play in earthwork include:

- Surveying: UAVs can be used to survey construction sites, which can help in planning and designing earthwork projects. The high-resolution aerial imagery captured by UAVs can be used to create accurate 3D models of the site, which can be used for earthwork design and planning.
- Monitoring: By monitoring events on construction sites, UAVs can help track the development of projects involving the laying of foundations. Time-lapse videos of the location can be made by taking routine aerial imagery and using them for this purpose.

- Inspection: Earthwork constructions like embankments, levees, and dams may all be inspected with UAVs. They are able to take high-resolution pictures of the structure, which can be utilised to spot any possible problems like erosion or structural damage.
- Mapping: UAVs can be used to make thorough maps of construction sites that can be utilised to schedule projects involving earthwork. In order to accomplish this, precise maps of the site can be made utilising aerial images, which can then be used for planning and design.
- Aerial Analytics: Project stakeholders can use the data collected by UAVs for effective planning and monitoring.

### 3.2 Earthwork Life Cycle

An earthwork operation includes four separate phases: planning, tendering, execution, and billing. These phases are shown in Figure 1, which is probably a schematic or chart that outlines the various stages of the operation. The Earthwork operation is carried out using a detailed document known as a Bill of Quantities (BOQ). This document includes a list of all the tasks that must be completed for the project, along with the equipment, materials, and labour that are required to fulfil each one. All activity in the construction process is covered by a contract that is built on the BoQ. To determine the project's total cost, each item in the BoQ is divided into precise measurements and a given rate. This indicates that a defined rate and measurement have been assigned to each individual task necessary for the Earthwork process, such as the quantity of material or labour hours needed. These two amounts can be multiplied together to find the overall cost of the task.

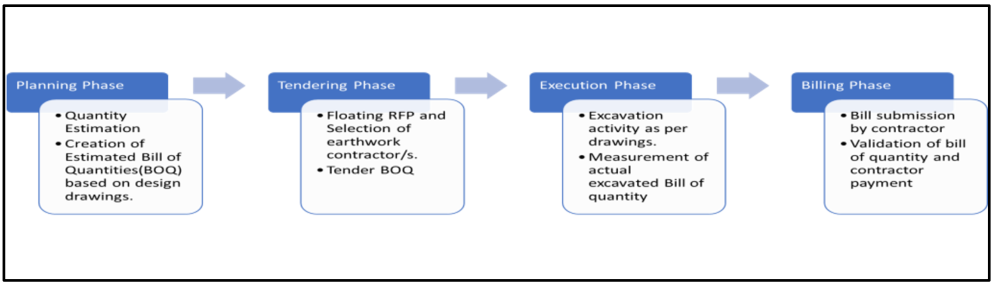


**Fig. 1:** Earthwork Life Cycle

The anticipated volume of work that the contractor must complete is specified in the BoQ (Bill of Quantities). After completing the package's cut-fill operations on the job site, the contractor submits a claim statement for the work completed. The amount of work completed by the contractor is important since it affects the project's overall budget. The cost of earthworks typically makes up between 5% and 10% of the total project cost. Yet, the percentage can change based on the type and size of the project, and for some projects it may be as low as 2% or as high as 15% or more. It's important to keep in mind that the percentage estimate is approximate and could vary greatly based on the particulars of the project. To ensure that the project's budget is not severely impacted, it is necessary to monitor and check the actual work accomplished versus the intended BoQ. In order to ensure that the project is completed within the allotted budget and timetable, monitoring and validating the work done is an essential step in the construction project management process.

## 3.3 Case Study Details

A case study was conducted on a commercial building project shown in Figure. 2 that was being built on a 10-acre tract of land, with 67% of the land being used for development, to help with this research. The project consists of four buildings, each of which has five basement levels and 21 stories.

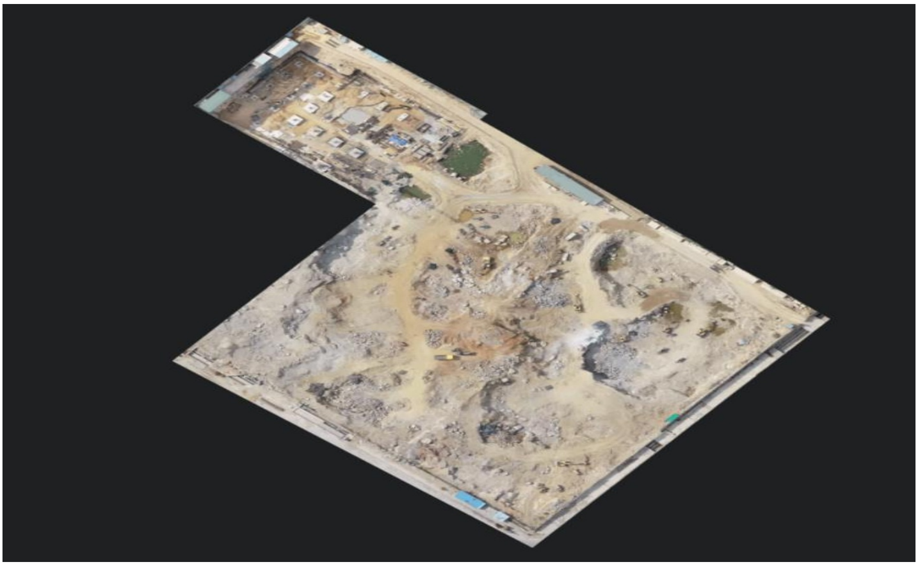

**Fig.2.** Preliminary site representation during data collection.

### *3.3.1 Data collection and Methodology*

Monthly data on earthwork was gathered from June 2019 to December 2020. In this study, a proposed framework of data gathering, data processing, and data analysis for digitalizing and monitoring earthwork utilizing UAVs at building construction sites is provided. The UAV periodically takes overhead pictures of the site while gathering data on a monthly basis. The second stage entails employing cloud computing to process these images and a web-based UAV portal programme called as D3D to produce an orthomosaic and 3D point cloud. The third stage then makes use of these outputs to create cross-section views and determine cut-and-fill volumes. For the purposes of progress monitoring and documentation, the UAV platform provides the cross-section views and cut-and-fill volumes. The D3D platform stores data and visuals used to monitor the project progress and record the status of earthwork operations.
A DJI Phantom 4 Pro commercial multirotor VTOL UAV with a 20-megapixel camera that measures 289.5 x 289.5 x 196 mm3 and weighs 1375 g was used to carry out the study. To guarantee that pre-flight and during-flight safety precautions were followed, the crew properly prepared the UAV and checked its condition, including battery capacity, GPS reception, IMU, calibration status, and connectivity to the controls and internet. Figure 4 depicts the UAV's flight path, and Fig.3 depicts the images overlapped by more than 80% to improve accuracy. The UAV's speed was set at 8–10 m/s while accounting for the flight path and the longest possible flight time. The images were obtained from the UAV's SD card and sent to the UAV portal for processing at the data processing stage after the UAV had flown for around 20 minutes.

Seven Ground Control Points (GCPs) and two Intermediate Control Points were installed in order to guarantee precise location of features and objects being studied. When georeferencing aerial or satellite photography, a GCP—a reference point on the surface of the Earth with well-known geographic coordinates—is utilized as the foundation. A real-time kinematic global positioning system was used to determine the latitude and longitude of the GCPs (RTK-GPS).

The coordinates shown below in Table 1 were based on EPSG:32644.

**Table 1**

| Name | Easting | Northing | Elevation |
|---|---|---|---|
| GCP1 | 5086.387 | 7850.213 | 568.791 |
| GCP2 | 5049.138 | 7842.017 | 568.553 |
| GCP3 | 4991.338 | 7793.775 | 568.093 |
| GCP4 | 5028.414 | 7753.08 | 568.676 |
| GCP5 | 5070.16 | 7793.563 | 568.622 |
| GCP6 | 5080.065 | 7800.6 | 568.585 |
| GCP7 | 5132.968 | 7849.827 | 591.696 |
| ICP1 | 5171.441 | 7800.304 | 591.318 |
| ICP2 | 5071.843 | 7932.763 | 590.916 |

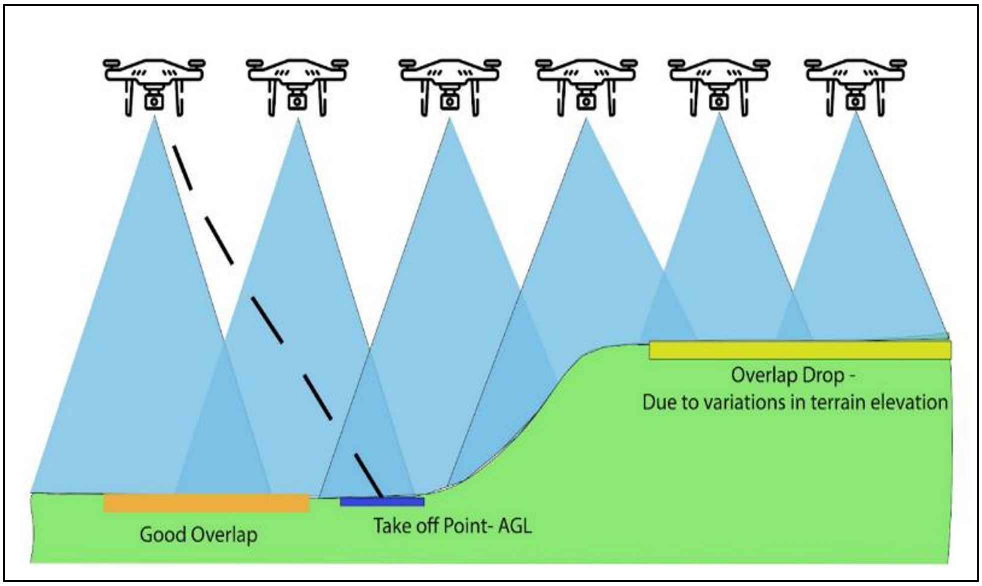


**Fig. 3.** Depiction of overlap of image captured by drone

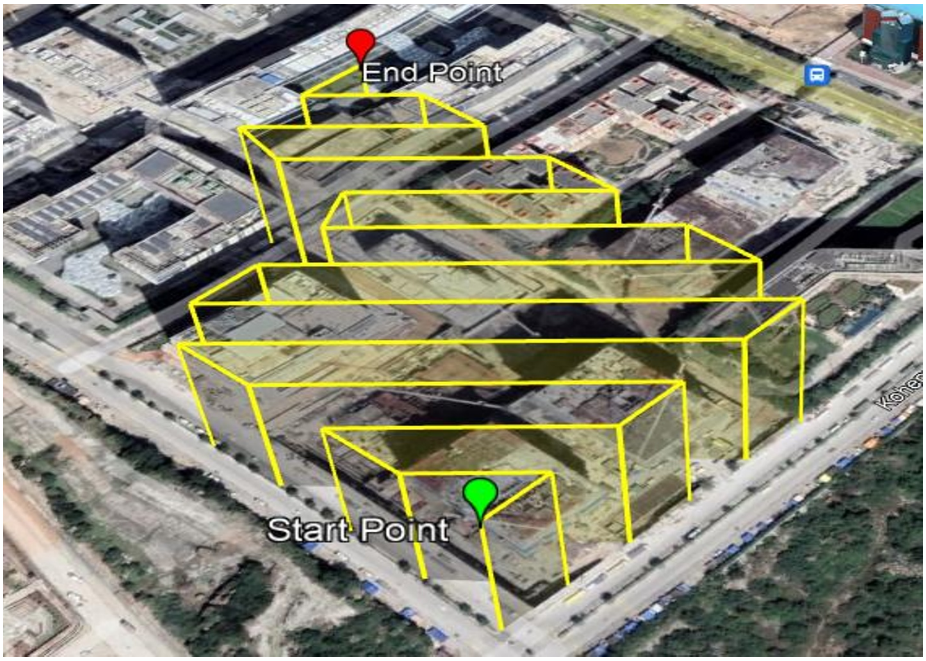


**Fig. 4.** Drone Flight Plan

### *3.3.2 Data Processing*

The UAV's local data storage was used to import the images it had taken, which were then posted to a UAV Portal. D3D, a cloud-based drone data processing web platform, was used for this study's purposes. The images were georeferenced using the GCPs, and the software produced a dense point cloud. A 3D model of the location is produced as a result of the point cloud's many connections to build a mesh, as seen in Figure 5(a). The mesh was then used to create the ortho-mosaic shown in Figure (5b). The final step was to save the processed data to a data storage system, saving the point cloud as an XYZ file that contained the X, Y, and Z coordinates of each point along with any other associated properties.

**Fig. 5(a):** Point Cloud 3D model

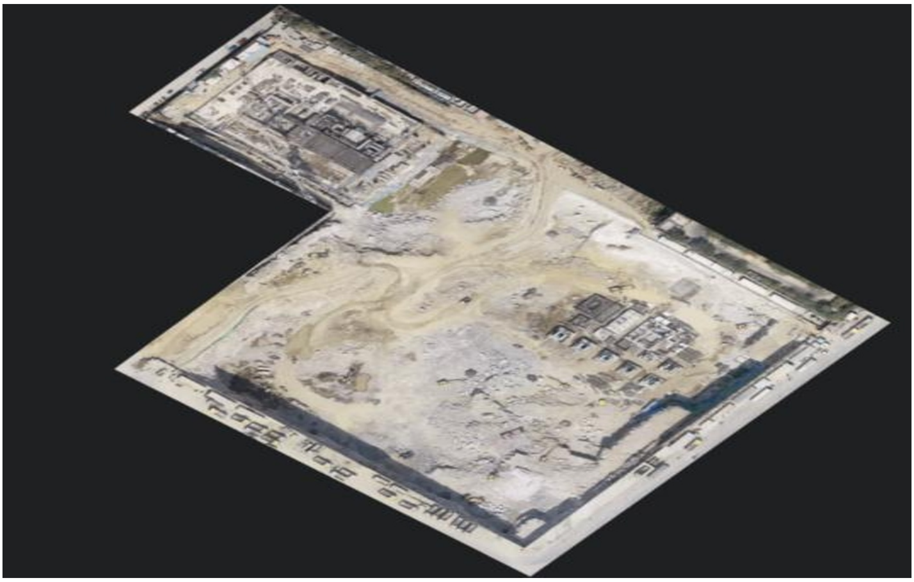

**Fig. 5(b).** Orthomosaic Map

### *3.3.3 Data Analysis and Visualization*

The site's Digital Surface Model (DSM) and Digital Terrain Model (DTM) were made using the D3D software in order to further interpret the data. This led a map to be created that showed where the site's elevations were. Figure 6's left side shows a June 2019 DTM analysis, while its right side shows a November 2020 DTM analysis. Red indicates that a location is at its lowest elevation. It is visually possible to see the difference in elevation between the two dates, which serves as a rapid yardstick for assessing the actual site's condition.

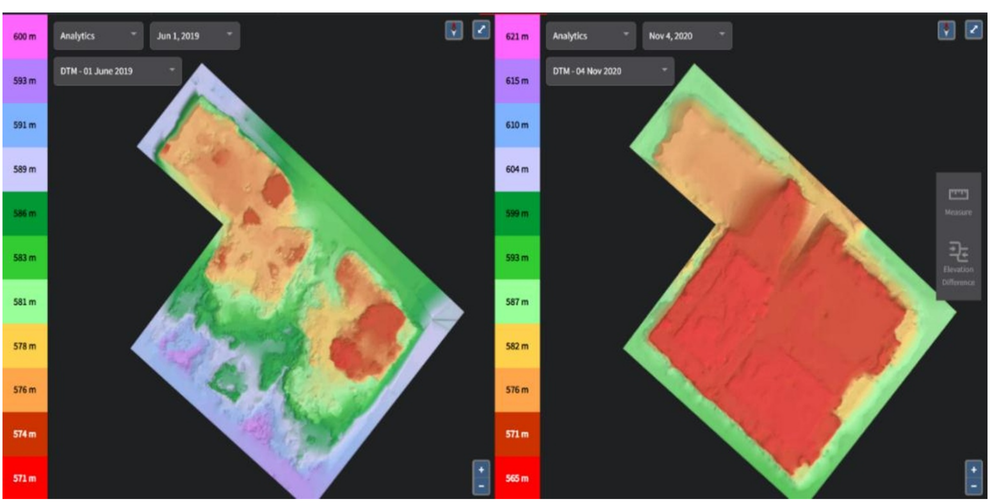


**Fig. 6.** Aerial Analytics Comparison between June 2019 and November 2020

# 4. Results and Discussion

## 4.1 Earthwork Quantity Comparison

The amount of earthwork that was measured during this was determined manually using data from a complete station survey and a UAV survey. The developer's contract's BOQ stated that 7,46,00 cubic meters of hard rock excavation were to be excavated. 7,20,442 cubic meters of actual excavation were found during the UAV-based survey. The intended and actual volumes differed significantly, as indicated in Table 2, by 3.42%. Thus, it was found that the UAV photogrammetry method of calculating earthwork volume produced correct findings and reduced the amount of time needed for operations.

## 4.2 Earthwork Cost Comparison

For the project's initial BOQ, an estimated volume was computed using the findings of a geotechnical study and a total station-based survey. By dividing the projected volume by the price per cubic meter of excavation, the estimated total cost came to Rs. 37.30 Crores. But following excavation, the DTMs produced by UAV photogrammetry were used to calculate the real volume. As can be seen in Table 2, the final bill stated that the real cost was Rs. 36,02,21,000, which constituted a cost difference of Rs. 1,27,79,000 (3.2%). This expense disparity was mostly caused by the substantial variation in the amount of excavation required for the two approaches.

**Table 2:** Excavation Quantity and Cost calculations

| | **Over all Site** | | |
|---|---|---|---|
| **Area** | **Type of Rock** | **Cut Volume as per UAV** | **Cut Volume as per Total Station** |
| **Total Calculated Volume** | Hard Rock | 7,20,442 | 7,46,000.00 |
| **Net volume difference (in cubic meters)** | | 25,558 | |
| **Net volume difference (in percentage)** | | 3.42% | |
| **Cost of Excavation @ Rs, 500 per Cubic Meter** | | Rs. 36,02,21,000 | Rs 37,30,00,000 |
| **Net Cost Difference** | Rs. 1,27,79,000 | | |
| **Net Cost Difference (percentage)** | 3.2% | | |

## 4.3 Project Progress Monitoring

Stakeholders often gather to discuss project progress in meetings since construction projects are complicated and dynamic. Having a comprehensive understanding of the construction site is essential for facilitating these discussions, and using drone technology can help with this. Drones give stakeholders effective site monitoring with the provision of high-resolution, real-time aerial intelligence of the construction site on a personal computer. Senior leadership no longer needs to visit the site to update their progress, which saves time and money. This allows stakeholders to review work that has already been done, plan work in the future with

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a competitive advantage, and maybe boost efficiency—although this is still a separate area of research.

### 4.4 Documentation

Over time, a construction project experiences substantial modification. For a number of reasons, including a) project progress monitoring; b) legal compliances; c) submissions to lenders and investors; and d) reconciliation in case claim settlements, it is crucial to document the actual situation on the ground and archive it. The orthomosaic maps, 360-degree panorama pictures, 3D models, and drone-based videos used in this study were periodically saved and then hosted on the cloud-based D3D portal. Figure. 7 depicts a split from the portal that compares the real site between November 2019 and November 2020.

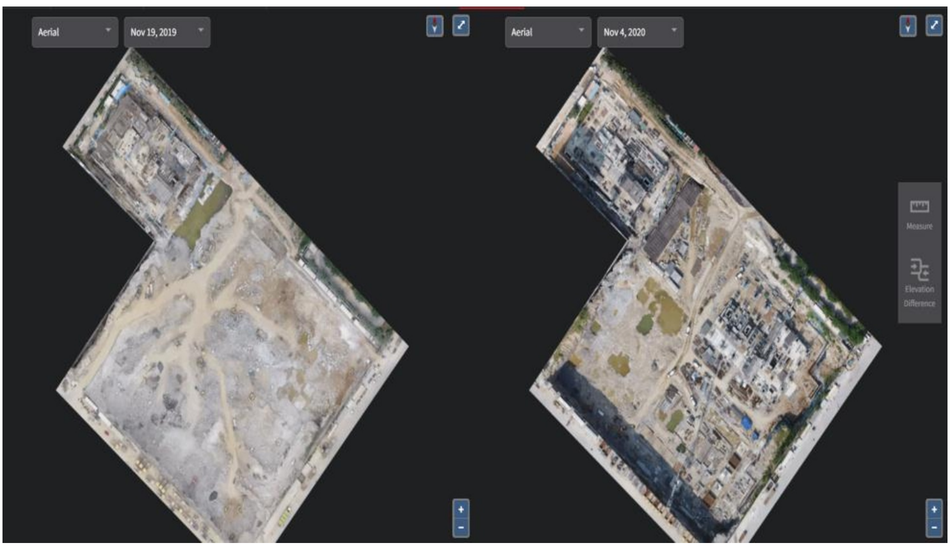


**Fig. 7.** Split View of project showing site progress on different dates

## 5. Conclusion

This study presents a strategy for increasing the effectiveness of cut and fill operations utilizing drone technology and aerial analytics. The method produced an orthomosaic map of the project site, a 3D model based on a point cloud, and subsequent excavation calculations. Additionally, it performed other tasks like tracking project progress, comparing the site over time, and documenting information for future use. The validation of the framework took place at a construction site in the Indian state of Telangana. We noticed a 3.42% difference between the actual earthwork quantity computed using a drone-based survey and the planned earthwork quantity calculated using total-station based survey. There were subsequent savings of Rs. 1.27 crores, which is a significant amount.

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