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Determination of Material Volume Using UAVs in Land Surface Change: The Case of Konuralp Campus (Düzce)*

Arazi Yüzey Değişiminde İHA Kullanılarak Materyal Hacminin Belirlenmesi: Konuralp Yerleşkesi (Düzce) Örneği

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Abstract

In this study examined the availability of UAV in determining material volume in excavation and fill works. The study aims to calculating the volume of an excavation work areas 1841 m² at the parking lot of the Faculty of Sports Sciences at Düzce University Konuralp Campus and a filling work areas 2759 m² on the access road to the Environmental and Health Specialization Laboratory. Autonomous UAV flights were performed before and after the excavation and filling works in the study areas. Besides, following these UAV flights, terrestrial measurements were made in the same way. The study found that UAV data analysis results an excavation volume of 7121 m³ in the parking area and a filling volume of 5752 m³ on the road. According to calculations used terrestrial measurement methods, the excavation volume in the parking area was 7007 m³ and the filling volume on the road was 5683 m³. An average difference of 1.42% was found between UAV data and terrestrial measurement methods. The results were showed the usability of UAV systems in detected material volume.

Keywords: UAVs, Total station, cut and fill volumes, digital elevation model.

Özet

Bu çalışmada, İHA teknolojisinin kazı ve dolgu çalışmaları materyal hacminin belirlenmesinde kullanılabilirliği incelenmiştir. Düzce Üniversitesi Konuralp Yerleşkesi Spor Bilimleri Fakültesi otoparkında 1841 m² büyüklüğünde yapılan kazı çalışması ile Çevre ve Sağlık İhtisaslaşma Laboratuvarı bağlantı yolunda 2759 m² büyüklüğünde yapılan dolgu çalışması hacminin hesaplanması çalışamaya konu edilmiştir. Kazı ve dolgu çalışmalarından önce ve sonra İHA ile uçuşlar otonom olarak gerçekleşmiştir. Ayrıca bu İHA uçuşlarını takiben yersel ölçümler de aynı şekilde yapılmıştır. Çalışmada, İHA verileri ile otopark alanında 7121 m³ kazı hacmi, yolda 5752 m³ dolgu hacmi bulunmuştur. Yersel ölçüm yöntemlerine göre yapılan hesaplamada ise otopark alanında kazı miktarı 7007 m³, yolda dolgu miktarı 5683 m³ bulunmuştur. İHA verileri ile yersel ölçüm yöntemleri arasında ortalama %1,42'lik bir fark bulunmuştur. Elde edilen sonuçlar materyal hacminin belirlenmesinde İHA sistemlerinin kullanılabilirliğini ortaya koymaktadır.

Anahtar Kelimeler: İHA, Total station, Kazı ve dolgu hacimleri, Sayısal yükseklik modeli.

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1. Introduction

In recent years, the development of technologies and image processing algorithms has further increased the importance of photogrammetry studies. Photogrammetry has been a long history, included mathematical calculations on three-dimensional (3D) images produced from superposition pairs of two-dimensional photographs (Erdin, 1992; Yilmaz, 2010). The developed UAV platforms have been significantly influenced by new generation image processed techniques. The increased use of the Structure-from-Motion (SfM) algorithm considered a development in photogrammetry, was of importance in the improvement of UAVs and their systems (Gülci et al., 2021). High-resolution digital elevation models (DEMs) and orthophotos have been easily creating with many commercial or open-source software operating with the SfM algorithm (Shervais, 2015; Wallace et al., 2016). SfM algorithm, which produces successful and accurate results even in complex topography, has accuracy within an accepted range when compared to laser scanning systems (Westboy et al., 2012; Seki et al., 2017). Programs with interfaces that make easier the processing of high resolution images in the digital media allow researchers to easily create 3D models. Consequently, the use of digital photogrammetry in different studies including natural sciences such as forest engineering was expanded and increased daily (Akgul et al., 2016; Osborn et al., 2017; Tercan, 2018).

Additionally, in photogrammetry studies that have been increased used digital cameras available to researchers, the location, size and shape of objects are determined from vertical and oblique have high resolution aerial photographs (Erdin, 1992). In recent studies, the merge of low-cost UAV imagery with the SfM technique was increasingly viewed as fast, affordable, accessible and innovative compared to terrestrial measurement and terrestrial LIDAR (Laser Imaging Detection and Ranging) (İnan and Öztürk, 2016; Gülci et al., 2017; Akgul et al., 2018).

UAVs have been typically equipped with cameras or sensors and can provided high-resolution images. These high-resolution images could be used to detected changes in the land surface. UAV systems enable the rapid collection of terrain data in a study area. To detect terrestrial changes with UAVs, it is necessary to plan and conduct multiple flights. Compared to aerial vehicles such as airplanes or helicopters, UAV systems all the time have been lower operating costs, make possible for more frequent data collection (Liang et al., 2023).

Total Stations was land surveying devices capabled of delicate point-based measurements on terrain. This allows the detected of changes in the land surface with millimeter sensitive. Total Stations was could create three-dimensional maps used measurements from the land, enabling detailed analysis of surface changes. They allow direct terrestrial measurement, making it was possible to detected land changes directly in the study area. However, the lengthy data acquisition process is a disadvantage. UAV systems are often used to cover big size study areas and collected data quickly, while Total Stations was preferred for more detailed and sensitive measurements. The combined use of these products have help in more comprehensively and accurately determined changes in the land surface (Anonymous, 2024).

In this study examined the determination of excavation and fill volumes used UAV and total Stations systems for works conducted at the Düzce University Konuralp Campus. The aim of this study is to assess the usability of UAV systems in calculating material volumes and to compared the results of UAV and terrestrial measurement.

1.1. Methods Used for Determining Material Volume

The methods used to determine the volume of excavation material can vary depending on the size of the excavation site, the type of material, and precision requirements. Various material volume calculation methods have been used from past to present.

1.1.1. UAV Systems

Satellites and manned aerial vehicles are important systems currently used to obtain remote sensing images. However, these systems have several disadvantages. UAVs, on the other hand, offer various advantages, such as lower cost, lighter weight, and the ability to capture images at low flight speeds. Unlike aircraft and satellite systems that capture images from high altitudes, UAVs can be used in cloudy weather for the same purpose (Xiang and Tian, 2011). Additionally, UAVs are safer as they pose less risk compared to piloted aircraft, and they offer flexibility in terms of desired flight altitude and timing. UAVs are classified for scientific or civilian use based on features such as platform size, flight tolerance, and capacity, often aligning with existing military categories (Watts et al., 2012).

Today, UAV systems are widely used in military applications for documentation, monitoring, and increasingly in civilian applications (Eisenbeiss and Sauerbier, 2011). Following the development in the design, research, and production of aerial platforms, the demand for UAVs in aerial photogrammetry has increased (Tahar et al., 2011). UAVs are used in agriculture for spraying, surveillance, road deformation detection, and documentation of cultural heritage (Mitch and Salah, 2009).

1.1.2. Total Station (Electronic Distance Measurement)

A Total Station is a highly precise and versatile measurement device used in topographic surveys. It is commonly used in construction, mining, mapping, and land surveying (GH, 2024). Total Station devices provide accurate location data by measuring both horizontal and vertical angles and distances. The Total Station sends laser or infrared beams to the points to be measured. These beams reflect off prisms or directly off target surfaces and return. The device determines the distance and position by measuring the return time and angle of the beams. The advantages of a Total Station include millimeter-level accuracy, the ability to perform both angular and distance measurements, data recording capability, and immediate calculations, along with user-friendly interfaces and software that provide ease of use. The Total Station is an indispensable tool in modern surveying techniques. It provides precise and reliable results, making it widely applicable. When used correctly and maintained regularly, it offers a significant advantage in topographic and engineering studies. However, the lengthy data acquisition process is a disadvantage (Pehlivan, 2019).

Total Station has been used in many scientific studies (Scherer and Lerma, 2009: Luo et al., 2016; Ulvi, 2018; Gülci and Kılınç, 2018) and in volume calculations in practice. The use of devices such as Total Station, which obtain data by terrestrial measurements, is less common than the use of UAVs in today's volume calculation studies. UAVs can scan more areas with high precision and in a shorter time and data can be generated (Özdemir, 2023).

2. Material and Method

2.1. Study area

The study area was located approximately 10 km from Düzce Province, specifically at the Düzce University Konuralp Campus in the northern part of the province. The research focuses on the excavation area at the parking lot of the Faculty of Sports Sciences (Area A) and the fill area along the access road to the Health and Environment Specialization Laboratory (Area B). The two areas are approximately 1 km apart. The parking lot excavation area covers 1841 m², while the road fill area measures 2759 m². Düzce Province is situated between the latitudes of 40°43' and 41°07' north and the longitudes of 30°49' and 31°50'' east, encompassing an area of 2593 km² in the Western Black Sea Region

(Anonymous, 2002). To the east and south of the province lies Bolu, to the west is Sakarya and to the north is the Black Sea (Figure 1). The average elevation of Düzce city center is 120 m, with elevations reaching up to 1850 m in mountainous regions (Anonymous, 1999).

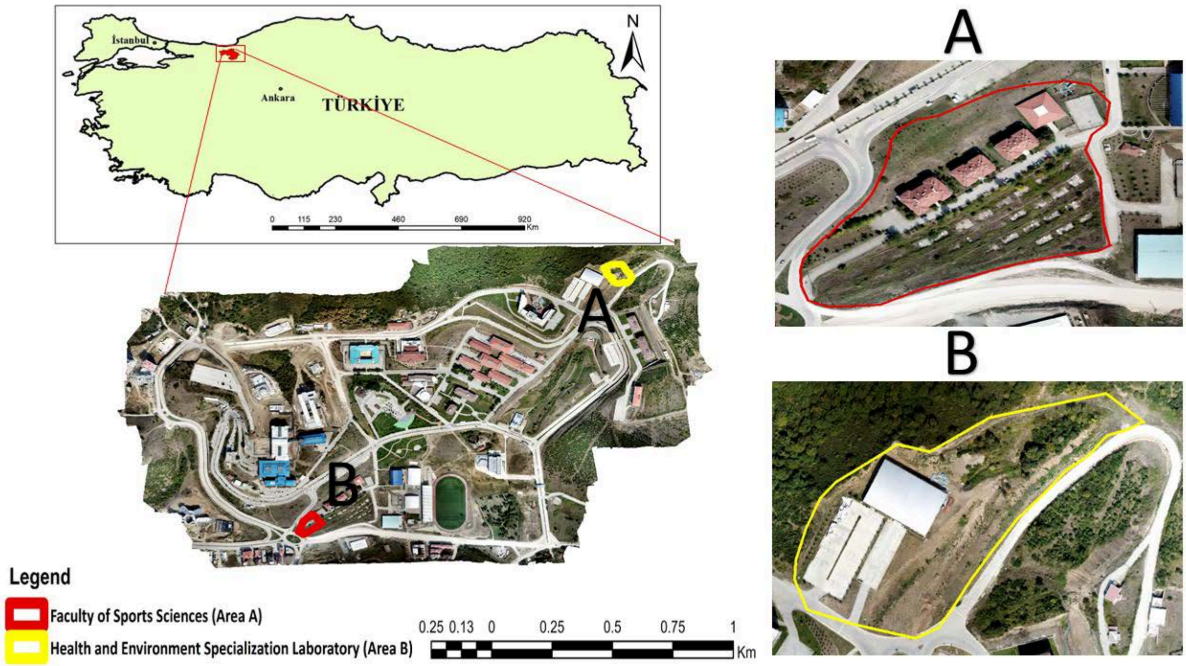


Figure 1. Study areas and their surroundings.

2.2. UAV System and Terrestrial Photogrammetric Methods for Acquiring Digital Images

2.2.1. Acquiring Digital Images with UAVs

In this study, the volume of material in the designated areas was calculated. A total of two flights were conducted using UAVs as part of the research. The image acquisition process with the UAV followed these steps: i) pre-field preparation, ii) field work, iii) execution of the flight, and iv) post-flight processing.

Autonomous flights were carried out in the study area, with front and side overlap rates set at 70% and 80%, respectively. The flight path was designed to cover the study area, with a camera angle of 90° and flying at an altitude of 100 m.

The flights were conducted autonomously using the DJI Phantom 4 RTK model UAV platform (Figure 2). The DJI Phantom 4 RTK system features a 1-inch 20-megapixel resolution CMOS sensor. It is equipped with a global navigation satellite system (GNSS) receiver that allows for high positional accuracy through multi-frequency RTK/PPK data acquisition. The flight planning process was created using the DJI GS RTK application from the controller of the DJI Phantom 4 RTK system.

Figure 2. DJI Phantom 4 RTK model UAV and remote controller.

2.2.2. Field Surveys

After the acquisition of UAV images, terrestrial measurements were initiated. In the terrestrial measurement method, three separate polygon points that are geologically difficult to change were established using a TOPCON GR5 RTK-GNSS (Global Navigation Satellite System) receiver, with 30-minute sessions conducted to set up these points. Two of the polygon points were used for connections, while the third was for control purposes. Subsequently, the established polygon points were connected using an electronic distance measurement device (Total Station: TOPCON OS200) (Figure 3), and elevation coordinate information of the surface was obtained through backsights and prisms. Taking into account the slope changes on the surface, measurements were conducted with a maximum distance of 5 meters. These procedures were carried out twice in the study areas, once before the excavation and fill work and once after. In the study, the terrestrial measurement was used as a reference for evaluating the accuracy of the volumes calculated with the UAV.

Figure 3. Field Surveys.

2.3. Determination of Excavation and Filling Volume in the Study Area

The images obtained using UAVs were processed to produce a high-resolution and accurate point cloud using Agisoft Metashape Professional Version 1.7.6 software (Figure 4). The software was run on Windows 10 64-bit operating system, Inter ® Xeon ® CPU E5-1650 v3 @ 3.50GHz 48 GB processor model and a workstation with 4 GB AMD FirePro W5100 graphics card technical specifications were used. During the image alignment process, the accuracy level was set to medium, while high quality settings were chosen for the production of depth maps and dense cloud generation. Since the images were acquired through flights conducted in RTK mode, YKN (Ground Control Points) were not defined in the image optimization process. The photogrammetric analysis of the images involved the steps of Align and Build Dense Cloud. The resulting point cloud was then exported in ".xyz" format. Similarly, the coordinates recorded by the electronic distance measurement device were exported to create ".xyz" format.

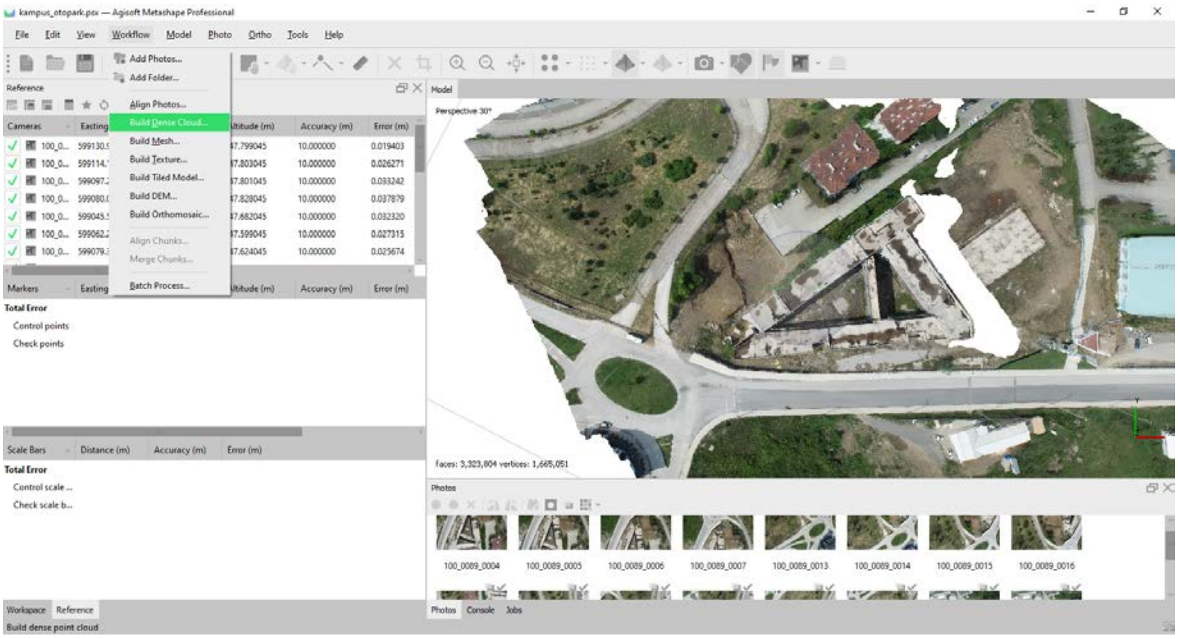


Figure 4. Dense Cloud Processing in Agisoft Metashape Professional Version 1.7.6.

The ".xyz" format data obtained from the UAV and field surveys were imported into NetCAD software to create a triangular model (digital elevation model) and obtain terrain surfaces (Figure 5). Subsequently, using the Netpro module, routes were created on the surfaces obtained before and after excavation and filling for both methods, with cross-sections defined every two meters. The resulting cross-sections were compared with those in the Netsurf module, and the volume was calculated using the TCK method (Figure 6). In TCK method; the application distance (AD) is calculated by the formula AD = [E/(E+F)] x L for excavation (E) and AD = [E/(E+F)] x L for filling (F). L is the distance between two sections. Area is the excavation and backfill areas per section. If both sections are in excavation or filling in the volume, the formula (A1+A2)*L/2 is applied (Netcad, 2024).

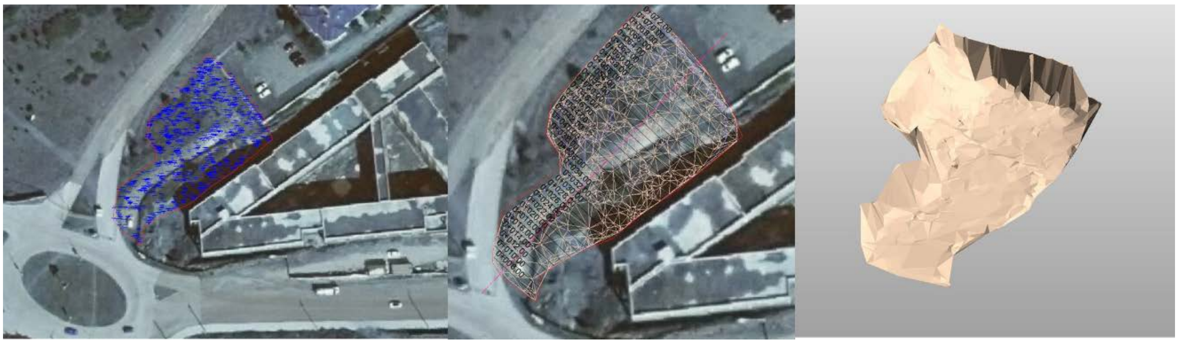
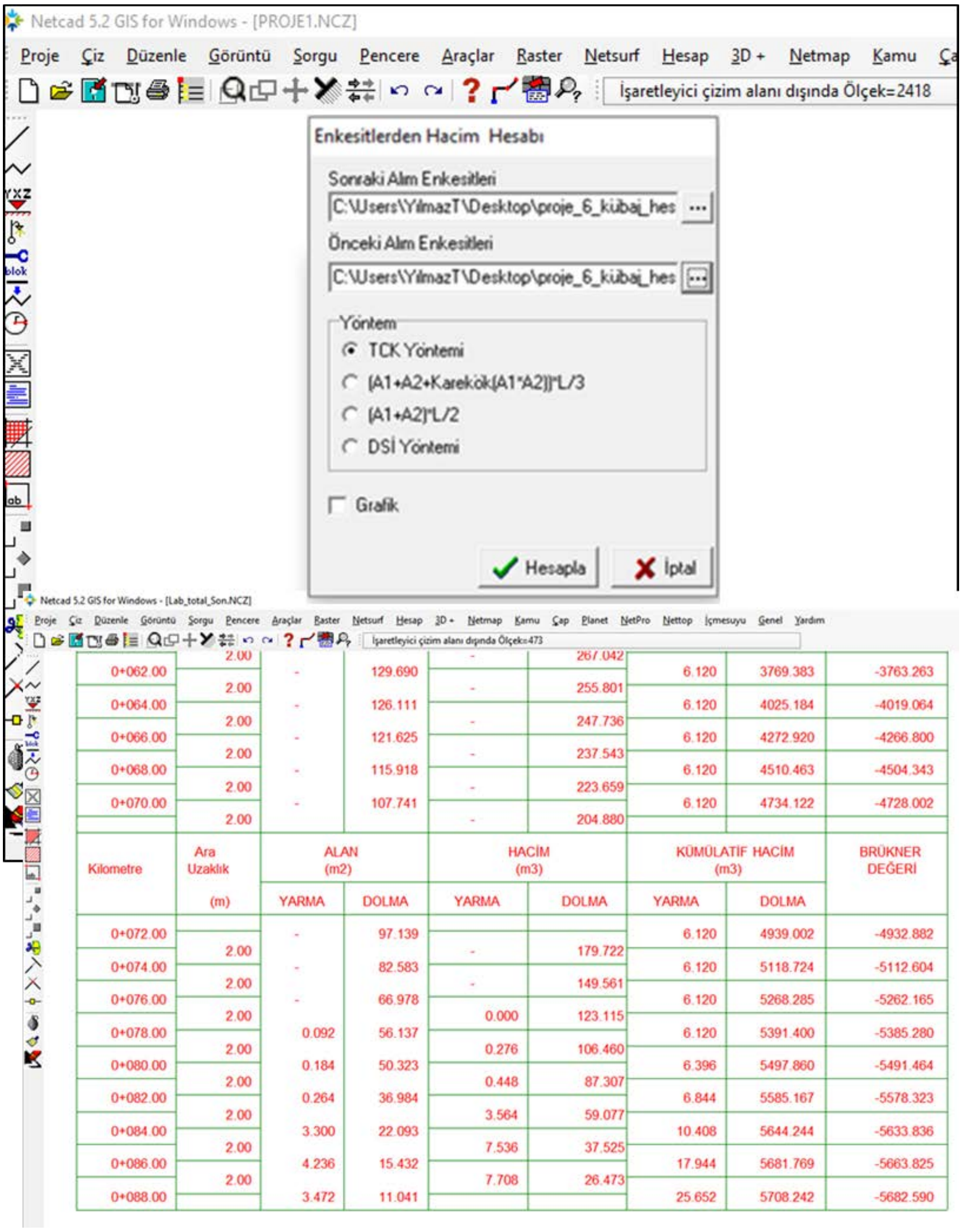


Figure 5. Data Processing in NetCAD Software.



Kilometre	Ara Uzaklık (m)	ALAN (m2) YARMA	ALAN (m2) DOLMA	HACİM (m3) YARMA	HACİM (m3) DOLMA	KÜMÜLATİF HACİM (m3) YARMA	KÜMÜLATİF HACİM (m3) DOLMA	BRÜKNER DEĞERİ
	2.00			-	267.042			
0+062.00		-	129.690			6.120	3769.383	-3763.263
	2.00			-	255.801			
0+064.00		-	126.111			6.120	4025.184	-4019.064
	2.00			-	247.736			
0+066.00		-	121.625			6.120	4272.920	-4266.800
	2.00			-	237.543			
0+068.00		-	115.918			6.120	4510.463	-4504.343
	2.00			-	223.659			
0+070.00		-	107.741			6.120	4734.122	-4728.002
	2.00			-	204.880			
0+072.00		-	97.139			6.120	4939.002	-4932.882
	2.00			-	179.722			
0+074.00		-	82.583			6.120	5118.724	-5112.604
	2.00			-	149.561			
0+076.00		-	66.978			6.120	5268.285	-5262.165
	2.00			0.000	123.115			
0+078.00		0.092	56.137			6.120	5391.400	-5385.280
	2.00			0.276	106.460			
0+080.00		0.184	50.323			6.396	5497.860	-5491.464
	2.00			0.448	87.307			
0+082.00		0.264	36.984			6.844	5585.167	-5578.323
	2.00			3.564	59.077			
0+084.00		3.300	22.093			10.408	5644.244	-5633.836
	2.00			7.536	37.525			
0+086.00		4.236	15.432			17.944	5681.769	-5663.825
	2.00			7.708	26.473			
0+088.00		3.472	11.041			25.652	5708.242	-5682.590

Figure 6. Volume Calculation in NetCAD Software.

3. Results

In the parking lot study area, when comparing excavation volume data from both methods, the excavation amount calculated from the difference between the first flight conducted before excavation with the UAV and the second flight thereafter was 7121 m^3, while the amount calculated from data obtained using terrestrial measurement methods was 7007 m^3. There is approximately a 114 m^3 difference between the values calculated by the two methods. The UAV results were found to be approximately 1.63% higher compared to the Electronic Distance Measurement. In the road study area, when comparing fill volume data from both methods, the fill amount calculated from the difference between the first flight conducted before filling with the UAV and the second flight thereafter was 5752m^3, while the amount calculated from data obtained using terrestrial measurement methods was 5683 m^3. There is approximately a 69 m^3 difference between the values calculated by the two methods. The UAV results were found to be on average 1.21% higher compared to the Electronic Distance Measurement (Table 1). It was determined that the values found as a result of both methods in the study areas were compatible with each other with an average of 98.58% in terms of accuracy.

Gülci and Kılınç (2018) evaluated soil pile volume measurements with UAVs and found a volume amount of 38.56 m^3, noting a difference of 1.94 m^3 (98.95% agreement) with Total Station measurements. Ulvi (2018) compared UAV and Total Station volume data in his study and found that the values obtained from both methods were 99.33% consistent in terms of precision. The study shows similarities with both of these studies. In a study by Türk et al. (2022), they found a total excavation of 384 m^3 and a fill volume of 188 m^3 on a 100-meter forest road using UAVs. Türk and Canyurt (2024) used UAV systems to calculate the excavation slope volume of a 640-meter section of a forest road. The study resulted in UAV data indicating an excavation volume of 2189 m^3 and a fill volume of 4183 m^3, whereas land survey results showed an excavation amount of 2080 m^3. They also found a +5% difference between UAV data and land survey results. Additionally, Balaban (2024) monitored surface changes in a quarry for six months using UAVs, calculating the excavation amount as 104170 m^3 and the excavation area as 44348 m^2. Such studies have demonstrated that UAVs can play a significant role in excavation and fill calculations.

Table 1. Material volume amounts in study areas.

Methods	UAV (A)	Total station (B)	Difference (A-B)	Mean Difference
Parking Lot Excavation Volume (m^3)	7121	7007	114 (%1.63)	%1.42
Road Fill Volume (m^3)	5752	5683	69 (%1.21)	

4. Conclusion

In this study, the material volume amount, which is crucial for determining excavation and fill costs, was calculated using UAV and terrestrial measurement methods, and the results from the two different methods were compared. Two UAV flights were conducted before and after the excavation at the parking lot of the Faculty of Sports Sciences and the fill work on the access road to the Environment and Health Specialization Laboratory at the Düzce University Konuralp Campus. Measurements were also taken using terrestrial measurement methods after each flight. The excavation area in question is approximately 1841 m^2, and the fill area is 2759 m^2.

There is an average difference of 1.42% between the UAV results and the terrestrial measurement methods involve a significant workload and are time-consuming in terms of land surveying for determining excavation and fill amounts. In addition, it should be taken into account that UAVs will be more advantageous in performing these works in places that cannot be walked in the field and that there is a high correlation between them and ground measurement in terms of accuracy. As an alternative to traditional methods for determining excavation quantities, this study demonstrates that UAVs can effectively determine material volume.

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