CASE STUDY OF ENVIRONMENTAL NOISE MONITORING AND SPATIAL MODELLING THROUGH GEOMATIC TECHNIQUES

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ABSTRACT

The study of outdoor acoustic wave propagation requires accurate three-dimensional representation of the environment in which sound propagates. Geomatic techniques, including Light Detection and Ranging (LiDAR), Global Navigation Satellite Systems (GNSS), drone photogrammetry, and (Geographic information systems) GIS, provide the spatial data needed to feed acoustic simulation models with high-resolution Digital Terrain Models (DTMs) and georeferenced information on obstacles, barriers, and land cover. This paper investigates the integration of geomatic methods with acoustic propagation modelling tools, with reference to the ISO 9613-2 standard and the CNOSSOS-EU framework. This case study, conducted in a semi-rural area near Rome (Italy), demonstrates the workflow from DTM acquisition to noise map generation, comparing three software platforms: SoundPLAN (3D), dBmap (3D with manual terrain), and dBmap (2D flat-terrain). Results confirm that the quality and resolution of the DTM exert a decisive influence on the accuracy of predicted sound levels: the absence of terrain modelling can lead to prediction errors exceeding 12 dB(A) at the same receiver. This paper discusses current limitations and outlines future directions, including high-resolution LiDAR integration, advanced GIS plugins, shared noise databases, and the potential role of machine learning in acoustic scenario optimization.

Keywords: *acoustic propagation; geomatics; Digital Terrain Model; noise mapping; GIS; ISO 96132; CNOSSOS-EU; SoundPLAN.*

1. INTRODUCTION

The prediction of outdoor sound propagation is a key task in several engineering fields, including environmental acoustics (Yang et al., 2026), assessment of noise pollution (Debnath & Singh, 2018; Yuan et al., 2026), urban planning (Berber Narin et al., 2026), the design of building elements with adequate sound insulation (Bahiraei et al., 2026), and occupational safety, where worker exposure to noise must be evaluated (de Andrade et al., 2026). Accurate noise maps are also required by European legislation, notably Directive 2002/49/EC on Environmental Noise, to identify exposed populations, design mitigation measures, and monitor the effectiveness of interventions over time (Dardanelli et al., 2017; Redondo Martinez et al., 2026).

Sound propagation in open environments is governed by a complex interplay of physical phenomena: the geometry of the terrain, the presence of buildings, natural obstacles, vegetation, meteorological gradients and the spatial arrangement of sources and receivers interact in determining the final sound pressure level (Attenborough et al., 2014). For this reason, an acoustic model must not be considered only as a mathematical calculation of attenuation, but as a spatial model in which physical propagation and territorial geometry are inseparable (Tai et al., 2026).

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Classical analytical models, such as ISO 9613-2 (1996) (Chanthima et al., 2026) and the more recent CNOSSOS-EU (2015) (Profumo et al., 2026), provide standardized computational frameworks that reduce this complexity to tractable equations. However, the predictive accuracy of any model depends critically on the accuracy of the terrain representation used as its geometric input.

Geomatics, the science that integrates geodesy, remote sensing, photogrammetry, cartography and Geographic Information Systems (GIS), offers a suite of tools capable of capturing the three-dimensional morphology of terrain and built fabric with accuracies that may range from centimetric to metric scale depending on the acquisition technique, the survey configuration and the processing workflow. Technologies such as aerial and terrestrial LiDAR (Light Detection and Ranging) (Baiocchi et al., 2023; Wehr et al., 1999) satellite photogrammetry and drone-based Structure-from-Motion (SfM) photogrammetry (Alessandri et al., 2021; Alfio et al., 2023; Lo Brutto & Dardanelli, 2017; Nex et al., 2014; Troisi et al., 2019) can generate Digital Terrain Models (DTMs) and Digital Surface Models (DSMs) that, once imported into acoustic software, significantly improve simulation realism (Li et al., 2005).

In the context of noise modelling, the geomatic contribution is twofold. First, it provides spatial input data: terrain elevation, building footprints and heights, obstacle geometry, land-cover information, source positions and receiver locations. Secondly, it supports the representation and interpretation of results, since sound level grids and iso-level contours are geospatial products that can be integrated with land-use maps, population distribution, sensitive receptors and planning constraints. This makes acoustic modelling a genuinely geo-acoustic process, where the quality of the predicted noise map depends on both the acoustic formulation and the spatial reliability of the model.

Despite this evident complementarity (Adamiak, 2024), the integration of geomatic workflows with acoustic modelling practice remains under-documented in the scientific literature, particularly for practicing engineers who must choose among competing software tools with very different terrain-handling capabilities. This paper addresses that gap by: (i) reviewing the theoretical foundations of outdoor acoustic propagation and the principal normative models; (ii) describing the geomatic pipeline from data acquisition to DTM generation; (iii) applying that pipeline to a real case study and comparing the outputs of three software environments; and (iv) discussing implications for future integrated practice.

The specific aim of the work is to assess how different levels of terrain representation affect acoustic prediction. The underlying hypothesis, developed from this paper's work, is that the lack of altimetric detail may generate significant errors in outdoor noise simulations, especially where slopes, ridges, depressions or natural obstacles produce diffraction and acoustic shadow zones. The comparison between a full 3D model, a manually reconstructed 3D terrain and a simplified 2D flat-terrain model is therefore used to isolate the role of geomatic input data varying only the geometric description of the terrain, while keeping source characteristics, receiver positions and environmental parameters unchanged.

1.1. Fundamentals of Acoustic Wave Propagation

Sound is a mechanical disturbance propagating through an elastic medium without net mass transport. It is generated by a vibrating body that transfers mechanical energy to the surrounding medium. The acoustic wave reaches a receiver through pressure variations, and its propagation is characterized by frequency, amplitude, propagation speed and energy distribution. In engineering applications, sound is commonly described through logarithmic levels expressed in decibels, including sound power level (1a), sound pressure level (1b), sound intensity level and other related quantities.

$$Lw = 10 \log10(W / W0) \quad [dB] \qquad (1a)$$

$$Lp = 10 \log10(p^2 / p0^2) = 20 \log10(p / p0) \quad [dB] \qquad (1b)$$

The distinction between source-related and receiver-related quantities is important: the sound power level describes the acoustic emission capacity of the source, while the sound pressure level describes the acoustic effect at a receiver position. This distinction is essential in predictive modelling because the same source power can generate different receiver levels depending on propagation distance, directivity, terrain, atmospheric conditions and obstacles.

The fundamental propagation equation (2) links the sound pressure level at a receiver to the source power level and the total attenuation along the path (Garai, 2001):

$$LP = LW + DI - ATOT \qquad (2)$$

where LP is the A-weighted sound pressure level at the receiver [dB(A)], LW is the sound power level of the source [dB(A)], DI is the directivity index, and ATOT (3) is the total attenuation [dB].

The attenuation term combines contributions from geometric divergence (AD), atmospheric absorption (AATM), ground effect (AGR), barrier diffraction (ABAR), meteorological effects (AMET), and additional factors from vegetation, industrial sites, and residential areas (AV, AS, AH):

$$ATOT = AD + AATM + AGR + ABAR + AMET + AV + AS + AH \quad (3)$$

In ISO-based calculations, the attenuation (4) is often grouped into a more compact expression in which additional effects are included in a miscellaneous attenuation term. This notation can be written as:

$$A = ADIV + AATM + AGR + ABAR + AMISC \qquad (4)$$

where ADIV is the attenuation due to geometrical divergence, AATM is atmospheric absorption, AGR is the ground effect, ABAR is the attenuation caused by barriers or obstacles, and AMISC includes additional contributions such as vegetation, industrial areas and housing areas.

The two formulations are conceptually compatible; the first is more descriptive, whereas the second follows the structure commonly adopted in normative calculation procedures.

Three canonical propagation geometries are distinguished. Spherical propagation (point source in free field) produces intensity decay proportional to the inverse square of distance; cylindrical propagation (linear source or channel effect) produces linear decay; plane-wave propagation (far field of extended sources) maintains constant intensity. Real outdoor scenarios are dominated by spherical propagation modified by all the attenuation terms listed above.

The transition between near field and far field must also be considered. In the near field, close to the source, the spatial distribution of acoustic energy may be irregular and highly dependent on source geometry. In the far field, the propagation pattern becomes more regular and can be represented with simplified analytical formulations. Since the far-field condition depends on wavelength, the same receiver may behave as near-field for some frequencies and far-field for others.

1.2. Principal Normative Propagation Models

Several internationally recognized models operationalize the above framework. Their principal characteristics are summarized in **Table 1.** The ISO 9613-2 model is the most widely used standard for industrial and environmental noise assessment. It is generally applied under favourable or moderately favourable propagation conditions, distances up to 1 km under moderately favorable meteorological conditions (temperature 10–15° C, 70% relative humidity, wind ≤ 5 m/s). The total attenuation (5) is computed as:

$$\mathrm{ATOT} = \mathrm{ADIV} + \mathrm{AATM} + \mathrm{AGR} + \mathrm{ABAR} + \mathrm{AMISC} \qquad (5)$$

where ADIV (6) is:

$$\mathrm{ADIV} = 20 \cdot \log10(\mathrm{d}) + 11\ \mathrm{dB} \qquad (6)$$

where d is the source–receiver distance in meters.

Table 1.
Comparison of outdoor acoustic propagation models.

Model	Origin	Source Type	Meteorology	Complexity	Accuracy	Normative use
ISO 9613-2	International	Generic	Standard conditions	Low	Medium	Widespread normative
CNOSSOS-EU	EU	Multi-source	Simplified	Medium	High	Mandatory in EU
Nord2000	Scandinavia	Multi-source	Advanced	High	Very High	Technical/scientific
Harmonoise	EU (research)	Modular	Simplified	High	High	Basis for CNOSSOS
RLS-90	Germany	Road traffic	Standard	Low	Medium	German national
CRTN	UK	Road traffic	Ignored	Low	Medium	UK national
NMPB	France	Road traffic	Simplified	Medium	High	French national

This expression represents spherical divergence, i.e., the spreading of acoustic energy over an increasingly large surface during propagation. The model's simplicity and widespread software implementation make it the default choice for environmental impact assessments across Europe.

CNOSSOS-EU was developed by the European Commission as a harmonized methodology for strategic noise mapping under Directive 2002/49/EC. It adopts a modular approach (emission‑propagation‑reception) applicable to road traffic, railway, industrial, and aircraft sources, and introduces a simplified meteorological correction factor (Cmet). Nord2000 offers the most physically rigorous treatment available, employing curved-ray tracing to model refraction under realistic atmospheric profiles; it is particularly suited to Scandinavian and complex-terrain scenarios.

Nord2000 offers a more detailed physical treatment of atmospheric effects by employing curved-ray concepts and more advanced meteorological descriptions. It is particularly suitable for complex terrain and atmospheric conditions, but requires more input data and greater modelling effort. Harmonoise, although not adopted as the final European standard, provided the conceptual and scientific basis for CNOSSOS-EU and introduced a modular structure capable of representing barriers, variable ground, reflections and meteorological stratification.

National road traffic models such as RLS-90 (*Richtlinien für den Lärmschutz an Straßen*), CRTN (*Calculation of Road Traffic Noise*) and NMPB (*Méthode Nationale de Prévision du Bruit*) were developed for specific regulatory contexts. Their use is often linked to national procedures and historical datasets. For this reason, the choice of the propagation model should not be based only on nominal accuracy, but on source type, regulatory context, available input data, terrain complexity and the objective of the assessment.

1.3. The Role of Geomatics in Acoustic Simulation

Acoustic simulation software requires a geometric representation of the propagation environment comprising: (i) the bare-ground terrain surface (DTM), (ii) above-ground obstacles including buildings, embankments and barriers (DSM or building footprints with heights), (iii) georeferenced source positions with emission spectra, and (iv) receiver locations. All these inputs must share a consistent spatial reference system. Geomatics provides the acquisition pipeline to generate these inputs. The resulting acoustic outputs, sound level grids and iso-level contour maps, are themselves geospatial products that can be overlaid with population data, land-use maps, and other GIS layers for exposure assessment and planning support (Salomons, 2001).

This paper's framework emphasizes that geomatics is not only a data-acquisition discipline, but also the operational bridge between territorial representation and acoustic prediction. The model construction process starts from georeferenced territorial data, continues with the insertion of sources and receivers in a coherent coordinate system, and ends with the production of noise maps that can be analyzed in GIS. This workflow makes it possible to compare alternative scenarios, assess mitigation strategies, and monitor the evolution of noise exposure before and after interventions.

In engineering practice, this relationship is particularly important because the same acoustic source may produce different sound distributions depending on the spatial model. Terrain morphology, building geometry, vegetation and barriers define the possible propagation paths. Therefore, errors in the spatial model can propagate into the acoustic results and may become one of the main sources of uncertainty in complex environments.

1.4. Terrain Data Acquisition Techniques

This paper distinguishes between traditional surveying instruments, such as GNSS (Global Navigation Satellite System) (Pipitone et al., 2023) and total stations, and more recent three-dimensional acquisition methods such as LiDAR and UAV (Unmanned Aerial Vehicle) photogrammetry. GNSS/RTK (Real Time Kinematics) (Dardanelli & Pipitone, 2021; Jin et al., 2024) surveys are especially useful for defining the coordinates of sources, receivers, barriers and control points. Total stations remain effective in urban or industrial contexts where vertical obstacles, walls, fences or local details must be measured with high precision.

LiDAR is one of the most powerful techniques for acoustic modelling because it produces dense three-dimensional point clouds. Aerial LiDAR allows large-area acquisition and supports the derivation of both DTM and DSM (Digital Surface Model) through point-cloud classification, while terrestrial LiDAR provides very detailed information on local obstacles, façades and infrastructure elements. UAV photogrammetry based on Structure from Motion can provide orthophotos and three-dimensional models at relatively low cost, although its ability to reconstruct the bare ground is reduced in areas with dense vegetation.

1.5. DTM Generation and Preparation

A Digital Terrain Model is a numerical representation of the bare-earth surface, excluding buildings, vegetation and other above-ground objects. Its construction is a crucial phase in acoustic modelling because terrain morphology directly affects the direction, intensity and spatial distribution of sound. Slopes, embankments, ridges and depressions may create diffraction conditions and acoustic shadowing that cannot be reproduced by a flat model.

During DTM generation, a clear distinction must be made between spatial resolution and vertical accuracy. The resolution describes the spacing of grid cells or points, whereas vertical accuracy describes the altimetric uncertainty of the elevation values, often expressed through (Root Mean Squared Error) RMSE. A very dense grid does not automatically guarantee high vertical accuracy, and conversely a coarser but well-controlled dataset may be suitable for preliminary assessment. For local-scale acoustic applications in complex terrain, vertical RMSE values below approximately 0.5 m are desirable, while coarser thresholds may be acceptable for strategic or regional-scale evaluations.

Once raw data are acquired, the processing pipeline involves: (i) point-cloud classification to separate points from vegetation (for LiDAR data) and structures; (ii) spatial interpolation (Triangulated Irregular Network, Inverse Distance Weighting, or Kriging) to generate a continuous raster surface; (iii) quality assessment against independent check points (i.e., target RMSE $\leq$ 0.5 m for acoustic applications); and (iv) format conversion to the input specifications of the acoustic software (ASCII grid, XYZ, etc.).

A clear conceptual distinction must be maintained between the DTM and the DSM. The DTM is used to model the bare ground and is important for ground effect, topographic screening and the relative elevation of source and receiver. The DSM, or equivalent building/vegetation layers, is required to represent above-ground obstacles, surfaces, barriers and elements involved in reflection, diffraction and shadowing. Urban and industrial scenarios often require the simultaneous use of both datasets.

Typical output formats include raster grids such as GeoTIFF or ASCII grid, vector formats such as DXF or shapefile, and point formats such as XYZ. Before importing these data into acoustic software, the model must be checked for coordinate-system consistency, elevation units, redundant geometries, excessive point density and topological errors. A lack of interoperability or a wrong coordinate reference system may compromise the spatial correspondence between terrain, buildings, sources and receivers. The resolution of the model also matters: grids finer than 2 m GSD are recommended for urban contexts, while 5–10 m may be acceptable for open rural terrain (Wechsler, 2007). All layers must share a consistent spatial reference system; in Italy the standard projection is UTM (i.e., Zone 32N: EPSG:32632).

1.6. GIS Integration and Software Interoperability

Modern acoustic simulation platforms (SoundPLAN, CadnaA, Predictor-LimA, NoiseModelling) accept standard GIS vector and raster formats. The interoperability workflow typically proceeds as follows: terrain data are pre-processed in QGIS or ArcGIS; building footprints with height attributes are exported as shapefiles; source geometries are assigned power spectra; and the complete project is imported into the acoustic engine. Output noise grids are then re-imported into GIS for overlay with sensitive receptor layers.

The case study shows that software packages differ substantially in their ability to manage terrain information. SoundPLAN can import and process DTM information and generate a three-dimensional ground model used for subsequent acoustic calculation. Other tools may require manual insertion of elevation points or simplified terrain reconstruction. When terrain is treated in two dimensions or neglected, the model cannot represent physical phenomena such as topographic shadow zones, diffraction over ridges or the influence of elevation differences on the source–receiver path.

Open-source tools and plugins extend QGIS with direct acoustic calculation capabilities. Plugins such as OpeNoise and platforms such as NoiseModelling (Bocher et al., 2019; Tagusari et al., 2023) allow the production of environmental noise maps within GIS-oriented workflows. H-RISK with NoiseModelling adds health-risk estimation. These tools lower the barrier to entry for practitioners and researchers while maintaining conformity with European normative standards.

2. STUDY AREA

The case study was conducted in a semi-rural area located in Rome (approximate position: 41° 57’ N, 12° 22’ E, elevation ~130 165 m, H, EPSG: 6705). The site is characterized by gently rolling terrain dissected by a small valley, with steep slopes reaching gradients exceeding 30%, scattered residential buildings and agricultural infrastructure. Three-point sources were simulated to represent farm machinery (equivalent sound power level LW = 115 dB(A) each, height 1.5 m above ground). Three receiver groups (R1, R2, R3) were positioned at representative locations, evaluated at heights of 1.5 m (ground floor), 4 m (first floor) and 7 m (second floor). The primary objective was to quantify the influence of terrain representation quality on predicted noise levels by running identical source-receiver scenarios through three software configurations: (A) SoundPLAN with full 3D DTM; (B) dBmap with manually reconstructed 3D terrain; (C) dBmap in flat 2D mode.

3. DATA AND METHODS

In the present case study, the Digital Terrain Model (DTM) was adopted as the main geometric input of the simulation model, as it was necessary to describe the effects of topography on sound propagation. The DTM used in the analysis was acquired from the Regione Lazio Open Data portal and selected as a suitable cartographic basis for the investigation of a semi-rural area, since it provided an appropriate balance between territorial coverage, immediate availability and altimetric detail. The adopted dataset has a spatial resolution of 5 m, which was considered consistent with both the scale of the analysis and the requirements of the acoustic modelling of the site. In the first calculation setup, SoundPLAN was used as the reference three-dimensional modelling environment (**Fig.1**).

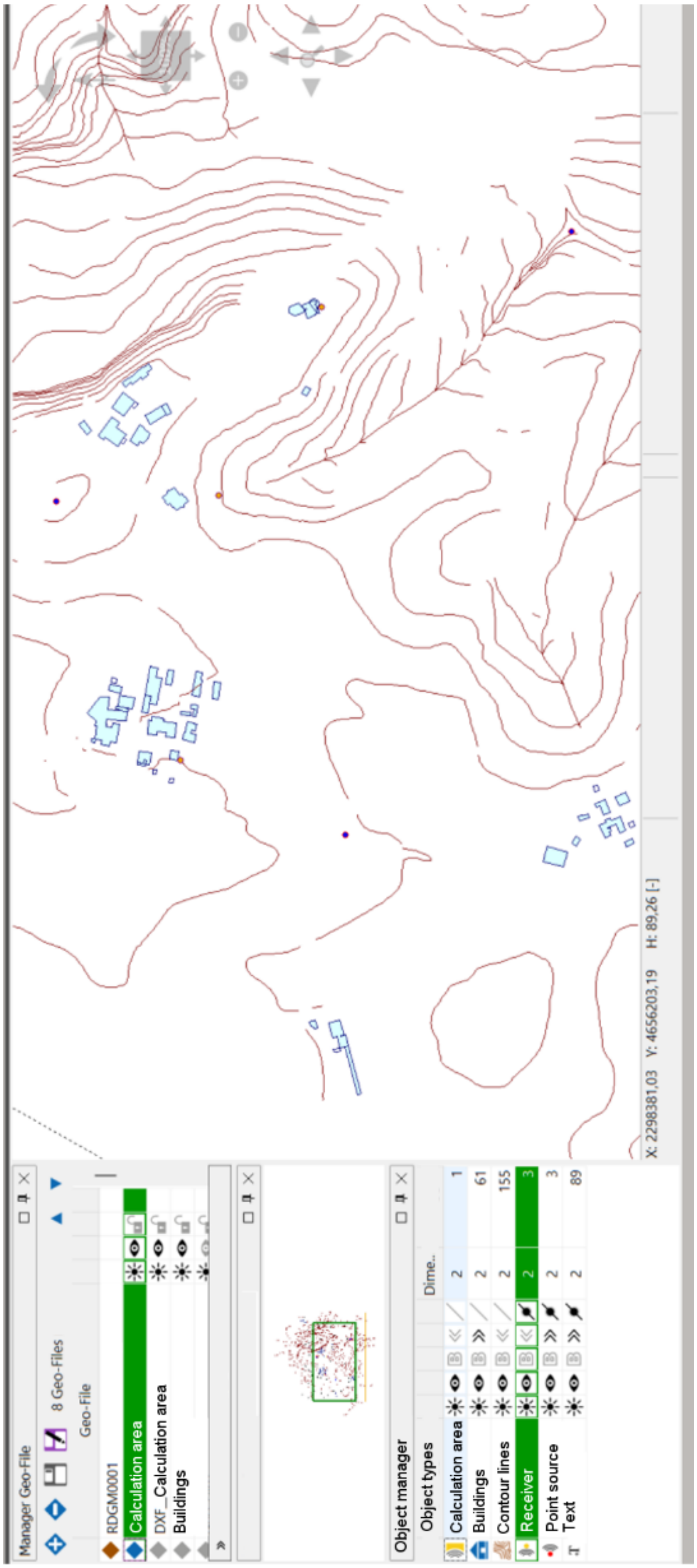

Fig. 1. Geofile processing in SoundPLAN

The DTM, downloaded in DXF format, was first processed in AutoCAD by removing unnecessary elements and retaining only the layers related to contour lines, spot heights and building information. The resulting file was then imported into SoundPLAN, where the Geofiles containing the elements required for terrain modelling were generated (**Fig.2**).

Based on these data, the software subsequently generated the DGM (Digital Ground Model), i.e., the three-dimensional terrain model onto which the height-attributed buildings were later projected.

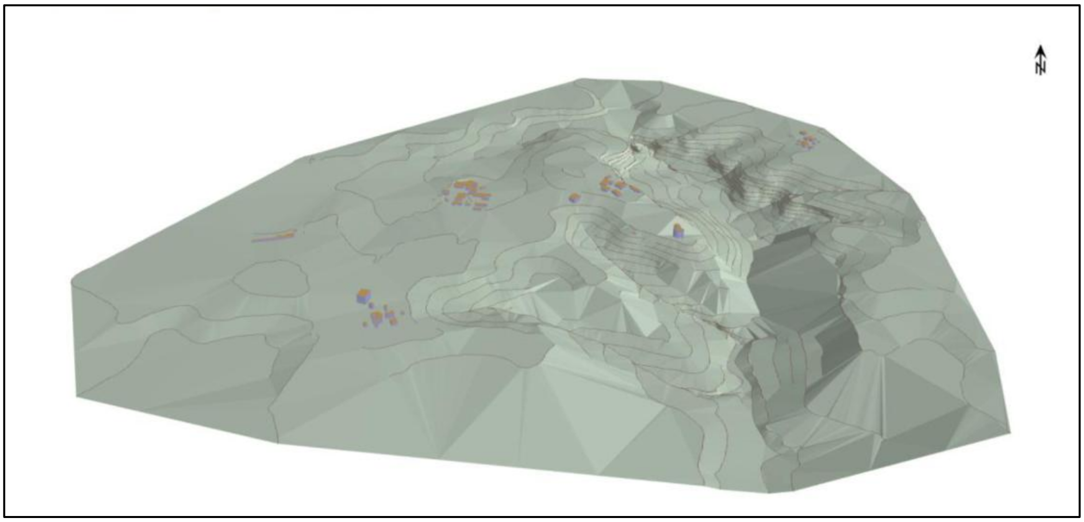

Fig. 2. Three-dimensional terrain model generated in SoundPLAN.

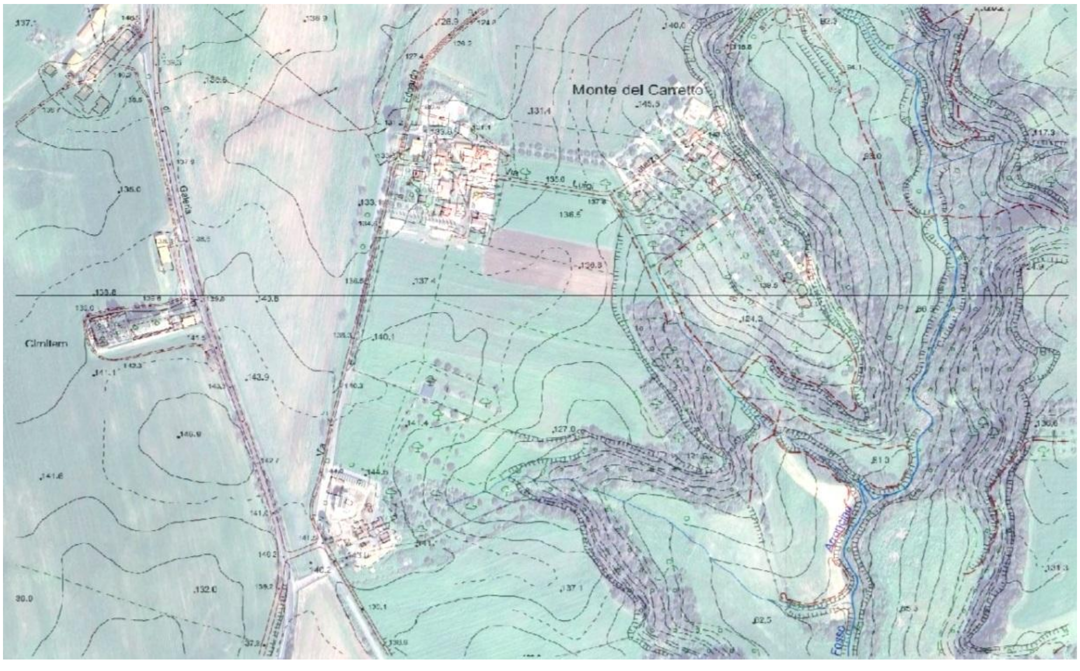

Fig. 3a. Manual terrain reconstruction in dBmap: georeferencing of elevation points on the cartographic base map (EPSG: 6708).

In the second setup, dBmap was used in three-dimensional mode. In this case, since direct DTM import was not possible, the terrain model was built manually by inserting ground elevation points. These points were derived from the same regional DTM used previously, then processed in QGIS and georeferenced with respect to the Google Maps base map of the study area. Once imported into dBmap, the software generated the three-dimensional terrain model through topographic triangulation and slope definition (**Fig.3a** and **Fig.3b**). Buildings were also inserted manually, starting from their planimetric footprints and from height estimates derived from the available cartographic documentation and three-dimensional imagery.

Fig. 3b. Manual terrain reconstruction in dBmap: three-dimensional terrain model obtained through triangulation.

In the third setup, dBmap was used in a simplified two-dimensional flat-terrain mode. In this case, no digital terrain model was created and the calculation area was represented by assuming a planar surface, thus obtaining a simplified scenario without explicit topographic effects. This configuration was intentionally retained as a comparison term with respect to the three-dimensional models.

Once the three different geometric representations of the site had been defined, the acoustic input scenario was set identically for all simulations in order to ensure the comparability of the results. Three-point sources, representative of agricultural machinery operating within the study area, were introduced, each characterized by an equivalent sound power level of 115 dB(A) and by an emission height of 1.5 m above ground level. The receivers, organized into groups R1, R2 and R3, were located in positions considered representative of the site (**Fig.4**).

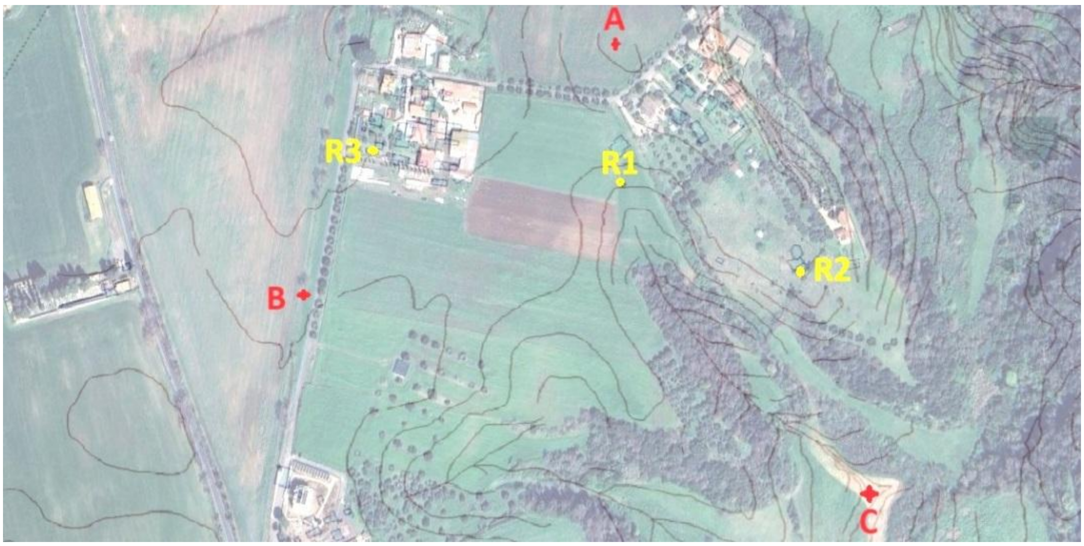

Fig. 4. Layout of sound sources and receivers adopted in the case study (EPSG: 6708).

The receivers were then evaluated at heights of 1.5 m, 4 m and 7 m, corresponding respectively to exposure conditions at ground floor, first floor and second floor level. Environmental parameters were kept constant in all simulations, assuming an air temperature of 20 ° C, relative humidity of 70%, atmospheric pressure of 1013.3 mbar, ground factor G = 0.5, representative of mixed ground conditions, and wind conditions favorable to propagation, in accordance with the reference conditions of ISO 9613-2. This methodological setting made it possible to directly assess the influence of the different levels of terrain representation on the acoustic simulation results while keeping all other model variables constant.

4. RESULTS AND ANALYSIS

The results of the acoustic simulations obtained with the three software configurations considered are reported in **Table 2**, which summarizes the A-weighted equivalent continuous sound pressure levels predicted at receiver points R1, R2, and R3 at a height of 4 m. The comparison was performed while keeping the emission framework, source positions, receiver locations, and environmental parameters unchanged, varying only the level of detail used to represent terrain morphology. The noise maps were obtained, respectively, with SoundPLAN, dBmap in three-dimensional configuration, and dBmap in two-dimensional configuration (**Fig.5a**, **Fig.5b** and **Fig.5c**). **Table 2** and the cartographic outputs provide the quantitative and visual basis for the subsequent comparison of the three modelling approaches.

Table 2

Predicted noise levels at receivers [dB(A)], height 4 m.

Receiver	SoundPLAN (3D)	dBmap (3D)	dBmap (2D)
R1	53.5	61.0	62.0
R2	48.0	57.0	59.0
R3	60.0	61.0	61.0

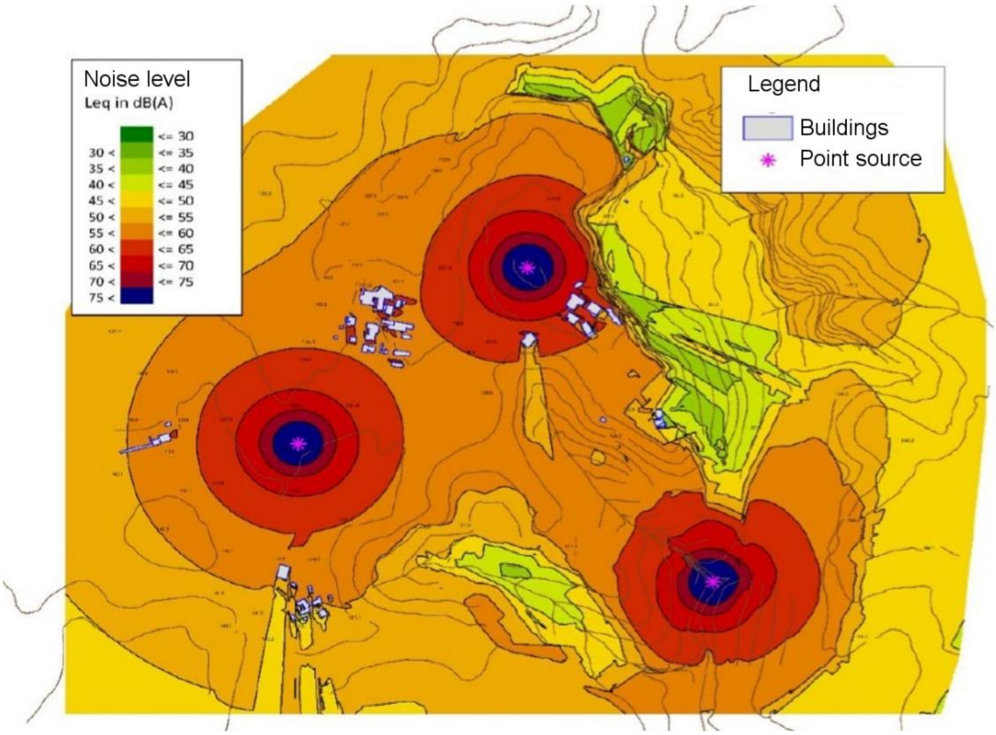

Figure 5a. SoundPlan noise map (EPSG: 6708).

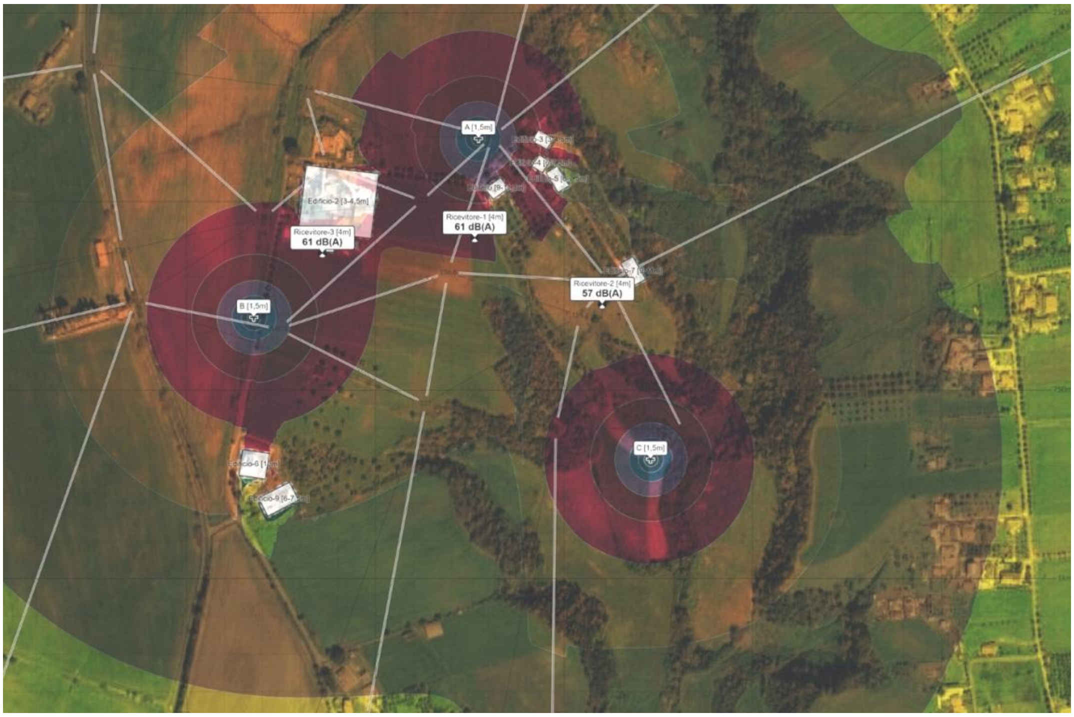

Figure 5b. dBmap 3d noise map (EPSG: 6708).

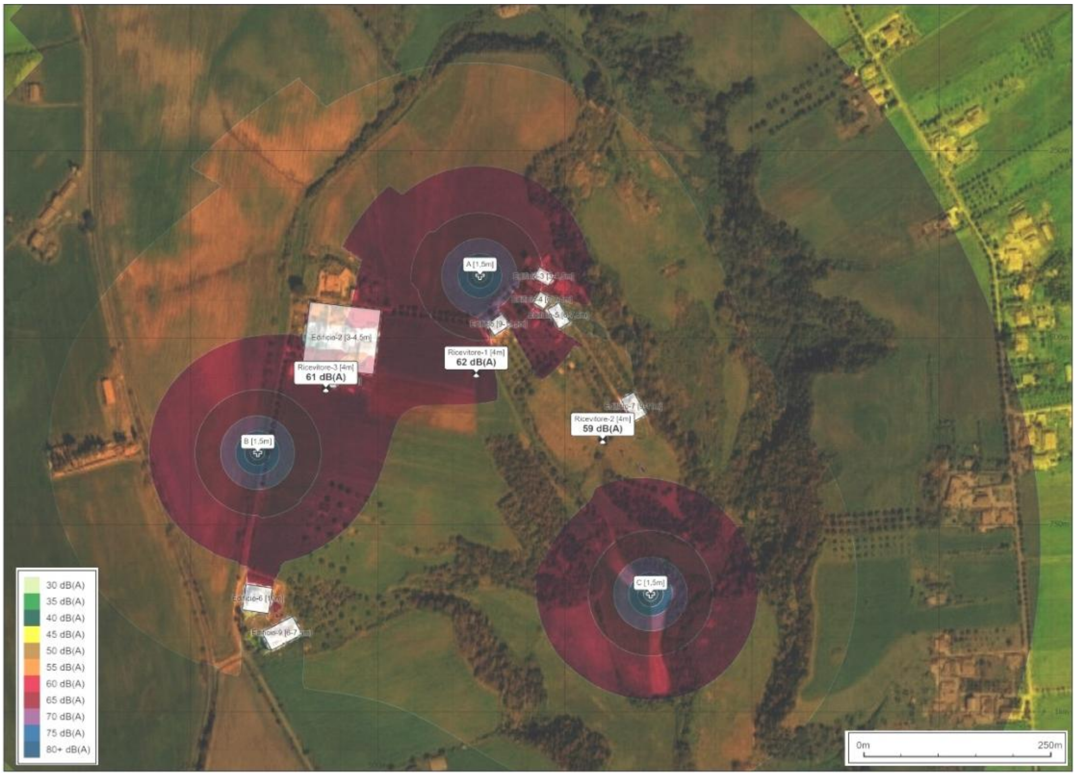

Figure 5c. dBmap 2d noise map (EPSG: 6708).

5. DISCUSSION

The results reveal substantial inter-software discrepancies that are directly attributable to the quality of terrain representation. At receiver R2 – located in a topographic depression behind a ridge crest relative to source B – SoundPLAN predicts 48.0 dB(A) while dBmap 2D returns 59.0 dB(A), a difference of 11 dB(A). This large discrepancy arises because the flat 2D model fails to represent the acoustic shadow cast by the intervening ridge; without terrain relief, the direct propagation path is unobstructed and ground-effect attenuation is underestimated. At receivers R1 and R3, the discrepancy between SoundPLAN and dBmap 3D is approximately 7–8 dB(A), attributable to the coarser triangulation mesh used in the manual dBmap reconstruction. At receiver R3, where terrain relief is less pronounced between source and receiver, all three configurations converge to approximately 60–61 dB(A), confirming that terrain modelling errors are most critical when significant topographic screening is present. These observations are consistent with the findings of Salomons (2001), who demonstrated that even modest terrain undulations ($\Delta h \sim 5$ m) can produce acoustic shadow zones with attenuation exceeding 15 dB relative to flat-terrain predictions. From a software perspective, SoundPLAN offers the most complete geomatic integration: direct import of high-resolution DTMs, automatic TIN construction, 3D building projection, and full compliance with ISO 9613-2 and CNOSSOS-EU. dBmap is more accessible and faster to set up but requires significant manual effort for terrain reconstruction and is unsuitable for morphologically complex sites. The 2D mode should be reserved for flat-terrain screening calculations only.

6. CONCLUSIONS

This paper has demonstrated the pivotal role of geomatic techniques in outdoor acoustic propagation modelling, highlighting how the quality of the digital terrain model (DTM) stands as a primary determinant of simulation accuracy. In topographically complex terrain, the absence or simplification of terrain relief can lead to prediction errors exceeding 10 dB(A), a margin that can ultimately determine whether a project meets or fails to meet Italian and European noise regulations. When high-quality data are available, LiDAR and UAV photogrammetry emerge as the most suitable sources for DTM inputs, as they combine high spatial resolution with relatively efficient acquisition processes, while open-data DTMs with a 5-meter resolution can still serve as a practical compromise for large-scale preliminary assessments.

The choice of software is equally critical and must take into account its ability to handle terrain complexity. Full three-dimensional acoustic modelling engines such as SoundPLAN, CadnaA, and Predictor-LimA are essential in contexts characterized by significant orography or dense urban structures, whereas simplified tools remain appropriate only in flat and obstacle-free environments. At the same time, the open-source ecosystem, including solutions like NoiseModelling, OpeNoise, and QGIS plugins, is becoming increasingly robust, offering viable alternatives particularly for large-scale strategic mapping, provided that sufficiently accurate DTM inputs are used.

Looking ahead, several development priorities emerge, including the need for standardized interoperability formats between GIS platforms and acoustic simulation engines, the automation of pipelines that convert terrain data into ready-to-use acoustic models, the creation of shared national databases for both noise sources and terrain information, and the integration of machine learning techniques to enable faster scenario evaluation and more efficient model calibration. In conclusion, geomatics and environmental acoustics can be seen as inherently complementary disciplines, and their full integration, spanning from high-resolution LiDAR surveys at the sub-decimeter scale to large-scale CNOSSOS-EU strategic noise mapping, provides the most rigorous and operationally effective framework for addressing noise pollution in complex real-world environments.

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