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GEODETIC SUPPORT AND AUTOMATED VERTICAL PLANNING IN THE DESIGN OF A KARTING COMPLEX USING AUTODESK CIVIL 3D

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Abstract. This paper presents a geodetic framework for the design of a karting complex based on an up-to-date topographic survey and a digital terrain model. The purpose of this study is to analyze the application of automated vertical planning in the design of linear sports facilities using a specialized digital design environment. The methodology is based on the integration of geodetic survey data, digital terrain modelling, and parametric design tools implemented in Autodesk Civil 3D. The approach demonstrates the potential for direct integration of geodetic data into parametric infrastructure design workflows. The track alignment is used as a linear reference element for defining design elevations, longitudinal slopes, and cross-sectional parameters, enabling the automated generation of design surfaces. The results demonstrate that the application of automated design relationships allows efficient coordination between horizontal and vertical planning and supports the optimization of earthworks and terrain modelling. A comparative analysis of traditional and automated design approaches indicates that the proposed method reduces the time required to update design solutions by approximately 30–40%. The originality of the study lies in the systematization of an integrated geodetic model combining survey data, digital terrain modelling, and automated vertical planning for the design of linear sports facilities.

Keywords: geodetic support, automated vertical planning, digital terrain model, parametric design, engineering geodesy, Autodesk Civil 3D, karting complex.

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1. Introduction

The design and construction of sports facilities with linear development, such as karting complexes, require high standards of geodetic support and spatial accuracy of engineering solutions. In modern engineering practice, these requirements are addressed through the use of digital terrain models and specialized software environments that allow the management of geometric relationships within the investment design process (Uren & Price, 2010; Wolf & Ghilani, 2018; Li et al., 2005; Burrough et al., 2015). The integration of digital models and geospatial technologies enables the combination of geodetic data and engineering design within a unified digital environment (Biljecki et al., 2016; Karan et al., 2014).

For linear sports facilities, vertical planning represents a key stage that determines the functionality, safety, and conditions for efficient surface drainage. Previous engineering studies confirm the importance of accurate vertical planning in achieving optimal terrain adaptation

and reliable project implementation (Stefanova, 2022). Despite the increasing use of digital terrain models and parametric design environments in engineering practice, the integrated application of automated vertical planning methods for sports facilities remains insufficiently systematized. Therefore, there is a need for a structured geodetic methodology that integrates digital terrain modelling and parametric design tools for efficient vertical planning of linear sports facilities.

The purpose of this paper is to present a geodetic design solution for the development of a karting complex through the application of automated vertical planning based on a digital terrain model in a specialized design environment. The study examines the practical use of parametric design relationships for generating and updating design elevations and slopes during the investment design process. The research is implemented through an applied engineering case study and includes a comparative analysis between traditional and automated design approaches.

The scientific contribution of the study lies in the systematization of an integrated geodetic model that combines geodetic surveying, digital terrain modelling, and parametric design tools to ensure automated coordination between horizontal alignment, vertical planning, and digital terrain representation.

When implemented within the Autodesk Civil 3D environment, this approach improves the accuracy and efficiency of the design process for linear sports facilities. In this context, geodetic support evolves from a supporting activity into an integrated component of the digital investment design process, corresponding to the concept of Geodesy 4.0.

The remainder of the paper is organized as follows. Section 2 presents the characteristics of the study area and the input data. Section 3 describes the geodetic survey and the development of the digital terrain model. Section 4 presents the master plan and automated vertical planning of the karting complex. Subsection 4.1 describes the application of Autodesk Civil 3D, Subsection 4.2 presents the efficiency analysis of automated vertical planning, and Subsection 4.3 provides a discussion of the obtained results.

2. Study area and input data

The object of the study is a karting complex located in the South-Eastern planning region of Bulgaria, Burgas Province, Kameno Municipality, within the land of the village of Vratitsa in the area known as “Kayata” (Figure 1). The project area covers several adjacent land parcels designated for the construction of a karting track and the associated service infrastructure.

The terrain is characterized by a clearly expressed overall slope and a smoothly varying relief, which significantly influences the design solutions for vertical planning. The terrain elevations within the project area vary approximately between 170 m and 185 m, indicating a moderate natural slope suitable for the development of the karting track alignment. The existing terrain conditions were analyzed based on an up-to-date geodetic survey used to assess the configuration of the relief and the existing elevation differences. These characteristics were taken into account in the selection of the track alignment and in the development of the vertical planning solution in order to

ensure compliance with the permissible design slopes and to optimize earthworks.

The input data for the project include horizontal and vertical geodetic control consistent with the adopted national coordinate and vertical reference systems, as well as spatial planning and regulatory constraints defining the permissible development parameters and alignment requirements (Republic of Bulgaria, 2001, 2006; Ministry of Regional Development and Public Works, 2001; 2003). Based on these data, a digital terrain model was generated and used as the basis for the preparation of the master plan and the vertical planning design.

The selected site provides suitable terrain conditions for analyzing the application of automated vertical planning within a digital design environment.

3. Geodetic survey and digital terrain model

The geodetic survey of the karting complex area was used to determine the spatial and elevation positions of the characteristic terrain points and lines within the design area. The survey was carried out in accordance with established principles and practices in engineering geodesy (Uren & Price, 2010; Wolf & Ghilani, 2018). The field data acquisition combined GNSS measurements and terrestrial surveying techniques to ensure adequate coverage and representation of the terrain characteristics within the project area. The obtained survey data served as the basis for further digital processing and are illustrated in Figure 2.

The methodological workflow of the study consists of three main stages: geodetic data acquisition, digital terrain model generation based on a TIN surface, and automated vertical planning using parametric design tools in Autodesk Civil 3D.

Based on the collected survey data, a Digital Terrain Model (DTM) was generated to represent the geometry of the existing relief through characteristic points and breaklines (Li et al., 2005; Florinsky, 2012; Pike et al., 2009). The digital terrain model enables detailed analysis and visualization of existing topographic conditions and provides the geometric basis for further engineering design in a three-dimensional environment.

The terrain surface was constructed using a Triangulated Irregular Network (TIN), enabling accurate modelling



Figure 1. Location of the study area near Vratitsa village, Burgas Province, Bulgaria (source: author's compilation based on Natural Earth (n.d.) datasets)

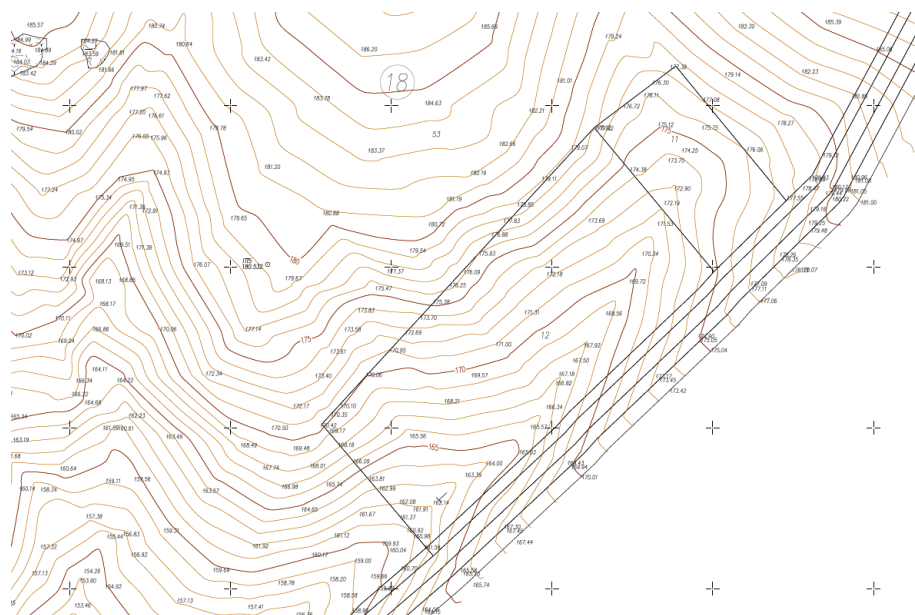


Figure 2. Geodetic survey of the karting complex area (source: author's compilation based on geodetic survey data)

of terrain morphology and elevation variations within the project area.

The reliability of the proposed design approach depends directly on the quality of the input geodetic data used for terrain modelling. Several criteria were considered in evaluating the suitability of the survey data, including positional and elevation accuracy, density of measured terrain points, completeness of breakline representation, and consistency with the adopted coordinate and height reference systems. Particular attention was paid to the identification of characteristic terrain features such as ridges, drainage paths, and slope discontinuities, which significantly influence the accuracy of the generated digital terrain model. The survey data were processed within a unified geodetic framework based on the national coordinate system and height reference system, ensuring consistency throughout the design process. In addition, visual and geometric verification of the generated TIN surface was performed to identify possible irregularities and to ensure that the digital terrain model accurately represented the existing topographic conditions. These quality control procedures are particularly important in areas with complex and variable terrain, where local inaccuracies may affect the determination of design elevations and earthwork quantities.

The generated terrain surface was subsequently used as the geometric foundation for automated determination of design elevations and slopes in the vertical planning process.

4. Master plan and automated vertical planning

The master plan was developed based on the generated digital terrain model and the functional requirements of the planned facility. It defines the spatial arrangement of

the main elements of the karting complex and the functional relationships between them. Within the design solution, the racing track, service areas, and supporting infrastructure are organized in accordance with the existing terrain conditions (Wilson & Gallant, 2000; Hirt, 2014) and the functional and safety requirements of the facility. The designed karting track has an approximate length of 1400 m and an average width of 7 m. The radii of the horizontal curves vary between 10 m and 25 m, while the longitudinal slopes do not exceed 5%, ensuring compliance with the applicable technical requirements for karting tracks. The master plan of the karting complex is presented in Figure 3.

The track alignment represents the main linear element of the project and serves as the basis for the development of the vertical planning solution. The parametric relationship between the track alignment, longitudinal profile, and design surfaces in the Autodesk Civil 3D environment allows the simultaneous determination of design elevations, longitudinal and cross slopes, and the adaptation of the track geometry to the existing terrain.

The applied approach enables smooth transitions between the different functional elements and contributes to the optimization of earthworks and rational terrain utilization while complying with the relevant regulatory requirements. The digital design environment also allows rapid updates of the design model when geometric or elevation parameters are modified and ensures continuous control of design elevations and slopes in different parts of the complex. The method is applied not only to the racing track but also to the adjacent functional areas, including the parking area (Figure 4).

The developed project model provides a geodetic basis for layout setting-out and control during the construction phase. The integrated digital model enables the direct use of design data for field staking and supports geodetic

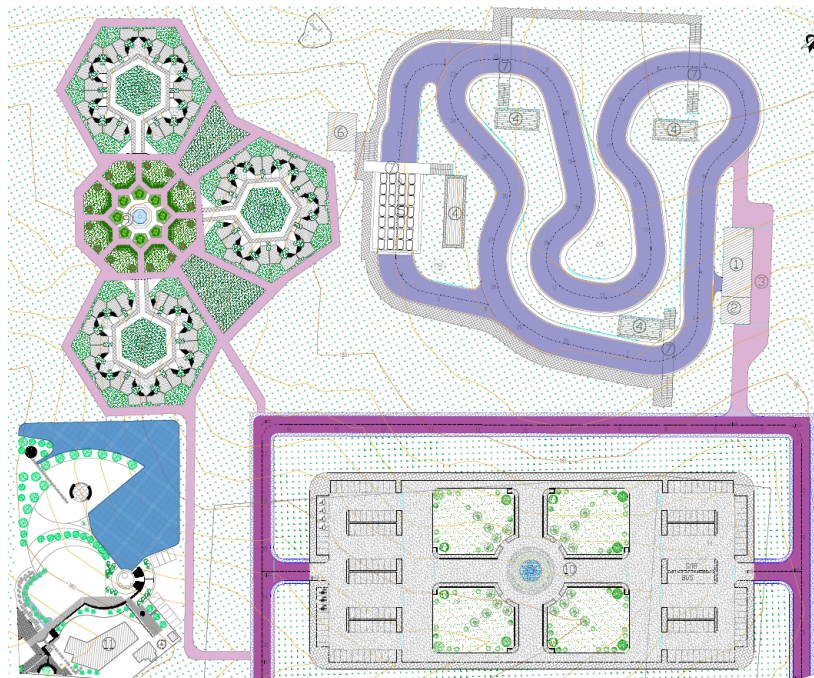


Figure 3. Master plan of the karting complex (source: author's compilation (Autodesk Civil 3D))

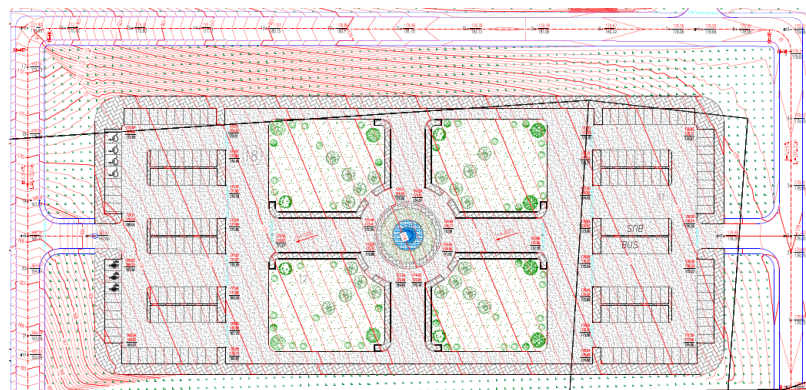


Figure 4. Vertical planning of the parking area (source: author's compilation (Autodesk Civil 3D))

monitoring of construction works to ensure the required design accuracy.

The comparison between the existing terrain surface and the designed surface demonstrates that the automated design model contributes to the optimization of earthworks and improves the coordination between horizontal alignment and vertical planning elements.

4.1. Use of Autodesk Civil 3D in the design process

The proposed design was developed within a specialized digital environment using the Autodesk Civil 3D software package in accordance with the recommended functionalities and workflows described in the official user documentation (Autodesk, 2024). The software environment enables the processing, modelling, and management of geodetic data, digital terrain models, and design elements within an integrated digital workspace.

A key element of the proposed approach is the relationship between the alignment, longitudinal profile, and design surfaces. This relationship is implemented through the parametric modelling capabilities of the Autodesk Civil 3D environment (Autodesk, 2024). The alignment serves as the basis for generating the longitudinal profile and applying standard cross-sections, through which the design surfaces are formed and the design elevations, longitudinal slopes, and cross slopes are determined. Any modifications in geometry or elevation parameters are automatically reflected in the associated project elements, enabling rapid evaluation and optimization of design alternatives.

To illustrate the automated approach, Table 1 presents the relationships between the main design elements and their corresponding automated functions in the Autodesk Civil 3D environment.

An additional advantage of the Autodesk Civil 3D environment is its ability to support data exchange between different software platforms and project stakeholders. The

Table 1. Main design elements and automated functions in Autodesk Civil 3D

Design element	Tool in Autodesk Civil 3D	Role in the design process
Alignment	Alignment	The main linear element used for defining the track layout and generating profiles and parametric design relationships
Longitudinal profile	Profile (surface and layout)	Determination and control of existing and design elevations and longitudinal slopes
Typical cross-sections	Assemblies	Definition of the structural cross-section and design cross slopes
Corridor design surfaces	Corridor surfaces	Automated generation of design surfaces for vertical planning

developed design model can be exported and shared using commonly applied formats such as DWG and LandXML, while interoperability with BIM-based environments can also be facilitated through formats such as IFC. However, challenges may arise when project participants use different software platforms or rely on conventional CAD-based workflows without BIM capabilities. This situation is particularly relevant when project information is transferred to contractors and other stakeholders who primarily use conventional CAD-based documentation rather than BIM-enabled workflows. In such cases, part of the parametric relationships and associated design intelligence may not be fully preserved during data transfer. Therefore, careful management of data exchange procedures and the use of standardized formats are essential for maintaining consistency and accuracy throughout the investment design process.

The use of an integrated digital design environment enables the implementation of a consistent digital design workflow in which geodetic data are directly applied in the development and updating of design solutions. This ensures continuous control and updating of project information within the investment design process. In the present study, these functionalities are adapted to the specific requirements of geodetic support.

4.2. Analysis of the efficiency of automated vertical planning

The application of automated vertical planning was evaluated through a comparative analysis between a traditional manual design method and automated modelling within the Autodesk Civil 3D environment. The evaluation was based on three main indicators: design update time, number of design iterations, and consistency between horizontal and vertical design elements.

This analysis is based on a real engineering project with specific geometric parameters of the racing track and associated service areas, enabling a quantitative comparison between the traditional and automated design approaches under practical investment design conditions.

The results indicate that the use of parametric design relationships and an integrated digital terrain model significantly reduces the need for subsequent design corrections and improves the reliability of the design solutions (Maune, 2007; Shan & Toth, 2018). The parametric relationship between alignment, longitudinal profile, and design surfaces enables simultaneous updates of interconnected

project elements and reduces the risk of inconsistencies between different stages of the design process.

The comparative analysis demonstrates that the automated approach reduces the time required to update the project solution by approximately 30–40% compared to the traditional manual approach. The evaluation was performed based on repeated design update operations carried out during the development of the case study project using both traditional and automated design workflows.

In the analyzed case study, the average time required to update vertical design parameters decreased from approximately 90–100 minutes in the traditional workflow to about 55–65 minutes in the automated environment. At the same time, improved control of longitudinal and cross slopes is achieved, and earthworks are optimized. These results highlight the practical benefits of automated vertical planning for improving the efficiency and reliability of engineering design workflows in geodetically supported infrastructure projects.

In addition to the time required for design updates, the efficiency of the proposed workflow was also evaluated with respect to the number of design iterations required to achieve the final vertical planning solution. In traditional design workflows, adjustments to the longitudinal profile and cross sections require repeated recalculation and manual updating of related elements. In contrast, the parametric modelling environment of Autodesk Civil 3D allows automatic updating of interconnected design components. The main differences between the traditional and automated design iteration processes are summarized in Table 2.

Table 2. Comparison of traditional and automated vertical planning workflows

Design stage	Traditional workflow	Automated workflow in Autodesk Civil 3D
Initial vertical planning	Manual profile design	Parametric profile creation
Adjustment of slopes	Recalculation of profiles	Automatic profile update
Cross-section update	Manual redrawing	Automatic corridor update
Earthwork estimation	Recalculation of volumes	Automatic volume update
Total design iterations	5–6	2–3

Table 3. Comparison of the main characteristics of traditional and automated vertical planning approaches

Criterion	Traditional design approach	Automated design in Autodesk Civil 3D
Design workflow	Manual calculation and separate processing of plan and profile elements	Integrated digital workflow with parametric relationships between design elements
Update of design parameters	Requires manual recalculation and adjustment of multiple design elements	Automatic update of interconnected design elements
Consistency between horizontal and vertical planning	Possible inconsistencies between plan and profile elements	Automatic synchronization between alignment, profiles, and surfaces
Time required for design updates	Relatively high due to manual adjustments	Reduced by approximately 30–40%
Earthworks optimization	Limited ability to quickly evaluate design alternatives	Faster evaluation and optimization using digital terrain modelling

The number of design iterations presented in Table 2 was estimated based on the typical sequence of profile adjustments and terrain optimization steps required to obtain the final vertical planning solution in the analyzed case study.

The comparison shows that the use of parametric design relationships significantly reduces the number of necessary design iterations. While the traditional workflow requires multiple recalculations and manual updates of design elements, the automated approach enables simultaneous modification of related components, resulting in a more efficient and flexible design process.

To further illustrate the differences between the traditional and automated design approaches, Table 3 presents a comparison of their main characteristics.

The comparison presented in Table 3 highlights the advantages of automated vertical planning in terms of design efficiency, consistency of design parameters, and optimization of terrain modelling. These results confirm that the use of parametric design relationships within a digital terrain modelling environment significantly improves the efficiency of vertical planning workflows in engineering design projects. The obtained results also demonstrate the effectiveness of the proposed digital design model as a tool for increasing productivity and accuracy in the design of linear sports facilities.

4.3. Discussion

The obtained results provide a practical evaluation of the role of automated vertical planning within an integrated geodetic design workflow. The application of the proposed design approach demonstrates high efficiency in projects with a clearly defined linear structure and a reliable digital terrain model. The accuracy of the obtained design solutions largely depends on the quality and density of the input geodetic data, as well as on the correctness of modelling the existing terrain surface. Inaccuracies in the digital terrain model may lead to local deviations in the determination of design elevations and may require subsequent design adjustments.

Despite the significant advantages of automated vertical planning, the design process remains dependent on the correct definition of parametric relationships and design constraints. In complex projects, conflicts may occur

between alignments, profiles, corridor components, and generated design surfaces, particularly when modifications are introduced during later design stages. In such situations, automated updates may produce unintended geometric inconsistencies or local deviations that require engineering review and manual correction. Therefore, automated modelling should be regarded as a decision-support tool rather than a fully autonomous design process. Regular verification of design elevations, slopes, surface continuity, and earthwork calculations remains essential for ensuring the reliability and technical feasibility of the final design solution.

The results confirm the potential of integrating geodetic data and parametric design tools within a unified digital environment, which is increasingly recognized as a key direction in contemporary geospatial engineering. This integration also contributes to the methodological development of geodetic support within digital infrastructure design environments.

The proposed method is particularly suitable for linear engineering and sports facilities where coordinated horizontal and vertical planning is required. In projects characterized by a highly fragmented spatial structure or limited availability of input data, the efficiency of parametric design relationships may decrease and therefore additional expert interpretation may be required.

In addition to the technical advantages of automated vertical planning, economic considerations should also be taken into account. The implementation of automated vertical planning requires an initial investment in specialized software, staff training, and adequate computer hardware capable of processing large geospatial datasets. These factors may represent a limitation for small organizations or projects with restricted budgets. However, the results obtained in the present study indicate that the reduction in design update time, the lower number of design iterations, and the improved consistency of project information can partially compensate for these initial costs. Consequently, the economic benefits of automated design workflows become increasingly significant as project complexity and the frequency of design modifications increase.

Although the case study presented in this research focuses on a karting complex, the proposed methodology applies to a wider range of linear infrastructure projects, including access roads, recreational tracks, parking areas,

and other small-scale transport facilities where coordinated horizontal and vertical planning is required.

Nevertheless, the integrated digital approach creates favorable conditions for the development of consistent digital workflows in the investment design process and supports the broader implementation of digital geodetic methods in engineering practice.

Although the proposed approach demonstrates significant advantages for automated vertical planning, several limitations should be considered, mainly related to the availability and quality of input geospatial data. In projects where the available survey data are limited or where the terrain is highly fragmented, additional engineering interpretation may be required. Future research may focus on integrating automated vertical planning with advanced geospatial data sources such as UAV photogrammetry and LiDAR, as well as on evaluating the application of the proposed approach to other types of linear infrastructure projects.

5. Conclusions

This study demonstrates the effectiveness of an integrated geodetic approach based on automated vertical planning and digital terrain modelling in the design of a karting complex. The developed design approach enables simultaneous determination and control of design elevations, longitudinal and cross slopes, as well as optimization of earthworks within the project area.

The results indicate that the integration of parametric design relationships within a digital design environment significantly improves the coordination between horizontal and vertical planning elements and reduces the need for subsequent design corrections. The proposed methodology establishes a direct connection between the design model, geodetic setting-out, and geodetic control during the construction phase.

The comparative analysis shows that the automated design approach reduces the time required to update the project solution by approximately 30–40% compared to traditional manual methods. These results highlight the advantages of integrated digital design environments for improving efficiency and accuracy in the planning and development of linear sports facilities.

The presented approach highlights the potential of integrated geodetic modelling as a practical tool for supporting digital design workflows in contemporary investment planning within the broader context of the Geodesy 4.0 concept. The proposed methodology also demonstrates how geodetic data can be directly integrated into parametric design environments, enabling more efficient coordination between terrain modelling and infrastructure design processes. Furthermore, the proposed approach can support the implementation of digital geodetic workflows in infrastructure planning and can be applied to other types of linear infrastructure projects requiring coordinated horizontal and vertical planning. The proposed

approach contributes to the development of integrated digital methodologies for geodetic support in contemporary infrastructure design. The study also highlights the importance of high-quality geodetic input data, reliable digital terrain modelling, and standardized data exchange procedures for achieving consistent design results. Although automated modelling significantly improves design efficiency, engineering supervision remains necessary for validating design solutions and resolving potential conflicts between interconnected project elements. These findings demonstrate that the successful implementation of automated vertical planning depends on the balanced integration of geodetic expertise, digital technologies, and engineering judgment.

Author contributions

Ani Stefanova conceived the research concept, supervised the study as thesis advisor, and contributed to the methodological framework and interpretation of the results. Ana Dimitrova carried out the geodetic data processing, developed the digital terrain model, and prepared the engineering design model in Autodesk Civil 3D as part of her diploma research. Both authors contributed to the analysis of the results and the preparation of the manuscript.

Disclosure statement

The authors declare that they have no competing financial, professional, or personal interests that could have influenced the work reported in this paper.

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