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# RESEARCH ON DIGITAL TERRAIN MODELING AND MORPHOMETRIC ANALYSIS BY INTEGRATING TOPOGRAPHIC, GNSS AND UAV DATA USING GIS TECHNIQUES

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***Abstract.*** *The paper presents a modern approach to digital terrain modelling and morphometric analysis by integrating data from classical topographic measurements, GNSS determinations and aerial images obtained with the help of unmanned aerial vehicles (UAVs). The study is based on real data collected in the field, supplemented with information resulting from the processing of aerial images using photogrammetry techniques. The dataset used included points with three-dimensional coordinates (X, Y, Z), determined by GNSS measurements, as well as aerial imagery used for three-dimensional reconstruction of the land surface. The image processing was carried out by Structure from Motion (SfM) methods, resulting in a dense cloud of dots and a detailed three-dimensional model. The integration of data from different sources allowed the generation of a high-resolution digital terrain model (DTM), based on which morphometric parameters such as slope, level differences and water runoff directions were analysed. The results obtained highlight the fact that the combined use of modern methods leads to a significant increase in the quality of the model, both in terms of detail and precision. The proposed method proves to be effective for applications in the agricultural, cadastral and territorial planning fields, providing support for the analysis and optimal use of land.*

***Keywords****: DTM, GNSS, GIS, terrain analysis, slope, Global Mapper, UAV, 3D*

## INTRODUCTION

In the current context of the accelerated development of geospatial technologies, modern methods of acquiring and processing topographic data have become essential in the development of digital terrain models. The use of GNSS equipment allows for the rapid and accurate determination of the coordinates of points in the field, while UAV-based technologies offer the possibility of collecting a large volume of data in a short time (COLOMINA and MOLINA, 2014; NEX and REMONDINO, 2014).

The integration of these technologies is a current direction in the field of topography, contributing to increasing efficiency and improving the quality of the data obtained. While topographic and GNSS measurements provide accurate data, the values obtained from aerial imagery allow detailed models of the land surface to be obtained (AGÜERA-VEGA et al., 2017; HARWIN and LUCIEER, 2012).

The processing of aerial images is carried out by digital photogrammetry techniques, especially by Structure from Motion (SfM) methods, which allow the three-dimensional reconstruction of the terrain by identifying the common points between the images. This generates point clouds and digital models that can be used in further analysis (WESTOBY et al., 2012; SNAVELY et al., 2008; ELTNER and SOFIA, 2020).

Within the processing and analysis process, GIS applications play an essential role, facilitating the integration of data from different sources and the generation of digital models of

the terrain. Software like Global Mapper provides effective tools for interpolation, visualization, and morphometric analysis (BURROUGH et al., 2015; de SMITH et al., 2018).

Land relief analysis is particularly important in the agricultural field, where even small variations in level can influence land use, drainage processes, or water distribution. For this reason, making an accurate digital model is a useful tool in substantiating decisions (PAȘCALĂU et al., 2025).

The present paper aims to highlight the possibilities offered by the integration of topographic data, GNSS and UAV in the realization of a digital terrain model and in the analysis of morphometric parameters.

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## MATERIAL AND METHODS

### Study area

The study was carried out at the University of Life Sciences "King Mihai I" from Timisoara, on an area located inside the university campus. The analysed area is characterized by a mixed use, including concrete platforms, alleys, parking lots and green spaces, being representative for topographic and cadastral applications in the urban environment.

From a geomorphological point of view, the land has low altimetric variations, specific to lowland areas, but sufficient to highlight the differences in level and their influence on water runoff and land use. This type of relief is commonly found in agricultural and urban applications, where even small differences in level can have a significant impact.

### Data used

Data from several sources were used to carry out the study, so as to ensure a complete analysis and high accuracy of the results:

- classic topographic measurements to identify the characteristic elements in the field;
- GNSS determinations in RTK mode for obtaining three-dimensional coordinates (X, Y, Z);
- aerial imagery obtained with the help of an unmanned aerial vehicle (UAV);
- data resulting from the photogrammetric processing of the images.

The set of aerial images consisted of 143 photos, captured with a DJI camera, with high resolution (approximately 4000×3000 pixels), ensuring a complete coverage of the analysed area and an appropriate overlap necessary for the three-dimensional reconstruction process [Șmuleac et al., 2017]. The GNSS data were used both for the positional control of the model and for the validation of the results obtained, the accuracy of the measurements falling within centimetre limits, specific to RTK technology (COLOMINA and MOLINA, 2014; NEX and REMONDINO, 2014].

### Equipment and software used

For the collection and processing of data, equipment and software applications specific to the field of geodesy and photogrammetry were used:

- GNSS receiver used in RTK mode for determining the coordinates of points in the field;
- unmanned aerial vehicle (UAV) for capturing aerial images;
- GIS software for data integration and analysis;

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- applications for photogrammetric processing and point cloud generation.

The data processing was mainly carried out using the Global Mapper application, which allows generating point clouds from images, integrating them with GNSS data and performing spatial analyses. The software provides tools for interpolation, three-dimensional visualization and derivation of morphometric parameters.

**Data processing**

The methodology adopted in the study was structured in several successive stages, so as to allow the efficient integration of data from different sources.

***Field data collection***

In the first stage, GNSS measurements were made in RTK mode, to determine the three-dimensional coordinates of the characteristic points in the field. The points were evenly distributed on the analysed surface, so as to allow a more faithful representation of the relief.

In parallel, a UAV flight was carried out over the study area, because of which aerial images with an appropriate longitudinal and transverse overlap were obtained. This overlap is essential for identifying common points between images and for three-dimensional surface reconstruction.

***Aerial image processing***

The aerial images were processed using digital photogrammetry techniques, based on Structure from Motion (SfM) methods (WESTOBY et al., 2012; JAMES and ROBSON, 2012; ELTNER and SOFIA, 2020). The process involved:

- Automatic identification of common points between images;
- calculation of the relative positions of the chambers;
- generating a three-dimensional point cloud;
- optimization of the model by bundle adjustment.

As a result of the process, tens of thousands of characteristic points were identified, resulting in a detailed three-dimensional model of the analysed surface.

$$GSD = \frac{H \cdot S_w}{f \cdot I_w}$$

The spatial resolution of aerial images can be estimated by the Ground Sampling Distance (GSD) parameter, determined according to the flight height and camera characteristics (COLOMINA and MOLINA, 2014; NEX and REMONDINO, 2014). A low GSD value indicates a high level of image detail and helps increase the accuracy of the three-dimensional model

***Point Cloud and Digital Model Generation***

The resulting point cloud was processed in the GIS environment to obtain the digital model of the terrain. At this stage, the following were achieved:

- filtering the data and removing the wrong points;
- classification of points (terrain / objects);
- generation of the digital model using the TIN method.

Irregular triangular lattice (TIN) interpolation allowed to obtain a continuous surface, suitable for the morphological analysis of the terrain (HARWIN and LUCIEER, 2012; LI et al., 2005).

***Morphometric analysis***

Based on the digital land model, the main morphometric parameters were determined, namely:

- the slope of the land;
- differences in level;
- water drainage directions;

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- longitudinal and transverse profiles.

The analysis of these parameters was carried out using the functionalities of GIS applications, allowing the identification of relief variations and the interpretation of the terrain behaviour (BURROUGH et al., 2015; DE SMITH et al., 2018).

***Data integration and validation***

The integration of data from GNSS measurements and UAV images made it possible to obtain a digital terrain model with a high degree of detail and precision. GNSS data were used for positional validation of the model, and the results obtained indicated a good concordance between the measured values and those resulting from the modelling (AGÜERA-VEGA et al., 2017; FERRER-GONZÁLEZ et al., 2020].

By combining these methods, a more complete and faithful model was obtained compared to the use of a single data source, demonstrating the effectiveness of the integrated approach.

## RESULTS AND DISCUSSIONS

Following the processing of data from GNSS measurements and UAV aerial images, a three-dimensional model of the analysed area was obtained, located inside the parking lot on the university campus. The integration of data from different sources allowed to obtain a digital model of the terrain characterized by a high degree of detail and good positional accuracy.

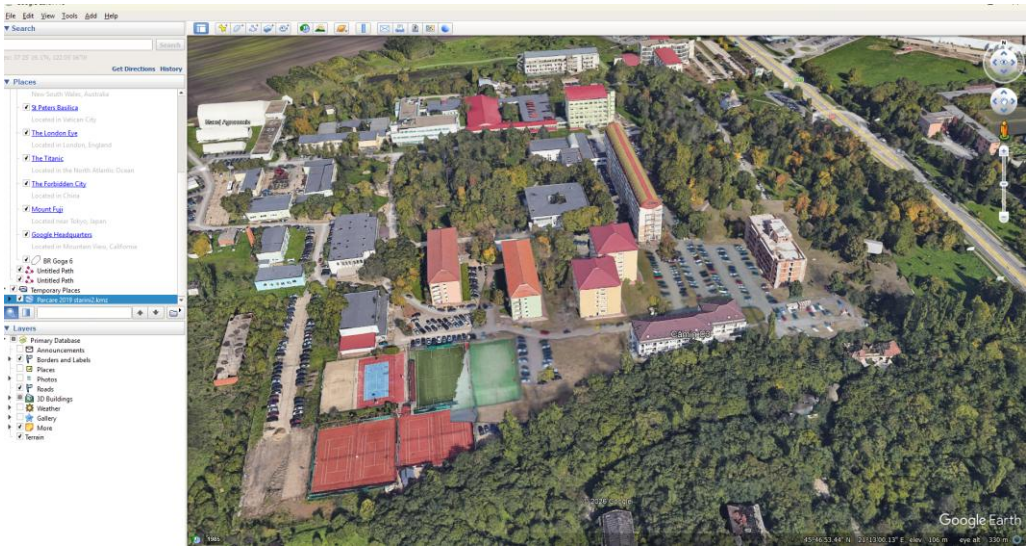



Figure 1. Three-dimensional view of the study area (Google Earth)

Figure 1 shows the three-dimensional visualization of the analysed area, highlighting the general configuration of the land, the location of the buildings and the existing infrastructure. This representation provides an overview of the studied area and facilitates the understanding of the spatial context.

**Positional control and analysis of GNSS points**

For the validation of the model, points determined by GNSS technology in RTK mode were used, exported in LandXML format (Table 1). The dataset included a number of 8 main points (POINT 1–POINT 8), evenly distributed in the study area.

*Table 1*

GNSS Determination of Field Targets

| No. Target | Y(m) | X(m) | Z(m) |
|---|---|---|---|
| ITEM 1 | 206071.1381 | 482793.6572 | 90.4670 |
| ITEM 2 | 206099.0815 | 482787.8057 | 90.3024 |
| ITEM 3 | 206109.3897 | 482755.7049 | 90.3767 |
| ITEM 4 | 206113.8756 | 482726.7483 | 90.4280 |
| ITEM 5 | 206095.3274 | 482734.3653 | 90.4036 |
| ITEM 6 | 206063.5472 | 482730.8019 | 90.3615 |
| ITEM 7 | 206080.0170 | 482755.2394 | 90.4319 |
| ITEM 8 | 206057.1504 | 482781.9794 | 90.4862 |

The coordinates of the points are expressed in the national Stereo 70 projection system, and the altimetric values show small variations of the terrain, approximately between:

- Zmin ≈ 90.30 m
- Zmax ≈ 90.48 m

This results in a difference in approximate level: $\Delta H \approx 0.18$ m

This variation confirms the relatively flat character of the area, specific to urbanized spaces, but sufficient for morphometric analyses.

In terms of accuracy, the RMS values of GNSS measurements are in the range:

- 1.30 – 1.53 mm (most points)
- with a maximum of ≈ 3.53 mm for an isolated point

These values confirm a good stability of the RTK solution and adequate accuracy for integration into the digital terrain model.

**UAV and orthophoto plane data analysis**

Based on the aerial images captured with the UAV, an orthophoto plan of the analysed area was generated, shown in the following figure.



Figure 2. Orthophoto plan of the study area with the location of GNSS points

Figure 2 shows the orthophoto plan resulting from the processing of aerial images, highlighting the structure of the analysed area, including parking platforms, buildings and green spaces.

The orthophoto plan highlights the structure of the analysed area, including:

- Parking platforms
- existing buildings
- Green spaces
- Traffic network

GNSS points are evenly distributed across the surface, ensuring adequate control for georeferencing the photogrammetric pattern (AGÜERA-VEGA et al., 2017; FERRER-GONZÁLEZ et al., 2020).

In terms of data quality, the images show:

- High resolution
- good contrast
- sufficient detail to identify the characteristic points

These conditions allowed for efficient processing and the generation of a coherent three-dimensional model.

**Analysis of the SfM process and residues**

Image processing using Structure from Motion (SfM) methods has led to:

- identification of more than 80,000 characteristic points
- generating a dense cloud of dots
- Estimating the positions of the chambers

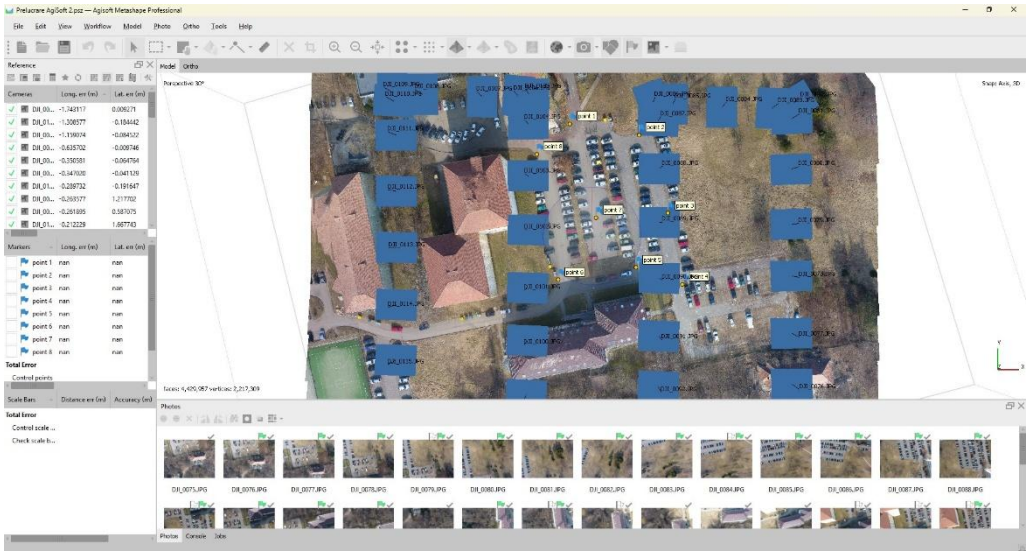


Figure 3. Configuring Images and Control Points in the SfM Process

Figure 3 highlights the distribution of aerial imagery and the positioning of the control points used in the three-dimensional reconstruction process (Table 2). The uniform coverage of the area is observed, an essential condition for obtaining an accurate model.

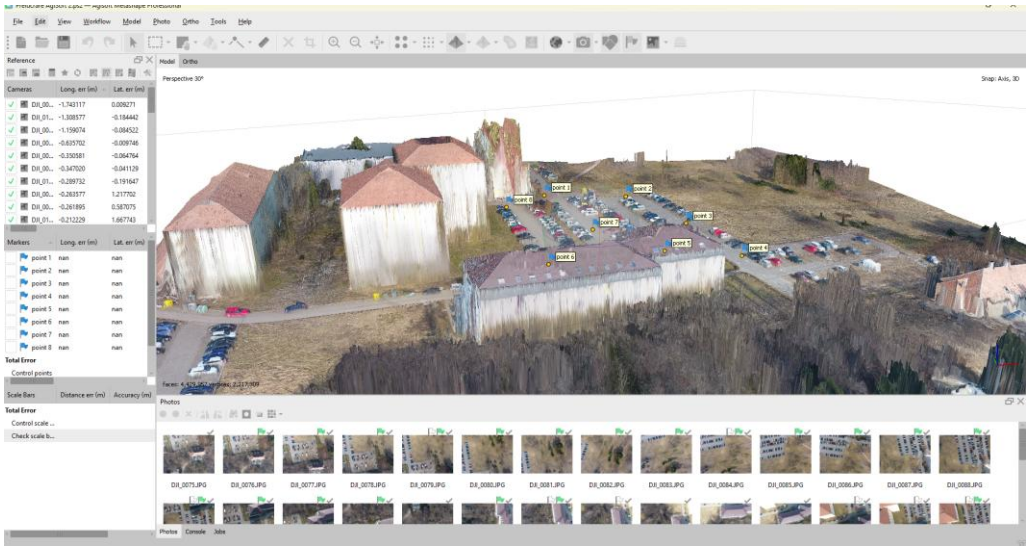


Figure 4. Three-dimensional surface model obtained by UAV image processing

The integration of this model with GNSS data allowed positional correction and improvement of the overall accuracy of the digital terrain model (WESTOBY et al., 2012; JAMES and ROBSON, 2012).

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Figure 4 shows the three-dimensional model resulting from the processing of aerial images using Structure from Motion (SfM) methods. The detailed reconstruction of the analysed area is observed, including the built elements and the parking platforms.

The model highlights a high point density and good surface continuity. Certain distortions in the vertical elements, specific to photogrammetric reconstructions, are also visible, caused by the geometry of the image capture and the lack of additional control points (HARWIN and LUCIEER, 2012; AGÜERA-VEGA et al., 2017).

The residual values obtained from the adjustment are presented in Table X.

Their analysis highlights the following aspects:

- Most of the average residue is between 0.2 and 0.6 pixels
- There are larger isolated values (up to ~1.1 pixels) associated with areas with low detail
- Maximum residue (≈ 3.9 pixels) is rare and does not affect the overall model.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} v_i^2}$$

To evaluate the quality of the photogrammetric adjustment, the mean square error (RMSE) is used, which expresses the overall deviation of the residuals. The low RMSE values confirm good model consistency and correct image alignment.

**Digital land model**

The resulting point cloud was used to generate the digital terrain model (DTM), using the TIN method (TONKIN et al., 2014; NEX and REMONDINO, 2014).

The integration of GNSS data with those coming from the UAV has led to:

- increasing the density of the dots
- Improving surface continuity
- Reduction of local errors

The resulting pattern allows for the faithful representation of surface details, including:

- Platform Edges
- Transition zones between surfaces
- small differences in level

Compared to the classic method (GNSS only), the use of UAVs has made a significant contribution in terms of model detailing.

**Morphometric analysis**

Based on the digital terrain model, the main morphometric parameters were calculated.

*a) Slope of the land*

The values of the slopes are low, most of them being below 2%, which confirms the flat nature of the terrain. However, areas with slightly steep slopes can be identified near the edges of the platforms.

$$p(\%) = \frac{\Delta H}{d} \cdot 100$$

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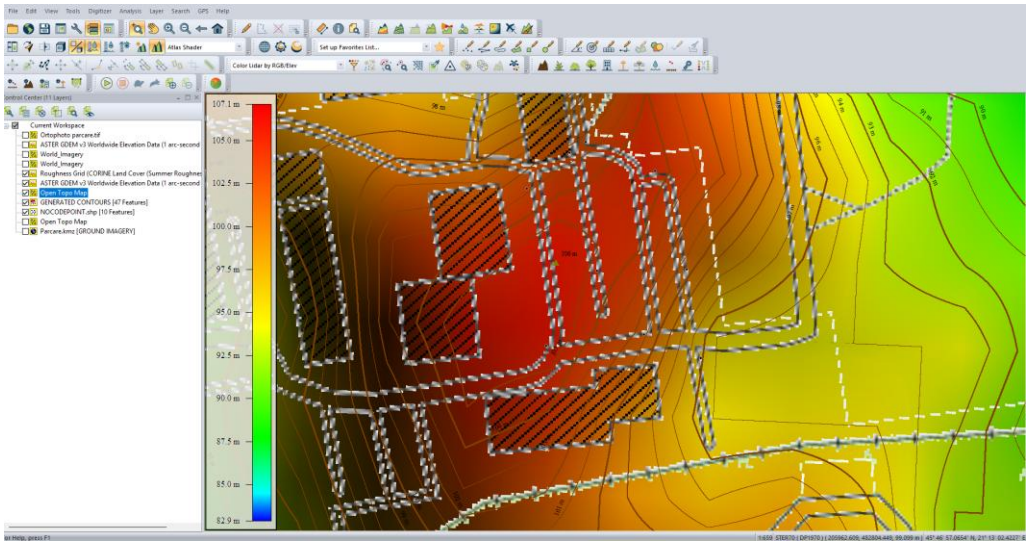



Figure 5. Digital model of the land generated in the GIS environment using the Global Mapper application

The slope of the land was estimated as the ratio between the difference in level and the horizontal distance between the points. The values obtained confirm the relatively flat nature of the analysed area (LI et al., 2005; BURROUGH et al., 2015).

*b) Differences in level*

The differences in level are small (≈ 0.18 m), but their distribution is not uniform, which leads to the appearance of accumulation micro zones.

$$\Delta H = Zmax - Zmin$$

$$\Delta H = 90.48 - 90.30 = 0.18\ m$$

*c) Drain Directions*

The analysis of the runoff directions highlighted the existence of areas where water tends to accumulate, especially in:

- Central areas of the parking lot
- Areas with small differences in level

This information is relevant for the design of drainage systems or for the optimization of land use.

Figure 5 shows the digital model of the terrain generated in the GIS environment using the Global Mapper application, highlighting the distribution of altimetric variations through a chromatic scale. There is a small variation in altitude values, specific to a lowland area, as well as local differences determined by the built elements and the surface configuration.

The representation allows the identification of areas with potential for water accumulation and the highlighting of the general drainage directions, aspects relevant for morphometric analysis

The distribution of the altimetric values confirms the results obtained from the GNSS measurements, highlighting a level difference of about 0.18 m, which indicates a relatively flat surface, but with relevant microvariations for the analysis of water runoff.

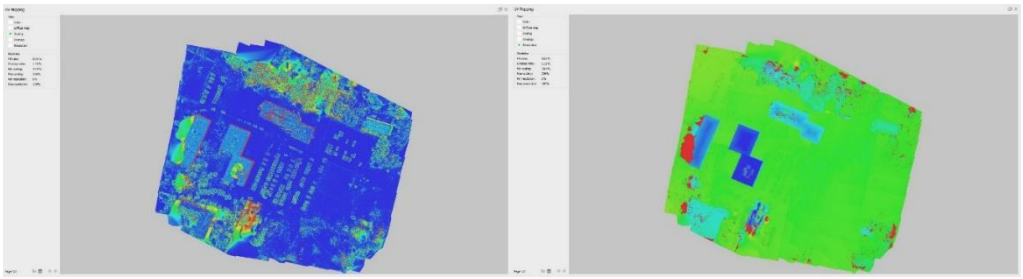


Figure 6. Analysis of the quality of texturing and image coverage (UV Mapping)

Figure 6 shows the analysis of the texturing parameters and image coverage within the photogrammetric process. The analysed indicators highlight the degree of overlap and the distribution of resolution on the modelled surface.

The values obtained indicate a good degree of coverage of the area, but there are local variations in resolution, determined by the geometry of the flight and the distribution of the images. These aspects influence the final quality of the three-dimensional model and must be considered in the interpretation of the results.

**Advantages and limitations**

The results obtained confirm the efficiency of integrating topographic, GNSS and UAV data in the development of digital terrain models (COLOMINA and MOLINA, 2014; TONKIN et al., 2014; WESTOBY et al., 2012].

Compared to classical methods, the approach used has the following advantages:

- High point density
- Full surface coverage
- Reduced data acquisition time
- the possibility of carrying out detailed analyses

The limitations of the method are mainly related to:

- lighting conditions during flight
- the presence of objects (vehicles, vegetation)
- the need for proper overlap between images (COLOMINA and MOLINA, 2014; NEX and REMONDINO, 2014).

## CONCLUSIONS

The paper highlighted the efficiency of the integrated use of topographic, GNSS and UAV data in the development of digital terrain models and in the analysis of morphometric parameters. The results obtained demonstrate that this approach allows obtaining a model characterized by a high degree of detail and good positional accuracy.

The integration of data from GNSS measurements with those resulting from aerial image processing led to a significant densification of the points and a more accurate representation of the analysed area. The determined level difference (≈ 0.18 m) confirms the relatively flat character of the studied area but also highlights the existence of microvariations relevant for the analysis of the water behaviour at the ground level.

The analysis of the residues obtained in the photogrammetric reconstruction process indicates a good consistency of the model, most of the values being in small ranges, which confirms the stability and correctness of the adjustment. Also, the use of SfM techniques allowed the generation of a detailed three-dimensional model, suitable for practical applications.

The results of the morphometric analysis showed low values of slopes (below 2%), as well as the existence of water accumulation areas, important aspects in the context of land use and design of landscaping works.

Overall, the proposed method proves to be efficient and applicable in practice, offering significant advantages over the classic methods, by reducing the working time and increasing the volume of information obtained. This approach can be successfully used in areas such as agriculture, cadastre and spatial planning, helping to inform decisions based on accurate geospatial data.

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