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THE INFLUENCE OF GEODETIC BASE QUALITY IN ROAD DESIGN

Abstract

This paper analyzes the impact of the quality of geodetic base, i.e., the method of obtaining spatial data for the purposes of road design. Quantities of earthworks, shape and size of the road body obtained by designing the road on geodetic base obtained from different sources (LiDAR scanning, topographic maps, and Open-source data) are compared to demonstrate the significance of selecting the type of spatial data used as a basis for design and the method of their collection.

Keywords: geodetic base, earthwork volume, DEM (Digital Elevation Model), LiDAR, NASA SRTM, ASTER GDEM, Global Mapper, topographic map, Civil 3D

УТИЦАЈ КВАЛИТЕТА ГЕОДЕТСКЕ ПОДЛОГЕ ПРИЛИКОМ ПРОЈЕКТОВАЊА САОБРАЋАЈНИЦА

Сажетак

У овом раду анализиран је утицај квалитета геодетске подлоге односно начин добијања просторних података за потребе пројектовања саобраћајница. Поређене су количине земљаних радова, облик и величина трупа саобраћајнице добијени пројектовањем саобраћајнице на геодетску подлогу добијену из различитих извора (Lidar снимањем, топографске карте и из Open-source података) у сврху показивања значаја одабира типа просторних података који се користе као основ за пројектовање и начина њиховог прикупљања.

Кључне ријечи: геодетска подлога, волумен земљаних радова, DEM, LiDAR, NASA SRTM, ASTER GDEM, Global Mapper, топографска карта, Civil 3D

1. INTRODUCTION

Geodetic bases are crucial aspects in any process of design, planning and construction of infrastructure, such as roads, bridges, buildings and other facilities. These bases constitute a set of information describing the geographical characteristics of a particular area, such as terrain, elevation, position of objects and parcel boundaries. During planning, they enable engineers to analyze the terrain and identify optimal locations for construction projects. In the design phase, they are used to create digital terrain models, facilitating precise design and adaptation of structures to the terrain. During construction, these bases are necessary for laying foundations, monitoring work progress and quality control. Given the importance of geodetic bases in the design process, it is crucial to gather, process and analyze them utilizing cutting-edge technologies and standards within the realm of geospatial sciences 6.[1]6.[2].

The lack of clear legal regulations regarding the mandatory use of specific geodetic bases in the design process poses a problem in many legal systems. This legal oversight can lead to inconsistent and unequal standards in the application of geodetic bases in the planning and construction of infrastructure projects. Additionally, the absence of specific guidelines can result in different interpretations and practices in different geographic areas, which can affect the quality, accuracy, and efficiency of the project. To overcome these shortcomings, establishing clear and comprehensive legal frameworks that prescribe standards and guidelines for the use of geodetic bases in design can be essential. These laws should define the types of data that must be used, data quality standards, procedures for their collection, processing and storage, as well as the obligations of professionals involved in the planning and construction process. Such a legal framework would not only ensure consistency and transparency in the application of geodetic bases but also ensure that the latest technologies and best practices in the field of surveying are integrated into the planning and construction process of infrastructure projects. By establishing clear legal guidelines, it is possible to improve the entire design process. The Planning and Construction Law of Bosnia and Herzegovina contains requirements for utilizing topographic maps, current georeferenced orthophoto bases, and certified cadastral-topographic plans in the development of planning documentation 6.[3].

One of the studies that addressed a similar issue is Comparison of digital terrain models based on topographic maps and remote sensing products 6.[4]. Within this research, various methods of data collection for creating a digital terrain model were analyzed. Various factors influencing the quality of geodetic bases were considered, including data collection methods, measurement accuracy and information processing procedures. The research results clearly indicate a relationship between the quality of geodetic bases and the precision of design. High-quality geodetic bases enable engineers to accurately identify terrain characteristics and adjust road designs, contributing to more efficient and safer road construction. Based on the results obtained from comparing four different methods of data collecting for creating a digital terrain model (DTM), it was concluded that LiDAR technology is the most detailed and highly efficient method for gathering high-precision data for DTM generation 6.[4]. The paper titled Improvement of the quality of geodesic support for road reconstruction emphasized the importance of enhancing geodetic support in the road reconstruction process6.[5]. Various approaches and techniques of geodetic research were analyzed with the aim of ensuring accuracy and reliability during road infrastructure reconstruction. Special emphasis was placed on identifying necessary changes to standards and regulations to ensure efficient and modern utilization of geodetic methods for improving the quality and safety of road projects 6.[5]. The case study Belgrade-South Adriatic Highway explores the application of MLS (Mobile Laser Scanning) and ALS (Airborne Laser Scanning) technologies in the mapping and analysis of road infrastructure along the stretch of highway connecting Belgrade and the South Adriatic 6.[6]. The MLS technology was used for detailed scanning of the road network using mobile laser scanners mounted on vehicles. It has been demonstrated that this technology enables rapid and precise data collection about terrain, surfaces and objects along the highway. ALS technology employs aircraft equipped with laser scanners to enable aero photogrammetric scanning of a wider area along the road route. This technology allows quick collection of high-quality three-dimensional terrain data, creation of digital elevation models and identification of potential road hazards. The result of this research showed that the combination of MLS and ALS technologies provides a comprehensive insight into the state of road infrastructure on the Belgrade-South Adriatic highway 6.[6].

Most research in this field points to the common conclusion that geodetic bases have a significant impact on the estimation and preliminary cost of earthworks during design. Specifically, this study analyzed earthworks that require significant financial resources and time. The subject of the study is a section of the planned roadway Bihać-Cazin-Velika Kladuša-Republic of Croatia located in the Una-Sana Canton, also known as the Euro Region or the Emerald of Bosnia and Herzegovina.

2. STUDY AREA

In this research, the selected project was used to highlight variations in the obtained results, given that the use of bases from diverse sources can result in significant differences in required works. The primary goal of constructing this roadway is to improve transport quality and traffic safety through the development of adequate road infrastructure. The Una-Sana Canton, containing the municipalities of Bihać, Cazin and Velika Kladuša, is located in the northwest part of Bosnia and Herzegovina. The total area of the canton is 4,841 square kilometers, making up 8.2% of the total area of Bosnia and Herzegovina, with a total population of approximately 305,000. Due to its geographical location and proximity to the Republic of Croatia, it is suitable for the development of roadways. It is situated along significant transportation corridors connecting Europe, the Mediterranean and the Middle East, offering substantial developmental opportunities for Bosnia and Herzegovina. The canton boasts a network of regional, local and arterial roads, as well as European routes connecting it with the Republic of Croatia 6.[7]. The starting point of the section is within the vicinity of the Maljevac border crossing. Statistical data indicate that the area of the Una-Sana Canton comprises 333.1 km of arterial roads, 507.7 km of regional roads, local roads and streets in settlements and cities. Unclassified roads are the most prevalent, accounting for 48.77%, followed by local and regional roads at 29.42%, regional roads at 12.83%, and arterial roads at 8.98%. The road infrastructure is over 30 years old, justifying the need for the construction of new roads. The area slated for the construction of the new roadway is also the area with the highest incidence of traffic accidents in the Una-Sana Canton, with 36.2% occurring in the city of Bihać, 22.3% in the city of Cazin, and 17% in the municipality of Velika Kladuša.

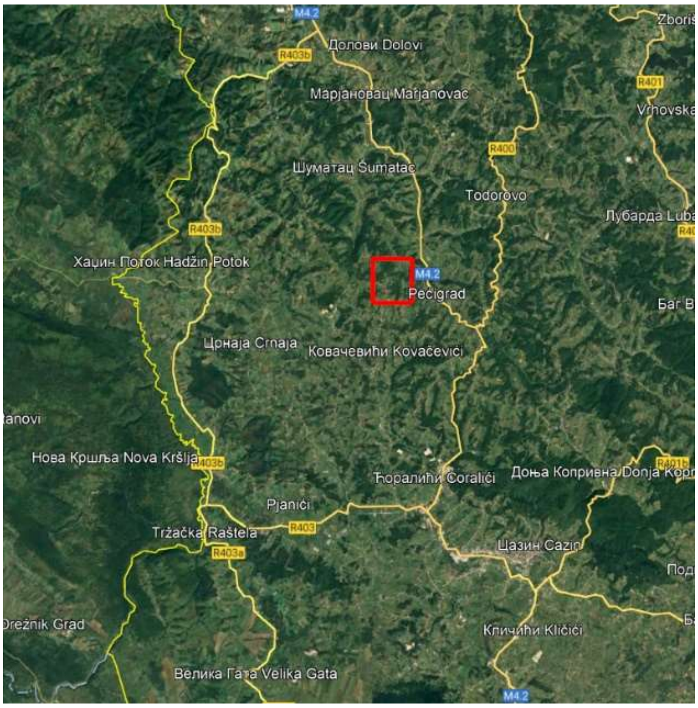


Figure 1. Study area

3. DATA ACQUISITION

Data acquisition for the specified study area involved three datasets obtained from different sources. The first dataset comprises a digital elevation model generated using LiDAR technology, i.e., aero photogrammetric scanning. The digital elevation model provides a raster representation of elevations i.e. a data matrix. The accuracy of these models depends on various factors. The simple data structure and wide availability have made them a popular tool for land characterization 6.[8].

The second dataset includes contours obtained by digitizing a topographic map, while the third dataset contains contours obtained from open sources.

First, we will provide a more detailed description of the data acquisition process for the first dataset. Through point cloud classification, points related to the ground, i.e., the terrain of the study area, were separated, which were then used to form the digital elevation model. Point cloud data was collected using the Riegl VQ-1560II sensor in combination with the Applanix AP60 inertial system, mounted on the gyro-stabilized platform Somag GSM 4000, thus maintaining the mounted camera, scanner and inertial unit in the desired orientation. This method of sensor orientation was employed due to the use of a crewed aircraft for flight execution, which was necessary due to the size of the work area. The result of LiDAR scanning is a point cloud with a density of more than 10 points per square meter. The characteristics of the sensor used are described in detail in Table 6.[9].

Table 4. Characteristics of the LiDAR system and integrated sensors

Specification of the laser scanner	
Instrument type	Riegl VQ-1560II
Scanning mechanism	Rotating polygonal mirror
Number of laser sources	2
Scanning angle	60°– effective 58°
Scanning mode	Parallel scanning lines per channel, intersecting scanning lines between channels
Frequency	from 2x 150kHz to 2x 2000kHz
Scanning speed	40-600 lines/second
Accuracy	20mm
Laser wavelength range	Near-infrared
Laser classification	Class 3B
Beam divergence	≤ 0.18 mrad @ 1/e ≤ 0.25 mrad @ 1/e2
Specification of the inertial system	
System	Applanix AP60
Type	IMU 57- Ri
Accuracy of the inertial unit: Roll Pitch Heading	 0.0025° 0.0025° 0.005°
Spatial accuracy	<0.05m horizontal <0.10m vertical
Specification of gyro-stabilized platform	
Platform	SOMAG
Type	GSM 4000
Angular stabilization range: Roll Pitch Drift	 ≤ ± 8.8º ≤ ± 7.0º ≤ ± 25.0º

Data obtained by manual digitization of a topographic map were chosen as a second data source. This is a process in which geographic data are manually recorded or drawn to create a digital version of cartographic data. Naturally, preference is given to automatic digitization since manual digitization requires significant time and human resources and can often result in errors or inconsistencies in the data 6.[10]. Topographic maps at a scale of 1:25,000 from 1980 were used, which were issued by the Republic Geodetic Authority Sarajevo, Cartography Institute "Geokarta," Belgrade 1980.

The third dataset represents a terrain model obtained from contours from open-source using the Global Mapper software environment. This is an advanced Geographic Information System (GIS) software that provides a wide range of tools for processing spatial data. The dynamic terrain visualization of Global Mapper supports the import and processing of elevation data and terrain visualization in 3D format, thus it was chosen for obtaining the terrain model. Global Mapper utilizes publicly available NASA SRTM (Shuttle Radar Topography Mission) and ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) elevation models. The ASTER GDEM is distributed free of charge to users worldwide by METI and NASA through the Earth Remote Sensing Data Analysis Center (ERSDAC) and the NASA Land Processes Distributed Active Archive Center (LP DAAC), as a contribution to the Global Earth Observing System of Systems (GEOSS). Images are captured across 14 spectral bands utilizing three distinct telescopes and sensor systems 6.[11]. The resolution of these available data is approximately 30 meters 6.[13].

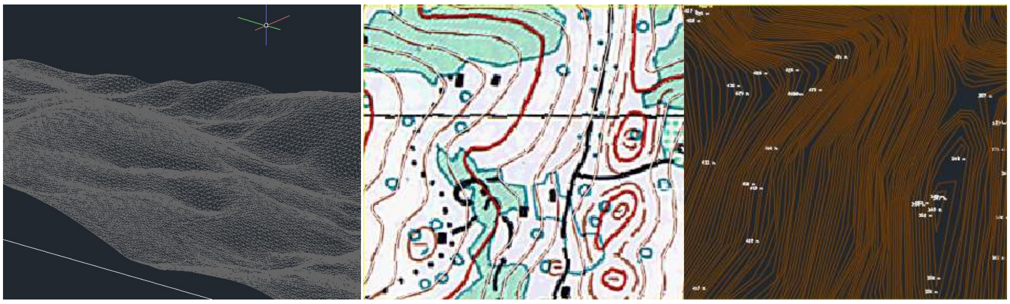
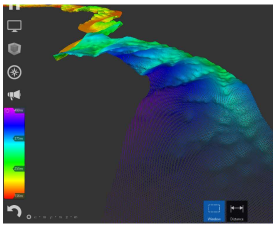
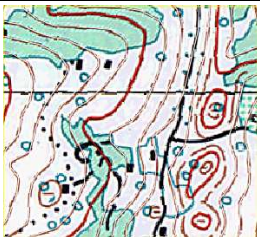
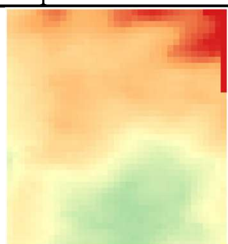


Figure 2. Used datasets (TIN network created from LiDAR data - left, part of a topographic map - middle, contours from open-source data - right)

In the following table, input data for various data acqusition methods are presented base on different criteria.

Table 5. Comparison table of data sources for different criteria 6.[14]

Criteria for comparison	**Data collection methods**		
	LiDAR point cloud	Topographic map	Open-source data
1. Data source			
2.Resolution	5mx5m	25mx25m	30mx30m
3. Density	10 points per square meter	equidistance 10 m	equidistance 5 m
4. Accuracy	< 0,05 m horizontal < 0,10 m vertical	± 3,7 m horizontal ± 2,0 m vertical	30m horizontal 20m vertical

4. METHODOLOGY

On three created datasets representing digital terrain surfaces of the study area, for the purpose of result comparison, a simplified version of a roadway with a total width of 20 meters was designed, with planned slope inclinations in cuts and fills of 1:1.5. Based on the design, digital surfaces of the roadway with slopes were generated relative to the three sets of data, i.e., three digital terrain surfaces.

The results refer to the analysis of excavation and embankment volumes (cut/fill factor), i.e., the total volumes of earthworks required for constructing the roadway corridor projected onto each dataset. The created digital roadway surfaces with slopes served as the comparison surface relative to the corresponding terrain surfaces (Base surface), and then were utilized for generating volume surfaces within the Civil 3D software environment. The primary purpose of volume surfaces is to calculate material quantities and analyze terrain. The data on material quantities from the created volume surfaces is used as part of the results of this study.

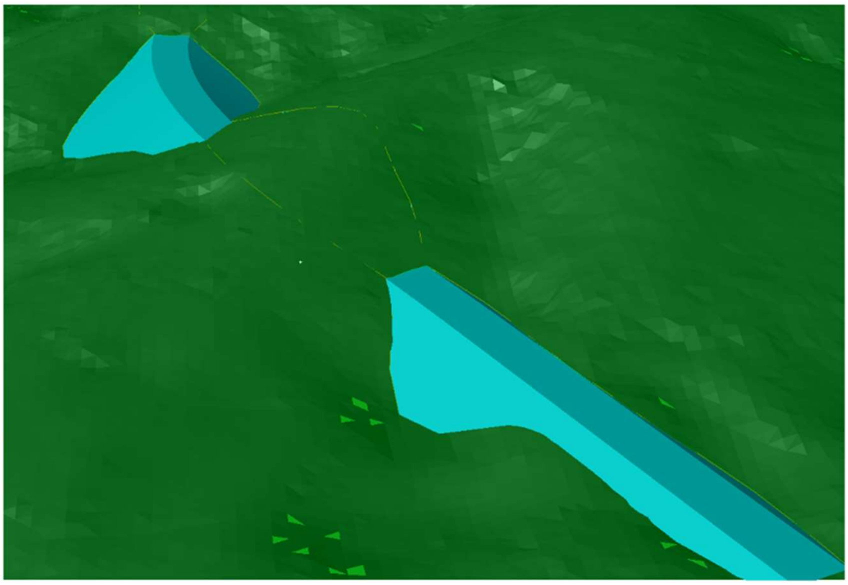


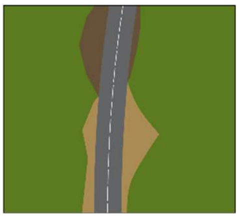
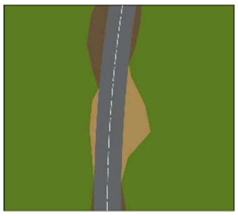
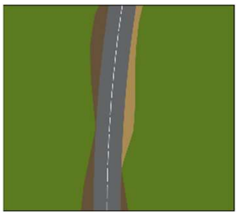
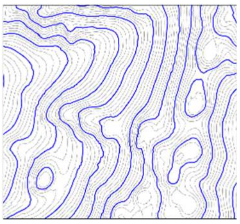
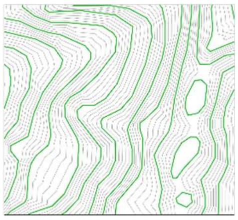
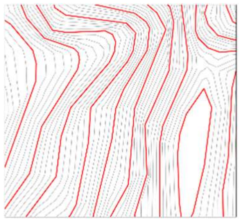
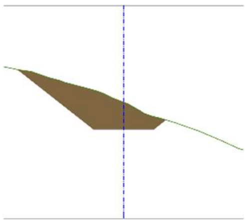
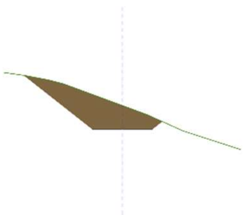
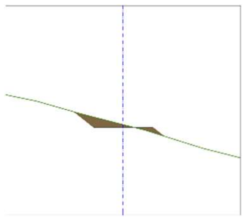
Figure 3. Projected roadway alignment onto the digital terrain surface.

5. RESULTS AND DISCUSSION

By comparing the created models, differences in the roadway alignment are observed, especially in the model formed using open-source data. Roadway models generated using LiDAR datasets and topographic maps show similarities along most of the route, which is expected considering that the contours of the isolated study area segment also exhibit similarity. Nevertheless, when comparing the quantities of earthworks, i.e., the volumes of embankments and excavations, differences in the results of 6% are noted.

When comparing the model generated using LiDAR data with the model based on open-source data, a significant difference in results, up to 30%, was noticed, mainly due to the resolution of the open-source elevation model. In the depiction of the roadway alignment on the isolated characteristic segment of the study area, a clear difference in the crest line of the cut and the toe of the embankment is observed. Additionally, elevation representations, or contours obtained from all three datasets, are shown for the same segment, revealing a lack of detailed representation of relief plasticity that directly affects the results.

Table 1. Shape of the characteristic section of the roadway alignment and the total volume of earthworks

		LiDAR	Topographic map	Open- source data
Roadway alignment at the characteristic section of the route				
Elevation representation of the characteristic section (contours)				
Characteristic cross-section profiles of the roadway				
Volume [m^3]	Embank ment	328296	282447	347611
	Cut	582237	573903	293400

6. CONCLUSION

With the constant advancement and increasing technical capabilities, the role of geodesy is evolving, becoming crucial in multidisciplinary and complex projects. Geodetic bases have a significant impact on the roadway design process, as they provide essential terrain information crucial for assessing topography, slopes, soil characteristics and other factors influencing the construction and appearance of roads. These bases are essential for setting road alignments, optimally distributing curves, as well as planning safe and functional solutions for traffic systems. High-quality geodetic bases enable engineers to efficiently identify potential obstacles, assess the impact of road infrastructure on the environment and minimize risks associated with road construction and exploitation.

Although the law contains provisions regarding the use of certain geodetic bases, it needs to be updated to adequately regulate the use of modern geodetic bases, such as high-resolution digital maps and geographic information systems. Since technology is constantly advancing, the law should more precisely define and encourage the use of the latest geodetic tools and techniques, which would enhance the planning and construction process, ensure more efficient spatial management and assist in estimating the amount of work and thus the assessment of project execution timelines and financial project frameworks.

Considering the efficiency, cost-effectiveness and quality of data collection, LiDAR systems justify their increasingly frequent use in creating precise and detailed geodetic bases for various engineering projects. By integrating different types of sensors, LiDAR enables meeting the requirements for collecting spatial information for various purposes. Research confirms that the use of high-resolution spatial data is necessary in the design phase to assess the scope of work, which directly impacts all necessary project resources. Additionally, this research demonstrates that the availability of open-source data in areas allocated for project design and construction should not imply their obligatory use.

Based on the obtained results, we conclude that the terrain model derived from open sources - Global Mapper, meets the requirements for conducting studies, previous research, general project outlines, as well as for conceptual design development. Based on the conceptual design, the scope of the project is defined, requiring higher precision. Therefore, it is essential for the geodetic base used in the development of conceptual, main, and as-built projects to meet their accuracy criteria. Considering that the research results showed a difference of 6% between data obtained through LiDAR technology and digitization of a topographic map, we can conclude that data obtained through both methods satisfy requirements of these project phases. Taking into account all the advantages such as cost-effectiveness, efficiency, reduced error potential and increased precision, priority is given to data collection through LiDAR technology.

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