GLL
Geomatics, Landmanagement and Landscape No. 4 • 2025, 157–166

ISSN 2300-1496 https://doi.org/10.15576/GLL/214573

Research paper

Received: 14.11.2025
Accepted: 21.11.2025
Published: 31.12.2025

Use of DTM data for the purpose of developing an earthwork volume balance

Paweł Kotlarz[1, ✉] 0000-0001-6520-6462
Karolina Burghardt[2]

[1] Department of Geodesy, Faculty of Environmental Engineering and Geodesy, University of Agriculture in Krakow
[2] Geodetic Students Society, University of Agriculture in Krakow
✉ Corresponding author: pawel.kotlarz@urk.edu.pl

Summary

The subject of this study is to develop an earthwork volume balance for future works related to the construction of a single-family housing estate. As part of the design and construction of a single-family housing estate, the earthwork balance is crucial, as it allows for effective earthworks management and appropriate cost calculation. Proper planning of earthworks reduces the need for soil transport and minimises operating costs. Two models were developed to conduct the earthworks budget: the current terrain model and the design terrain model. The current terrain model was created on the basis of an integration of geodetic measurements and data from the digital terrain model (DTM). Then, based on the design assumptions, a design terrain model was generated, taking into account the planned embankments, excavations, and the target foundation level of buildings and road infrastructure. Analysis of the differences between the current and design terrain models made it possible to determine the volume of earth masses to be removed, relocated, or managed on the project site. Geodetic methods and GIS tools were used in the calculation process, enabling precise determination of volumetric differences. The obtained results indicate the possibility of optimising earthworks management through appropriate distribution of embankments and reduction of the volume of soil requiring removal. The conclusions from the analysis can contribute to better planning of construction investments and reduce their environmental impact.

Keywords

earthwork balance • construction of the housing estate • terrain model • geodesy • DTM

CC BY NC

1. Introduction

The subject of this study is the development of an earthwork balance sheet, which will provide information on the volume of material needed to be removed or supplied for the final development of the investment site. Earthworks, which are a type of construction works, involve transforming the terrain by removing or adding material and transporting it. Before any investment begins, a cost estimate is prepared to answer the question of costs for each stage of the works. Determining the scope of earthworks is necessary for a correct estimation of investment costs. According to the Waste Act (Dz.U. 2013 poz. 21 – Journal of Laws 2013, item 21), material obtained from excavations is waste requiring disposal, unless it is used for construction purposes in its natural state on the site where it was extracted. This means that soil from excavations can be reused on the investment site for landscaping, but any excess soil must be disposed of. Transport and disposal of excess soil is costly and represents a significant item in the cost estimate. Even the storage of excavated soil cannot take place outside the area covered by the building permit, which means that the area must be chosen correctly so that the stored material does not interfere with construction works. Issues related to the removal or addition of soil are often the subject of administrative proceedings concerning unauthorised construction. Levelling the terrain has an impact on the land surrounding the area of works. Raising the ground level changes the water conditions on the disturbed land and neighbouring plots, often causing rainwater to flow from the raised area onto neighbouring plots. According to the Water Act (Dz.U. 2017 poz. 1566 – Journal of Laws 2017, item 1566).

The landowner must not:

1) change the direction and intensity of runoff of rainwater or meltwater on their land, or the direction of runoff from water sources, to the detriment of neighbouring land,
2) discharge water or introduce sewage onto neighbouring land.

If the aforementioned works have been carried out in violation of the law, the landowner is obliged to remove obstructions and changes in water drainage caused on his land by accident or by the actions of third parties, to the detriment of neighbouring land. If the changes in the water condition on the land caused by the landowner have a detrimental effect on neighbouring land, the head of municipality, mayor or city president, ex officio or upon request, shall order the landowner to restore the previous condition by way of a decision. As a result, in many cases, such works require notification or a building permit, unless the plot already has an appropriate design and permit. This issue is not so pertinent in the case of a single object, such as a single-family dwelling. In this study, the area of analysis is a housing estate comprising 34 single-family dwellings. In order to correctly determine the volume of earthworks, it was necessary to obtain information about the terrain before the commencement of construction works and the layout of the designed area. The initial information was collected using LIDAR (Light Detection and Ranging) data from ALS (Airborne Laser Scanning), provided by the Main Office of Geodesy and Cartography. It was verified at selected points using

RTN satellite measurement technology. The designed area was identified using data obtained from the development plan for the plot.

2. Study area

The object chosen for the purposes of this study is an investment site located in Krakow, in the Wola Justowska district, covering an area of over 1.1 hectares.

Krakow is one of the most important urban centres in the country and remains a regional and international hub of social, economic and cultural life. It is the capital of the Małopolska Province, the seat of:

- the Voivode of Małopolska,
- the Marszal of Małopolska Voivodeship,
- the Starost of Krakow.

Source: www.bip.krakow.pl

Fig. 1. Location of the municipality of Krakow within the Krakow county

The city of Krakow covers an area of 327 km^2 and is divided into 18 districts. The division was drawn up on the basis of historical determinants. At the same time, both former cadastral divisions and parish divisions were taken into account, but the main idea was to create as convenient as possible transport links within a district.

Source: www.bip.krakow.pl

Fig. 2. The districts of the city of Krakow

The city of Krakow is divided into the following districts:

I – Stare Miasto (Old Town)
II – Grzegórzki
III – Prądnik Czerwony
IV – Prądnik Biały
V – Krowodrza
VI – Bronowice
VII – Zwierzyniec
VIII – Dębniki
IX – Łagiewniki – Borek Fałęcki
X – Swoszowice
XI – Podgórze Duchackie
XII – Bieżanów – Prokocim
XIII – Podgórze
XIV – Czyżyny
XV – Mistrzejowice
XVI – Bieńczyce
XVII – Wzgórza Krzesławickie
XVIII – Nowa Huta

Wola Justowska, where the discussed property is located, belongs to district VII – Zwierzyniec. It lies in the western part of the city, in the Rudawa river valley. Wola Justowska boasts many attractive sites, such as Villa Decius and its surrounding park. The close proximity of the Wolski Forest makes it a sought-after residential neighbourhood. The attractiveness of these areas affects the property prices, which are among the highest in Krakow.

Source: www.poczetkrakowski.pl

Fig. 3. Location of Wola Justowska

3. Research materials

The research used LIDAR (Light Detection and Ranging) measurement data from ALS (Airborne Laser Scanning) provided by the Main Office of Geodesy and Cartography. This data represents the terrain in the form of a cloud of measurement points with specific XYZ coordinates. The files are saved in LAS format and, in addition to point coordinates, contain information about the class of a given point and the intensity of signal reflection. Points may also have assigned RGB values (corresponding to blue, green and red colours) acquired from aerial photographs. The following point classes are recognised in LAS files:

0 – points processed but not classified,

2 – points on the ground,

3 – points representing low vegetation, i.e. in the range of 0–0.40 m,

4 – points representing vegetation at medium height, i.e. in the range of 0.40–2.00 m,

5 – points representing tall vegetation, i.e. above 2.00 m,

6 – points representing buildings, structures and engineering objects,

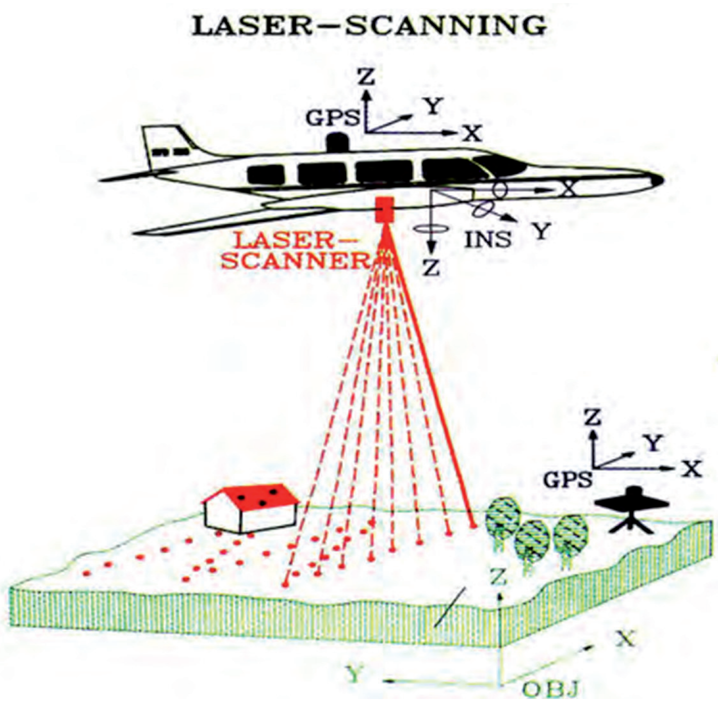
7 – noise,

8 – points representing water bodies,

12 – points from areas of multiple coverage.

LIDAR measurement data serve, among other things, to create and update DTM and DSM, but they also provide useful analytical material on their own. Poland has nationwide coverage with ALS data with varying point densities from 4 points/m² to as many as 20 points/m² (in cities) [www.geoportal.gov.pl].

LIDAR aerial scanning is a modern measurement technique used for mapping terrain surfaces with measurement points. Measurements are performed by determining the distance between the flying object and the measured terrain. The scanning device is mounted on board an aeroplane or helicopter and scans the terrain at high frequency with a pendulum motion perpendicular to the direction of flight. The aircraft's flight paths are planned in such a way that adjacent strips of scanned terrain overlap by approximately 30%. The distance is derived from the time difference between the moment a single signal is emitted and the moment it returns to the scanning device. The scanning system consists of two components: an airborne segment installed on board (e.g. an aeroplane) and a ground segment (Fig. 4) [Andersen 2002, Tarek 2002].



Source: Andersen [2002]

Fig. 4. LIDAR system

The collected data were used to develop a digital terrain model. It is a digital representation of the terrain surface created by a set of appropriately selected points located on that surface and interpolation algorithms enabling its reconstruction in a specific area [Gaździcki 1990].

The accuracy of aerial laser scanning depends on many factors, including:

- error in measuring the distance between the platform and the ground, resulting from the precision of determining the time of pulse transmission, the phase of the measurement signal, flight altitude, terrain type, terrain slope, etc. [Kraus and Pfeifer 1998],
- lower accuracy of determining the coordinates of point X, Y in relation to the height coordinate Z due to random errors and inertial drift of the INS navigation system [Borowiecki and Ślusarski 2010],
- errors caused by the faulty operation of individual components of the LIDAR system [Borowiecki and Ślusarski 2010],
- errors occurring at the stage of processing the measurement results, related to data processing and transformation [Maas 2003].

In order to assess the accuracy of the aerial scanning used, a field measurement was carried out using the GNSS RTN technique. This is necessary to check the quantitative and qualitative aspects of the involved data. The data obtained from the field measurements were compared with LIDAR data [Elaksher et al. 2023].

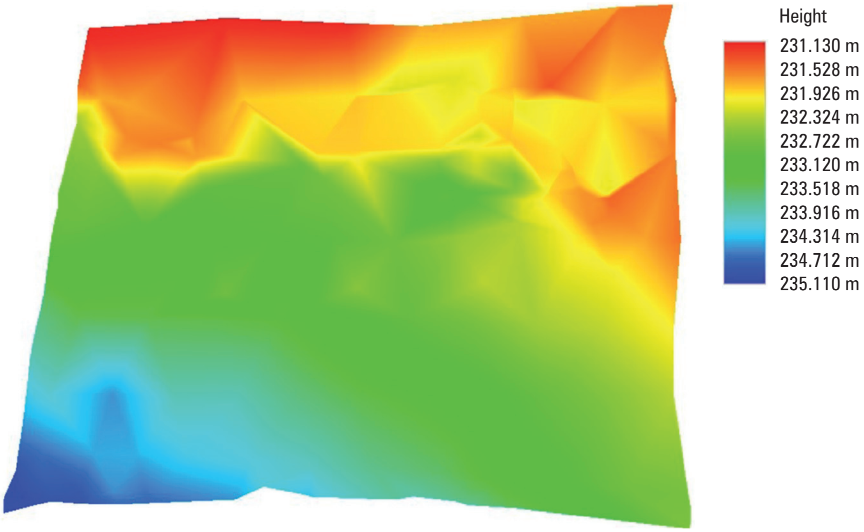
The materials mentioned above were used to create a model of the existing terrain. The earthworks were intended to transform this terrain according to the project. The final shape of the plot reflects the land development plan attached to the construction design and, in accordance with Article 34(3) of the Construction Law, is drawn up on a current map for design purposes or a copy thereof, and includes:

a) determination of the boundaries of a plot or area,
b) location, outline and layout of existing and planned buildings, including utility networks and construction equipment located outside the construction site,
c) method of wastewater disposal or treatment,
d) transport system and greenery layout, indicating characteristic elements, dimensions, elevations and distances between objects, in relation to existing and planned development of neighbouring areas,
e) information about the area affected by the construction.

4. Method of data processing

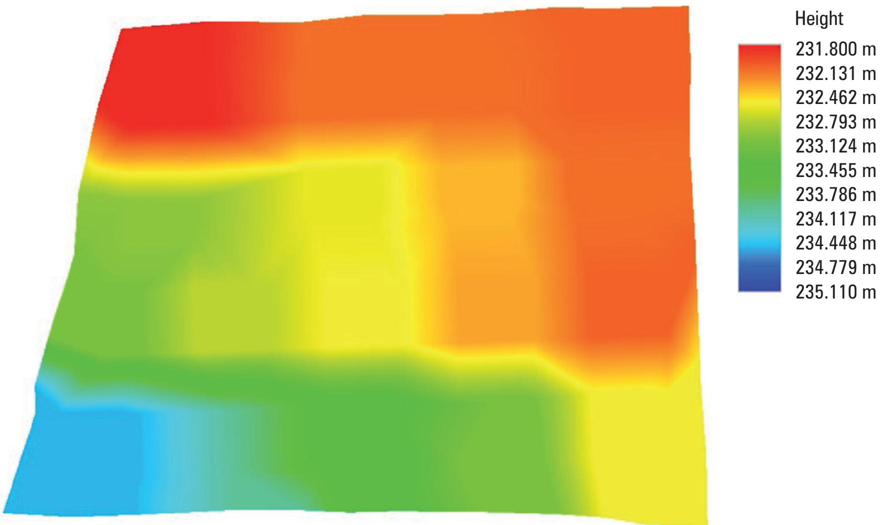
A digital terrain model was created based on filtered LIDAR data. Its consistency with the GNSS RTN measurement carried out in the field was verified. Comparison of direct measurement points with LIDAR data yielded the following values [Hejmanowska 2013]:

Mean error	$m_{mean} = 0.078$ m
Maximal error	$m_{max} = 0.280$ m
Minimal error	$m_{min} = -0.133$ m
Root mean square error	RMSR = 0.114 m



Source: Authors' own study

Fig. 5. Existing terrain model



Source: Authors' own study

Fig. 6. Model of the designed terrain

The obtained results show that the mean error of 0.078 m falls within the permissible deviation for Class II terrain details of 0.30 m [Rozporządzenie 2020].

A model of the existing terrain was developed based on direct measurements and data from a digital terrain model.

The situational and elevation positions of characteristic points constituting the corners of buildings, embankment boundaries, roads and pavements were read on the basis of the design assumptions shown in the land development plan. These data were used to create a model of the design area, taking into account the necessary embankments and excavations. The models were generated in Bentley's MicroStation environment.

The models obtained using the Mesh Utilities tools of the MicroStation environment were used to compare the existing terrain with the designed terrain. This tool allows the calculation of the volume between two models (e.g. before and after excavation).

5. Results

The comparison showed the balance of earthworks to be done.

Table 1. Results of earthwork balance

Parameter	Value [m³]
Cut	1268.62
Fill	1257.14
Net	+11.48

Table 1 presents the results of the earthwork balance analysis for the investment. It indicates the volume of soil to be excavated (Cut), the amount of material needed to construct embankments (Fill), and the net balance, showing the surplus or shortage of earth mass on the investment site.

6. Conclusions

The adopted method allowed for a precise determination of the scope of earthworks necessary to be carried out on the investment site. The resulting balance of 11.48 m^3 means that the earth masses on the investment site are almost perfectly balanced. This indicates that the material removed as a result of the excavation should be stored in an appropriate place on the construction site, as it will be necessary for the final landscaping. The analysis shows that the appropriate design of the height of the building foundations and the layout of the roads reduces the need to transport excess soil off the construction site and dispose of it. Minimising the earth mass to be removed reduces construction costs and CO_2 emissions related to transport. Introducing a similar earthworks balance analysis at the design stage increases the efficiency of the investment and allows for better environmental management.

References

Andersen H.-E. 2002. The use of airborne laser scanner data (LIDAR) for forest measurement applications. WFCA.

Borowiecki I., Ślusarski M. 2010. Lotniczy skaning laserowy LIDAR Miasta Krakowa (ocena dokładnościowa). Infrastructure and Ecology of Rural Areas, 3, 127–137.

Elaksher A., Tarig A., Abdullatif A. 2023. A Quantitative Assessment of LIDAR Data Accuracy. Remote Sens., 15(2), 442.

Gaździcki J. 1990. Systemy informacji przestrzennej. Polskie Przedsiębiorstwo Wydawnictw Kartograficznych im. Eugeniusza Romera SA, Warszawa.

Hejmanowska B. 2013. Zastosowanie rozkładu Laplace'a do określania niepewności danych przestrzennych na przykładzie NMT i systemu IACS. Wydawnictwa AGH.

Kraus K., Pfeifer N. 1998. Determination of terrain models in wooded areas with airborne laser scanner data. ISPRS Journal of Photogrammetry and Remote Sensing, 53, 193–203.

Maas H-G. 2003. Least-Squares Matching with Airborne Laserscanning Data in a TIN Structure. IAPRS.

Rozporządzenie Ministra Rozwoju z dnia 18 sierpnia 2020 r. w sprawie standardów technicznych wykonywania geodezyjnych pomiarów sytuacyjnych i wysokościowych oraz opracowywania i przekazywania wyników tych pomiarów do państwowego zasobu geodezyjnego i kartograficznego (Dz.U. 2020 poz. 1429).

Tarek Z. 2002. Skanowanie terenu laserem lotniczym. Geodeta, 12, Warszawa.

Ustawa z dnia 14 grudnia 2012 r. o odpadach (Dz.U. 2013 poz. 21).

Ustawa z dnia 20 lipca 2017 r. – Prawo wodne (Dz.U. 2017 poz. 1566).

www.bip.krakow.pl

www.geoportal.gov.pl

www.poczetkrakowski.pl