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3d Modeling of Emergency Helicopter Landing Sites or HEMS Using Integrated LiDAR and Photogrammetric Data

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Abstract

This article presents a method for 3D modeling and an analysis of potential emergency helicopter landing sites using integrated LiDAR and photogrammetric data to support Helicopter Emergency Medical Service (HEMS) operations. This method integrates airborne laser scanning data, high-resolution digital terrain and surface models, and advanced GIS tools to evaluate terrain conditions, detect obstacles, and model obstacle limitation surfaces in accordance with ICAO and national aviation regulations. This method was also tested on a section of the A4 motorway (Wrocław–Opole), identifying the most operationally favorable location. The results demonstrate the effectiveness of combining 3D geospatial data with GIS-based analytical procedures in supporting decision-making processes related to helicopter landing site planning. This approach can be applied to other regions and transport infrastructures to enhance emergency response capabilities. Moreover, it provides a robust framework for integrating geospatial analysis into aviation safety and urban planning initiatives.

Keywords: 3D data, airborne laser scanning, GIS, helicopter landing sites, HEMS, spatial analysis

1. Introduction

Ensuring the possibility of rapid and safe landing of Helicopter Emergency Medical Service (HEMS) aircraft and other medical rescue units is a key element of effective emergency response. In operations related to providing assistance to victims of traffic accidents, disasters, or sudden illnesses, the time and accuracy of locating the incident site play a decisive role in the life-saving process (Wiatrowski et al., 2019). In operations outside designated landing sites – particularly in densely urbanized, mountainous, or otherwise hard-to-reach areas – it is essential to quickly identify a location that allows safe emergency or intervention landings while maintaining the operational safety standards defined for medical aviation (EASA, 2021).

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Traditionally, the selection of a landing site relies on the pilot's knowledge and experience, visual assessment of the area, and real-time evaluation by the crew (Holt, 2000). Although this method is often sufficient, it remains prone to errors due to perceptual limitations, weather conditions, or time of day. Modern approaches to planning and analyzing emergency landing sites increasingly utilize geospatial data, integrating topographic information, photogrammetric data, and point cloud data obtained using LiDAR (Light Detection and Ranging) technology (Herban et al., 2017).

The rapid development of spatial imaging technologies, including terrestrial and aerial 3D scanning, along with the growing availability of high-resolution satellite and photogrammetric data, provides new tactical and analytical opportunities in HEMS landing planning (Remondino et al., 2014). Three-dimensional data allow for precise representation of terrain, slope analysis, identification of terrain obstacles (e.g., trees, power poles, buildings), and accurate assessment of approach and departure areas. Combined with Geographic Information Systems (GIS) tools and spatial analysis algorithms, these data can serve as the basis for automated or semi-automated procedures supporting decision-making by rescue helicopter crews (Longley et al., 2015; Małecki et al., 2022).

The scientific literature emphasizes that the limited availability of safe landing sites significantly affects HEMS effectiveness, especially in densely populated urban areas (Bledsoe et al., 2006). Proper planning and early identification of potential landing sites can significantly reduce the time to reach the patient and increase operational safety (Kadıoğlu et al., 2020). Modern approaches to planning and analyzing emergency landing sites increasingly rely on geospatial data, integrating topographic, photogrammetric, and LiDAR-derived point cloud information (Herban et al., 2017). Research also addresses the identification of safe landing zones in real time using airborne LiDAR data (Massoud et al., 2023), as well as algorithms evaluating terrain based on slope, dimensions, and shape (Mertova & Bures, 2021). Furthermore, terrain analysis using interferometric radar constitutes an important complement to these methodologies (Shimkin et al., 2020). In terms of cartographic usability, studies on operational maps for rescue helicopter flights and their reception by users are also key (Wielebski & Medyńska Gulij, 2023). However, few studies focus on a comprehensive methodology that integrates modern spatial data with operational requirements and rescue helicopter safety standards. Previous research has analyzed, among other factors, the impact of topography, land cover, and technical infrastructure on the selection of safe operational zones (Hassan et al., 2019).

In recent years, the development of 3D technologies combining LiDAR and photogrammetric data has opened new possibilities for terrain analysis in terms of landing zones. A hybrid approach combining LiDAR and photogrammetric point clouds using SfM (Structure from Motion) and machine learning methods ensures high accuracy of 3D models, which is crucial for identifying obstacles and terrain features (Maskeliūnas et al., 2025).

Recent reviews of UAV (Unmanned Aerial Vehicle) technologies indicate that the combination of UAV photogrammetry and LiDAR allows for fast, accurate, and high-resolution spatial data acquisition, which performs well in diverse terrain conditions (Kovanič et al., 2023).

The integration of data from multiple sources – TLS (Terrestrial Laser Scanning), UAV-LiDAR, and mobile sensors – has become standard in creating comprehensive 3D models of buildings and infrastructure (Altuntaş, 2024).

Comparisons of LiDAR and image-matching methods indicate their complementarity depending on terrain conditions and the required level of accuracy (Carrilho et al., 2020).

As a result, the integration of laser scanning, UAV-LiDAR, TLS, and photogrammetry, supported by point cloud analysis and GIS environments, currently represents the most effective approach for creating reliable spatial models. Such 3D data allow for the development of automated procedures to identify safe HEMS landing sites, even in challenging terrain or urban environments.

The aim of this article is to present a method for 3D modeling and analysis of potential emergency helicopter landing sites for Helicopter Emergency Medical Service (HEMS) operations, based on integrated LiDAR and photogrammetric data. The proposed approach combines technical and operational aspects, taking into account both aviation parameters and terrain constraints. The developed method can serve as a practical tool to support HEMS crews in real time, enhancing operational safety, objective decision-making, and the effectiveness of rescue operations.

2. Method

The method developed for selecting locations and modeling emergency landing sites for helicopters was designed as a multistage, repeatable, and fully scalable analytical process based on the integration of elevation data, GIS tools, and geometric modeling compliant with aviation regulations. This approach enables objective assessment of the terrain and identification of locations that meet HEMS operational requirements and ICAO standards.

The main assumptions of the method include: the use of publicly available high-resolution ALS, Digital Terrain Model (DTM), and Digital Surface Model (DSM) elevation data; the application of standardized terrain assessment criteria (slope, presence of obstacles, accessibility); modeling of obstacle limitation surfaces in accordance with ICAO Annex 14 and national Civil Aviation Authority (CAA) guidelines; and the possibility of automating analyses within a GIS environment.

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The developed method for selecting and modeling emergency HEMS helicopter landing sites using 3D data consists of the following key stages: identifying existing landing sites, selecting the study area, acquiring a 3D data, spatial analysis in a GIS environment, and creating obstacle limitation surfaces (Figure 1).

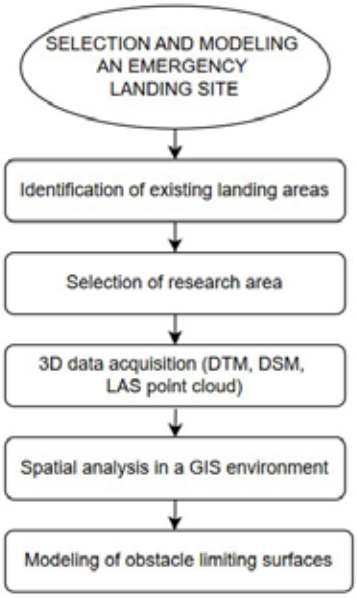

Figure 1. Scheme for selecting and modeling emergency landing sites for air ambulance helicopters.
Source: the authors' own work.

2.1. General assumptions of the developed method

The aim of the method was to develop a repeatable framework for selecting and modeling emergency HEMS landing sites based on:

- high-resolution 3D data (Digital Terrain Model, Digital Surface Model, point clouds),
- analyzing obstacles and terrain morphology,
- modeling obstacle limitation surfaces in accordance with ICAO and CAA guidelines,
- assessing operational and logistical accessibility.

The method also assumed the possibility of replicating results in other regions of the country without the need for field measurements, relying solely on publicly available national datasets.

According to the Polish Aviation Law (2002), a landing site is an area designated for aircraft take-offs and landings that does not require registration in the airport registry. In Poland, landing sites include: airplane landing sites, general helicopter landing sites, hospital-based landing sites, and municipal landing sites. In the context of Helicopter Emergency Medical Service (HEMS) missions, hospital-based and municipal landing sites are the most relevant; however, HEMS helicopters also land in ad hoc locations, particularly on national roads and highways.

Helicopter landing sites must meet requirements regarding: the dimensions of the Final Approach and Take-Off Area (FATO), obstacle limitation surfaces, ground load-bearing capacity and evenness, proper marking, and provision of a safe approach path.

For an EC135 helicopter, the minimum landing zone dimensions during the day are 25 × 25 m, and at night 50 × 25 m. The approach path must be free of obstacles within a 1:6 slope plane. These specifications form the basis for determining the minimum infrastructure requirements.

2.2. Main Stages of the Research Process

The research process consisted of five main stages:

1. Identification of Existing Landing Sites

Based on the Civil Aviation Authority (CAA) registry (as of 2023), a map of aerodrome landing area, heliport, and hospital heliport was created (Figure 2). These data were combined with the national road network, particularly highways, which enabled the identification of a new emergency landing site along a selected section of the A4 motorway between Opole and Wrocław. This approach allowed for a precise spatial analysis in terms of accessibility to rescue incidents.

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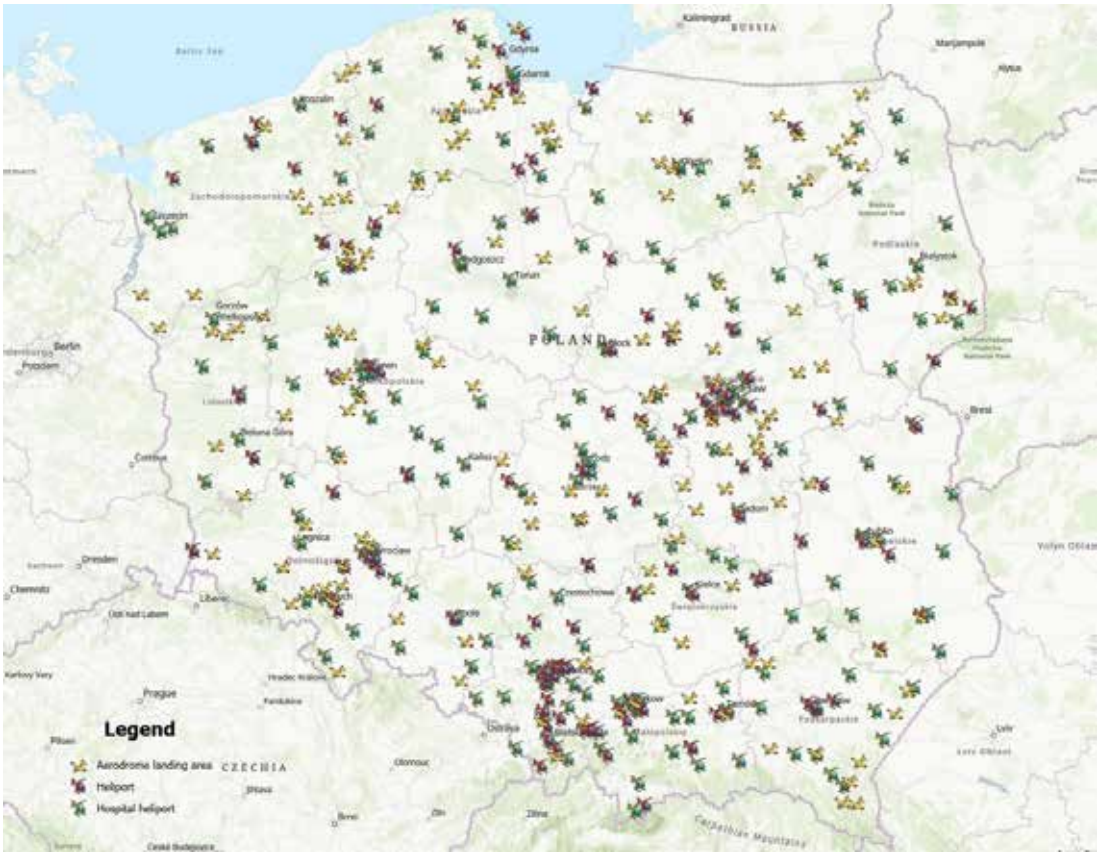

Figure 2. All types of airports in Poland. Source: the authors' own work.

2. Selection of the Study Area

A section of the A4 motorway was selected (Figure 3), characterized by a high number of HEMS interventions and convenient access for emergency services. The analysis took into account:

- building density,
- proximity to road junctions,
- terrain morphology,
- potential obstacles.

Figure 3. Location of the planned landing sites. Source: the authors' own work..

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3. Acquisition of 3D Data

Data were obtained from the resources of the Main Office of Geodesy and Cartography (GUGiK), including LAS/LAZ point clouds (density 10–12 pts/m^2), a DSM in the PL-EVRF2007-NH vertical reference frame, and a 1 m resolution DTM.

The processing workflow included point classification (ground, buildings, vegetation, infrastructure), noise filtering, surface interpolation, and height normalization (DSM minus DTM).

4. Spatial Analysis in a GIS Environment

The spatial analysis was performed in the ArcGIS Pro software environment. Based on the landing site evaluation criteria (Table 1), the following operations were carried out: a terrain slope analysis, a point and linear obstacle assessment, generation of safety buffers, a simulation of approach surfaces (1:6 and 1:2), and visibility modelling.

Table 1. Criteria for evaluating landing site locations

Criterion	Acceptable Value	Optimal Value
Terrain slope	≤ 6°	≤ 2°
FATO area	≥ 25×25 m	≥ 30×30 m
Obstacles in approach path (1:6)	No obstacles > 10 m within 60 m	No obstacles
Access road distance	≤ 300 m	≤ 150 m

Source: the authors' own work.

5. Modeling Obstacle Limitation Surfaces

The operation of municipal landing sites requires continuous monitoring and maintenance of the surface throughout the year. During the spring and summer seasons, the grass must be mowed regularly, and cut vegetation should not be left on the landing area. In winter, snow removal of both the landing site and access road is necessary to ensure safe take-offs and landings. Regardless of the season, the surroundings of the landing site should be monitored for new obstacles.

The take-off and landing axis should align with the prevailing wind directions, with an allowable deviation of up to 45° to the right or left. The approach area must be flat, level, dust-free, and free of obstacles. The minimum surface dimensions are 25 × 50 m, and paving is not mandatory.

Obstacles along the take-off and landing axis must not exceed the height defined by the obstacle limitation surface, inclined at a 1:6 slope relative to the landing site level (Figure 4), expanding at an angle of 30° from the lateral edges of the approach area. In the immediate vicinity of the axis, point obstacles such as masts, chimneys, or isolated trees should be avoided. Lateral obstacles must remain within an area defined by a plane inclined 1:2 relative to the terrain level (Figure 5).

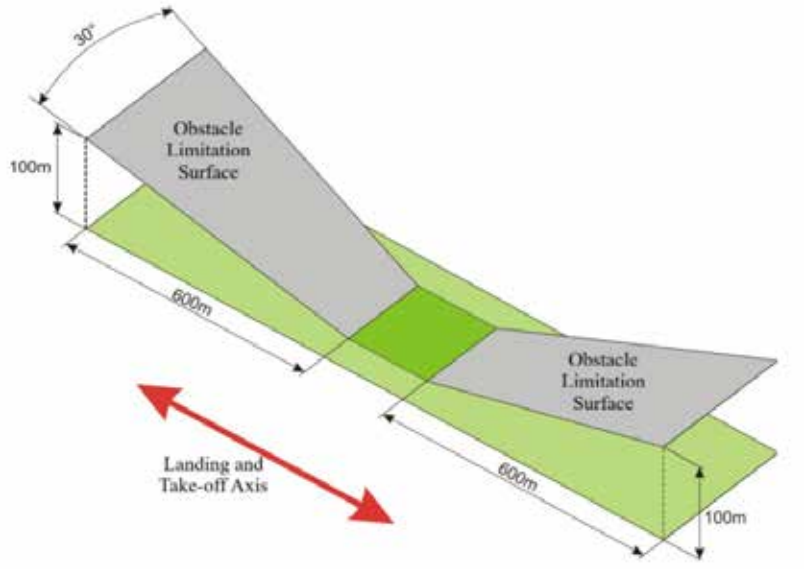

Figure 4. Diagram of a municipal site. Adopted from: https://www.lpr.com.pl/static/upload/store/Ladowiska/Miejsca_gminne/Miejsca-gminne-wytyczne-dla-gmin.pdf. Copyright by Publisher.

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Figure 5. Obstacle limitation surfaces along the takeoff and landing axis. Adopted from: https://www.lpr.com.pl/static/upload/store/Ladowiska/Miejsca_gminne/Miejsca-gminne-wytyczne-dla-gmin.pdf. Copyright by Publisher.

Based on ICAO standards (2014) and CAA guidelines (2014), the following surfaces were designed: the approach surface, take-off climb surface, side surfaces, and the FATO and TLOF (Touchdown and Lift-Off Area) surfaces.

Surface parameters:

- 1:6 slope for the approach surface,
- 30° lateral expansion,
- permissible obstacle height modeled as a function of distance.

As a result of the conducted studies, a complete three-dimensional model of the emergency landing site was developed, integrated with the terrain model and obstacle analysis. The results include terrain analysis, geometric modeling, and visualization of the safety surfaces.

3. Results

3.1. Topography Analysis and Data Preparation

The area of Sarny Wielkie, located in Kędzierzyn-Koźle County, is characterized by favorable geodetic conditions – the terrain is flat with minimal height variation (≤1.2 m over a distance of 50 m). After removing classification errors and integrating the LiDAR data, an accurate DTM with a resolution of 0.5 m was generated. The terrain analysis showed that the slopes do not exceed 2%, which meets the requirements specified for municipal landing sites.

3.2. TLOF Landing Site Design

Based on the spatial data, a TLOF surface with dimensions of 50 × 25 m and an elevation of 152 m a.s.l. was designed. The surface slope analysis showed values of 0.8% in the longitudinal direction and 0.6% in the transverse direction, which remain within CAA standards. The TLOF area was positioned with an approach direction of 270°, ensuring optimal conditions with respect to prevailing regional winds.

3.3. Obstacle Limitation Surfaces (OLS)

In the next stage, an OLS model was developed, including the approach, take-off, and side safety surfaces (Figure 6). For the approach, a slope of 1:6 and a length of 600 m were adopted, while the side surfaces were inclined at 1:2 and expanded at an angle of 30°. Spatial analysis showed that within a 600 m radius from the TLOF center point, there are no obstacles exceeding the safety planes. Only minor infrastructure elements, such as lighting poles and low buildings, were within the permissible height limits.

Figure 6. Designed surfaces limiting obstacles in 2D. Source: the authors' own work.

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The visualization of the model in ArcGIS Pro (Figures 7–8) allowed for a comprehensive assessment of the surrounding environment. By using 3D layers, a spatial representation of the approach zones was obtained, enabling their further transfer to MATLAB.

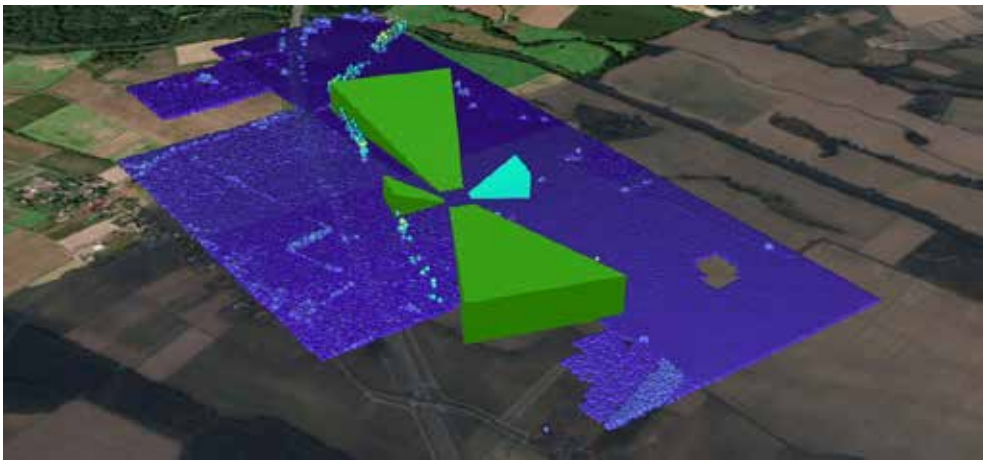

Figure 7. Designed surfaces limiting obstacles in 3D. Source: the authors' own work.

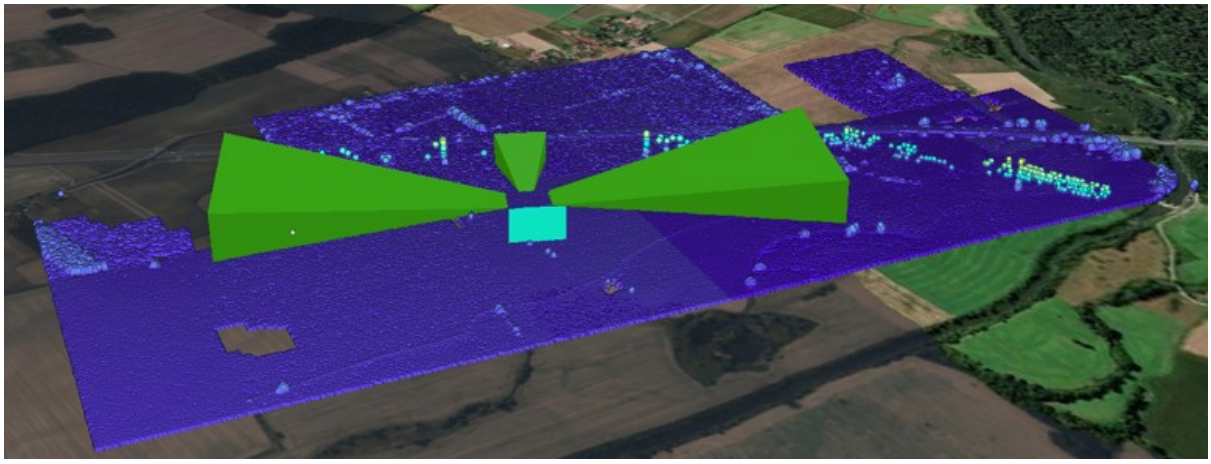

Figure 8. Designed surfaces limiting obstacles in 3D. Source: the authors' own work.

3.4. Three-Dimensional Modeling in MATLAB

After exporting the data from ArcGIS Pro, a geometric analysis and validation of the model were carried out in MATLAB. The process began with the application of Delaunay triangulation to represent the OLS (Obstacle Limitation Surface) planes and generate a spatial point mesh, resulting in a realistic 3D terrain model. This approach is well established in computational geometry for reconstructing surfaces from point clouds (e.g., Lopez-Fernandez et al., 2017).

In MATLAB, advanced functions such as trisurf and scatter3 were employed to visually overlay the LiDAR point clouds on the triangulated OLS surfaces (Figure 9), providing an intuitive and precise way to inspect for potential safety violations. By examining the "fit" between the mesh and the raw LiDAR data, we were able to verify that no terrain elements intruded into the protected safety volumes. The highest obstacle heights remained below 90% of the permissible OLS height, which ensures compliance with safety constraints.

This hybrid workflow – combining geospatial preprocessing in GIS, mesh generation via Delaunay triangulation, and 3D visualization and validation in MATLAB – significantly enhances the fidelity of terrain representation and the rigor of safety assessment in HEMS landing site planning.

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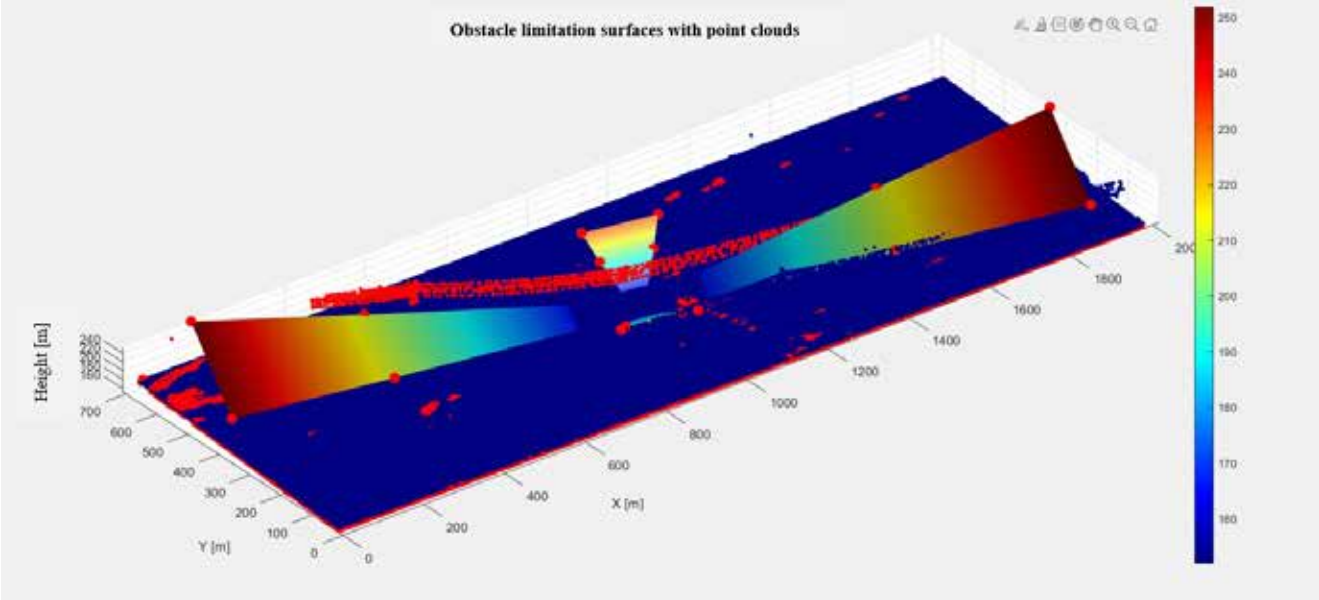

Figure 9. Resulting airspace model (prohibited zones – red color). Source: the authors' own work.

3.5. Validation of Results and Comparison of Computational Environments

The comparison of results between ArcGIS Pro and MATLAB showed high consistency in the data – the deviation in elevation values for key boundary points did not exceed ±0.04 m. Visual differences between the models were due to different interpolation methods: ArcGIS Pro generates continuous rasters, while MATLAB operates on irregular triangle triangulation. However, both environments provided convergent geometric results and conclusions regarding safety.

3.6. Final Safety Assessment

Based on the combined analyses, it was determined that the Sarny Wielkie location meets all formal and technical requirements for use as an emergency HEMS landing site. The approach area remains free of colliding obstacles, and the geometric parameters of the TLOF and OLS comply with CAA (2014) regulations and EASA (2021) guidelines. The integration of LiDAR data, GIS, and numerical modeling confirmed the high accuracy and reliability of the applied method, enabling its practical implementation in the spatial planning of emergency services.

4. Discussion of Results

The obtained results are consistent with the latest trends in scientific literature regarding the use of spatial technologies (LiDAR, GIS, 3D modeling) in the context of emergency landing sites (HEMS). Our approach, integrating OLS analysis, TLOF, and LiDAR point clouds within ArcGIS Pro and MATLAB environments, confirms the effectiveness of hybrid methods and their operational significance.

First, the study by Massoud et al. (2023) demonstrated that a real-time algorithm can identify Safe Landing Zones (SLZ) based on LiDAR data collected from an airborne platform. Their method generates DSM models, slope and roughness maps in flight, and supports pilot decision-making even under limited computational resources. This confirms that the integration of 3D sensing and analytical algorithms – as applied in our study – is practically feasible and effective.

Second, the work by Erskine et al. (2022) analyzes the impact of spatial data resolution on the accuracy of identifying Helicopter Landing Zones (HLZ). The authors compare models with resolutions ranging from 1 m to 30 m and show that as resolution decreases, the accuracy of HLZ identification declines. This finding supports our observations – the use of a high-precision DTM (0.5 m resolution) significantly enhances the reliability of topographic analysis and the geometry of approach areas.

A third important aspect is the use of alternative measurement technologies. Shimkin et al. (2020) presented an interferometry-based radar system for real-time terrain assessment, allowing slope and obstacle detection directly from the helicopter. Their approach is an excellent complement to LiDAR-GIS methods, particularly in conditions where optical data are limited (e.g., poor visibility or night operations).

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A fourth aspect is the cartographic user perspective. Wielebski & Medyńska Gulij (2023) conducted an evaluation of thematic maps that can be used by HEMS crews, analyzing readability, graphical appeal, and operational usability. Their results emphasize that creating a technically correct model is not enough – the maps must also be understandable and practical for end users.

In light of the above studies, our research makes the following contributions:

1. Comprehensive approach – we combine LiDAR data, OLS analysis, and 3D modeling, providing a more holistic operational view than many previous studies.
2. High data resolution – the DTM model with 0.5 m resolution ensures higher accuracy than lower-resolution models, directly impacting risk assessment and safety.
3. Validation across computational environments – comparison between ArcGIS Pro and MATLAB shows that different tools yield consistent, convergent results; such redundancy increases method reliability.
4. Operational usefulness – our method can serve as the basis for practical implementation procedures, supporting spatial planning of HEMS landing sites by emergency services.

Limitations and future directions remain: despite the high resolution and geometric accuracy, we did not assess the structural load-bearing capacity of the terrain (e.g., the strength of the landing surface), which is crucial for practical rescue operations. Additionally, future research could focus on dynamic real-time SLZ identification – combining LiDAR, radar, and machine learning methods – which could further enhance mission flexibility and safety.

5. Conclusions

The conducted study confirmed that integrating three-dimensional spatial data with GIS tools and the MATLAB environment provides an effective solution for designing HEMS emergency landing sites. The combination of geospatial analysis with numerical modeling enabled accurate representation of terrain morphology, identification of obstacles, and assessment of compliance with CAA and EASA regulations.

The analyzed location in Sarny Wielkie meets all safety requirements – the obtained geometric parameters of OIS and TLOF demonstrate the feasibility of operational use of this site within HEMS operations. The developed method is universal and can be implemented in other regions of Poland, providing a foundation for a national system of emergency landing sites. Further research should focus on automating the site selection process and analyzing dynamic terrain models under variable atmospheric conditions.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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