The Contribution of High-Precision LiDAR in Environmental Studies: Applications to Solar Energy Planning, Flood Risk Management and Biomass Estimation

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Key words : LiDAR, Lasergrammetry, Solar Energy Planning, Flood Risk, Biomass Estimation, Environmental Surveying

1. SUMMARY

Recent advances in LiDAR and laser scanning technologies are redefining the role of surveyors in environmental management. High-resolution point clouds enable the generation of Digital Terrain Models (DTMs) and Digital Surface Models (DSMs) with centimetric accuracy, paving the way for a new generation of applications that combine technical rigour with sustainable development objectives.

This paper highlights the measurable added value of precision laser scanning in environmental studies through three major application domains. First, in solar energy planning, LiDAR-derived DSMs and DTMs are used to assess solar potential, optimise panel layout and minimise shading effects. Second, in flood risk management, high-resolution terrain models support accurate hydrological simulations and the identification of vulnerable areas. Finally, in biomass and vegetation analysis, canopy heights and structural parameters extracted from point clouds enable environmental monitoring and the estimation of carbon stocks.

Beyond technical performance, the paper emphasises the added value for decision-makers and project developers: increased project reliability, enhanced 3D visualisation, reduced delivery times and improved communication through digital twins. By transforming precise laser data into actionable environmental indicators, surveyors can play a central role in building smarter, greener and more resilient territories.

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2. INTRODUCTION

Environmental challenges such as renewable energy development, climate change adaptation and ecosystem protection require accurate and up-to-date spatial information. Surveyors and geomatics professionals increasingly contribute to environmental decision-making by providing precise three-dimensional representations of terrain and surface objects.

LiDAR technology has become one of the most powerful tools for acquiring high-resolution elevation data over large areas within timeframes compatible with the operational constraints of land-use planning and environmental engineering projects.

Modern laser scanners, whether airborne, terrestrial or drone-mounted, can now produce dense point clouds with centimetric accuracy and metric homogeneity over several square kilometres.

These datasets form the basis for Digital Terrain Models (DTMs) and Digital Surface Models (DSMs) that can be directly exploited in computational workflows: photovoltaic park sizing, hydrological modelling, shading analysis, volumetric biomass estimation or environmental scenario simulations.

In practice, LiDAR data are no longer a simple cartographic deliverable, but a structuring input dataset for engineering consultancies, conditioning the reliability of models and, ultimately, the quality of investment and planning decisions.

3. APPLICATION DOMAINS

LiDAR technology has a broad and constantly expanding impact across many fields of environmental and territorial management. Its ability to provide high-resolution three-dimensional data supports applications ranging from urban planning, infrastructure monitoring, coastal erosion assessment, landslide detection, precision agriculture, cultural heritage documentation and natural hazard management, to climate change adaptation and environmental monitoring.

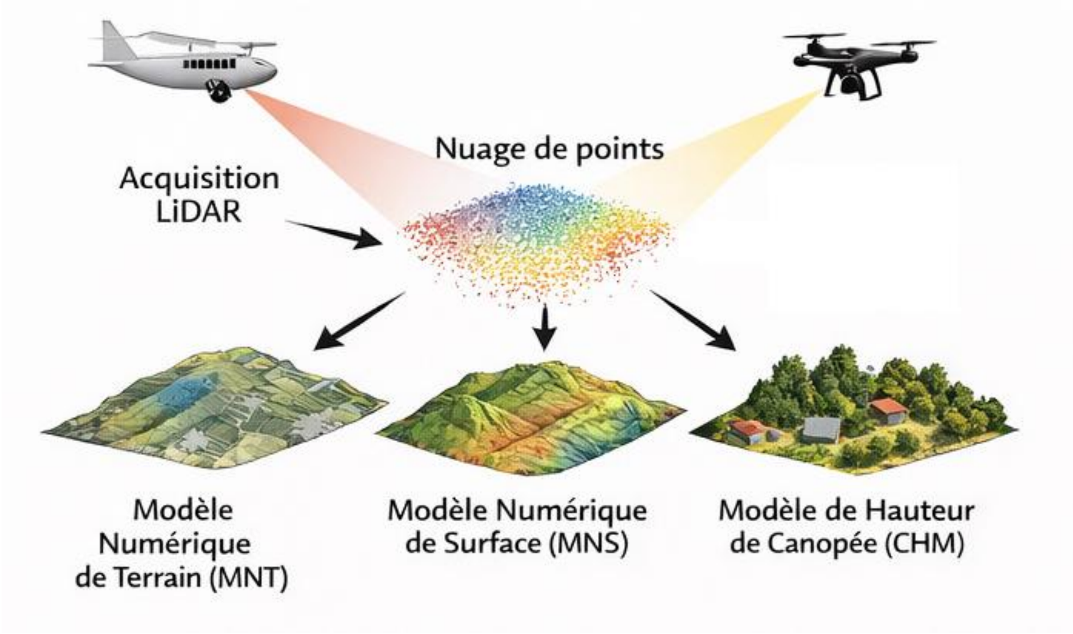

Figure 1: LIDAR data product

Among this wide range of possibilities, this paper focuses on three application domains in which the added value of LiDAR can be directly measured in terms of design quality, risk reduction and economic optimisation of projects.

Solar energy planning illustrates how high-resolution DSMs and DTMs make it possible to optimise equipment layout and measurably improve energy yield estimates.
Flood risk management shows how precise LiDAR-based DTMs concretely modify the results of hydraulic simulations and the localisation of at-risk areas.
Finally, biomass analysis demonstrates how data extracted from point clouds can partially replace heavy and costly field inventories.
These three cases correspond to real-world project situations in which the surveyor becomes a key player in the environmental engineering chain.

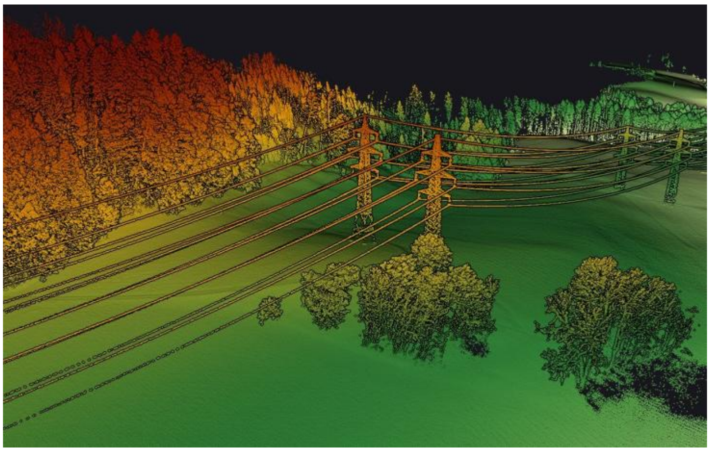

Figure 2: LIDAR DATASET

3.1 Solar Energy Planning – Example of LiDAR-Based Hillshade and Solar Potential Analysis

The performance of photovoltaic installations strongly depends on terrain orientation, slope, shading conditions and the actually exploitable surface area. However, traditional feasibility studies still frequently rely on coarse elevation models or sparse field surveys, which can lead to inaccurate estimates of energy production and sub-optimal panel layout.

In this context, LiDAR-derived DTMs and DSMs represent a decisive change in scale. They faithfully reproduce the geometry of relief, vegetation and artificial structures, providing an objective basis for modelling solar irradiation and cast shadows.

A practical example illustrates the concrete added value of LiDAR-derived DSMs and DTMs for evaluating and optimising solar sites at an operational scale. In a hilly peri-urban area considered for the installation of a ground-mounted solar farm, airborne LiDAR data were acquired at a density of 10 points/m². After classification and filtering, a high-resolution DTM (0.5 m grid) and a DSM were generated. From these datasets, slope and aspect maps were produced to identify areas meeting optimal panel inclination criteria.

A shading model was then computed to simulate relief-induced shadows at different times of day and across seasons. The DSM was also used to model shading caused by surrounding vegetation and buildings. Combining these results with solar irradiation simulations made it possible to identify micro-zones with maximum solar exposure and minimal shading losses.

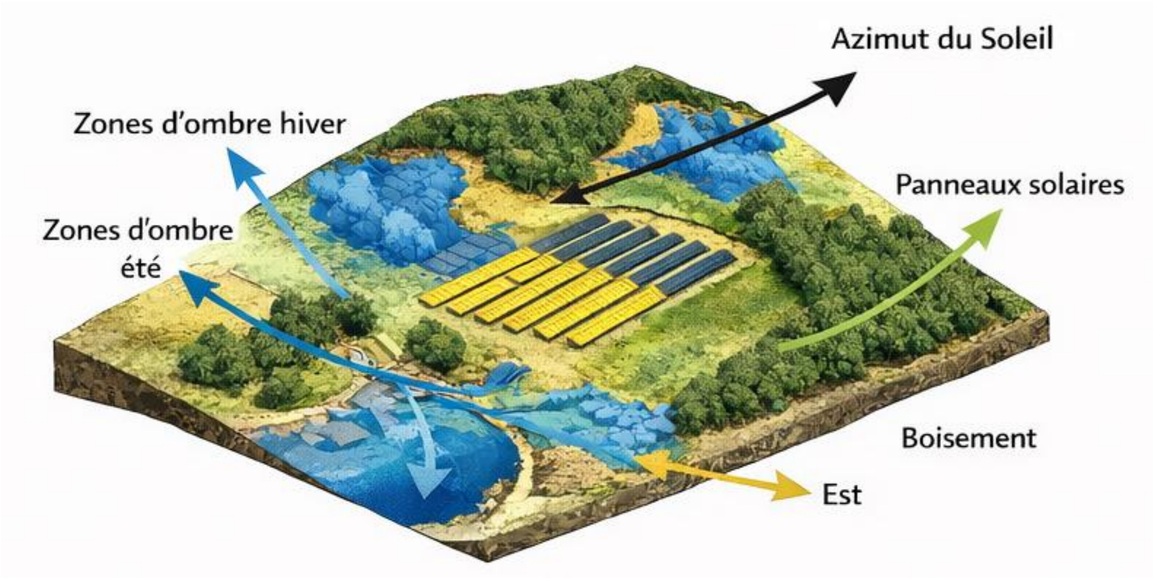

Figure 3: example of a photovoltaic project

Compared with a preliminary study based on a national 10-m resolution DTM, the LiDAR analysis revealed several shaded areas previously considered favourable, thus avoiding inefficient panel installation. The refined model improved the estimate of annual energy production by approximately 8–12%, demonstrating the direct economic benefit of high-precision elevation data.

In a real 18-hectare photovoltaic project in southern France, the integration of a 0.5-m resolution LiDAR DSM enabled optimisation of solar table layout by accounting for micro-topographic variations of less than one metre. This fine-scale optimisation resulted in a gain of about 6% in usable surface area compared with the initial layout based on a metric-resolution DTM.

Moreover, hourly shading modelling over a full year highlighted localised yield losses caused by a wooded edge and a slight natural embankment. Shifting certain panel rows by only 3 to 5 metres reduced these losses by nearly 70%, without significantly modifying the overall land footprint of the project.

These adjustments, impossible to detect using coarser elevation models, generated an estimated economic gain of several tens of thousands of euros per year over the operational lifetime of the installation. This example illustrates how high-precision LiDAR data directly transform technical design quality and the financial profitability of solar projects.

In urban environments, similar workflows enable mapping of rooftop solar suitability. The LiDAR DSM supports automated detection of roof facets, calculation of their orientation and estimation of exploitable surface areas, supporting large-scale municipal solar planning initiatives.

Furthermore, LiDAR-based rooftop analysis is a powerful decision-support tool for local authorities. By automatically identifying suitable roof surfaces and quantifying their solar potential, municipalities can estimate how many buildings could host photovoltaic systems and assess the total renewable energy capacity available at the city scale. This information supports urban energy planning, incentive programme design and the development of smart and sustainable cities.

These examples show how LiDAR data transform solar energy planning from approximate site selection into a precise, data-driven optimisation process

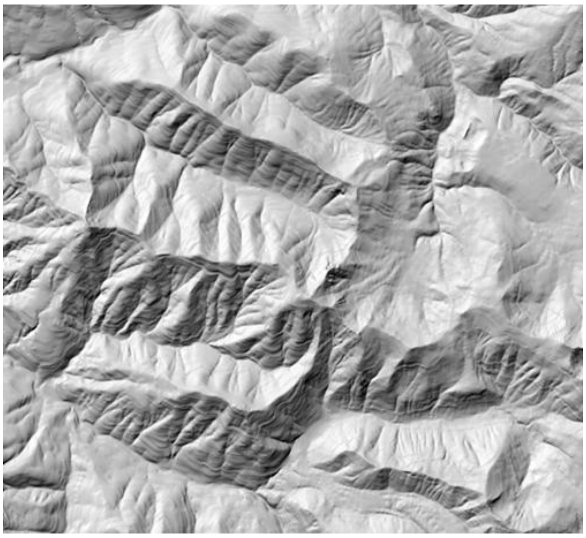

Figure 4: DTM MODEL

3.2 Flood Risk and Hydrological Modeling – Example of High-Resolution DTM for Slope and Flow Analysis

Flood risk mapping critically depends on the quality of topographic representation. Even small elevation errors can significantly alter the simulated extent of flooded areas, particularly in low-relief or urban environments, where a few centimetres of difference can condition a local overflow.

In this context, high-resolution LiDAR DTMs provide a major improvement by enabling the restitution of micro-topographic features that govern water flow and accumulation.

An illustrative example concerns flood modelling in a medium-sized catchment subject to recurrent seasonal flooding. Two elevation datasets were compared: a conventional 5-m resolution photogrammetric DTM and a 0.5-m resolution LiDAR DTM. Both datasets were used as inputs for hydrological and hydraulic simulations.

Slope and flow-direction maps generated from the LiDAR DTM revealed micro-topographic features such as embankments, kerbs and drainage ditches that were invisible in the coarser DTM. These elements strongly influence runoff pathways and water accumulation zones. As a result, LiDAR-based simulations predicted localised flooding in residential areas that had not been identified in previous risk maps.

Field validation conducted after a subsequent flood event confirmed the accuracy of the LiDAR-based predictions. This enabled local authorities to prioritise mitigation measures such as drainage network improvements and dyke reinforcement.

A similar case was observed in a peri-urban municipality crossed by a small canalised stream. The LiDAR DTM revealed discontinuous topographic thresholds formed by kerbs, driveway entrances and partially obstructed hydraulic structures. These discontinuities, invisible in a metric-resolution DTM, were identified as local blockage points favouring punctual overflows during heavy rainfall.

By integrating these elements into the hydraulic model, engineers were able to simulate stormwater surcharge scenarios and precisely identify areas where targeted interventions (cleaning, creation of gutters, local kerb raising) would significantly reduce flood risk.

Corrective works carried out following this study resulted in a measured reduction in overflows during subsequent intense rainfall events, confirming the operational value of LiDAR DTMs for low-cost, high-impact risk-prevention interventions.

In another urban example, the LiDAR DTM enabled precise delineation of impervious surfaces and micro-slopes, improving stormwater management planning and reducing the risk of sewer overflow.

These cases demonstrate that high-resolution LiDAR DTMs significantly improve the reliability of flood-risk assessments and support evidence-based disaster-management strategies.

Beyond simple terrain representation, LiDAR DTMs form the geometric basis of advanced virtual hydrological simulations. By integrating LiDAR-derived slope maps with complementary thematic datasets such as soil permeability maps, land-use data, drainage networks and rainfall records, it becomes possible to simulate multiple rainfall and runoff scenarios. These simulations allow different precipitation intensities, event durations and climate projections to be tested, providing a dynamic understanding of flows under diverse conditions.

This multi-parameter modelling makes it possible to precisely identify flood-prone areas, estimate water depths and evaluate the effectiveness of protection measures such as retention basins, network improvements or flood-protection structures. By combining LiDAR topography with other environmental data, authorities can move from static maps to predictive risk-assessment tools, fostering proactive planning and improved emergency preparedness.

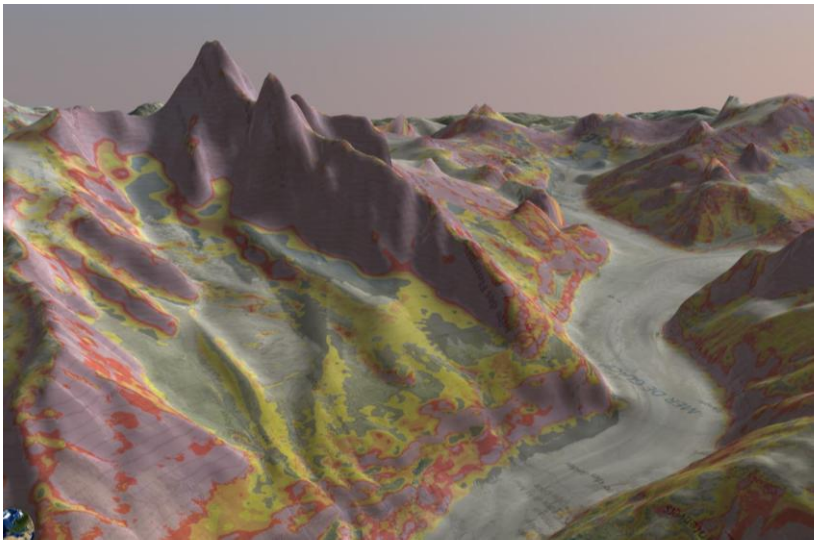

Figure 5: 3D SLOPE MODEL

3.3 Biomass and Vegetation Analysis – Example of Canopy Height and Biomass Estimation

Accurate estimation of forest biomass is essential for sustainable resource management, optimisation of harvesting plans and carbon-stock reporting under climate policies.

Traditional field inventory methods provide reliable measurements, but they are time-consuming, labour-intensive and spatially limited. They often rely on extrapolating a few sample plots over much larger areas, introducing significant uncertainties.

In a representative forest study area, airborne LiDAR data with a density of 15 points/m² were acquired over a mixed woodland. After ground and vegetation classification, a Canopy Height Model (CHM) was generated by subtracting the Digital Terrain Model (DTM) from the Digital Surface Model (DSM). Individual tree heights and crown dimensions were extracted using segmentation algorithms.

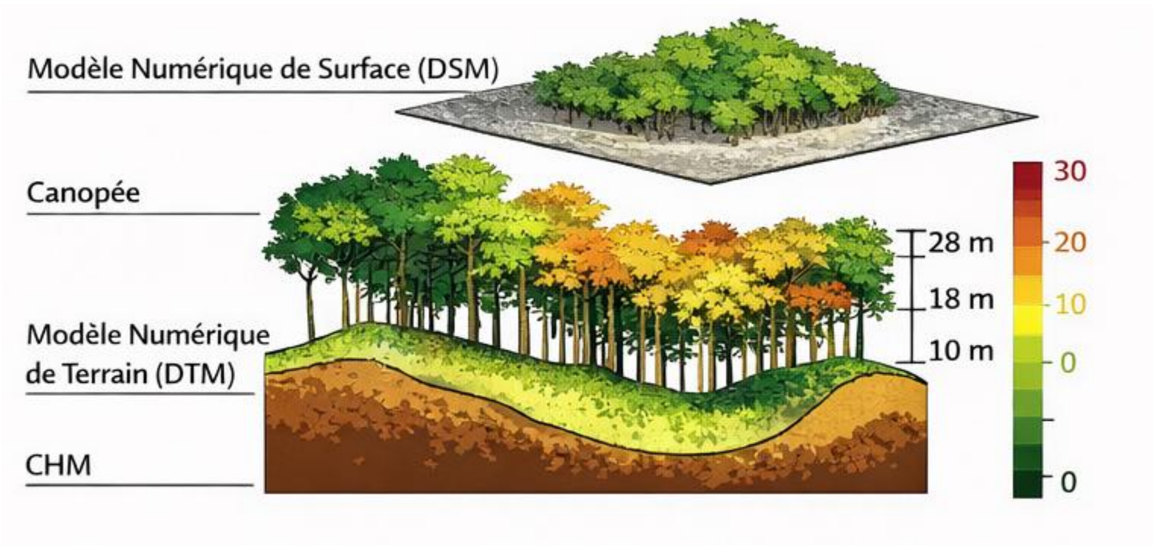

Figure 6: canopy height model

Biomass estimates derived from LiDAR metrics were then compared with measurements from field sample plots. The results showed a strong correlation between LiDAR-derived canopy height and measured tree volume, with estimation errors below 10%. In addition, spatial distribution maps of biomass density were produced, enabling identification of high-growth zones and degraded sectors requiring restoration.

In another commercially exploited forest area, LiDAR surveys were used to map age classes and standing volumes at the parcel scale. This information made it possible to optimise harvesting plans and schedule forest rotations by accounting for real spatial variability in growth.

Forest managers were thus able to prioritise high-productivity zones and postpone harvesting in less mature sectors, improving both economic profitability and resource sustainability. Moreover, LiDAR data served as the basis for carbon-stock estimation under a voluntary carbon-offset programme, with uncertainties lower than those obtained by extrapolation from a few field plots.

This type of application shows that LiDAR is not limited to a descriptive function, but constitutes a genuine strategic decision-support tool for ecosystem management and environmental valorisation of territories.

A repeated LiDAR acquisition two years later made it possible to detect vegetation growth trends and disturbance events such as illegal logging or storm damage. This temporal monitoring capability supports continuous environmental assessment and carbon-reporting obligations.

Beyond forest studies, similar approaches are applied to agricultural landscapes for crop-height estimation and yield prediction, illustrating the versatility of LiDAR-based vegetation analysis.

These examples confirm that LiDAR constitutes an efficient and scalable solution for biomass assessment and long-term ecosystem monitoring, providing an operational alternative for characterising vertical stand structure over large areas with a resolution and homogeneity unattainable by field methods alone.

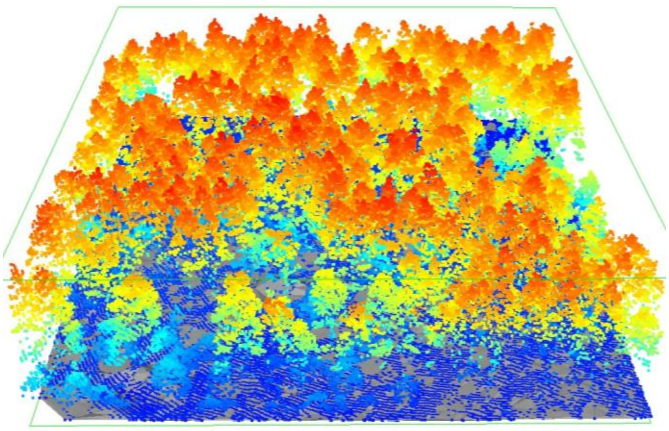

Figure 7: LIDAR DATASET FOR A VEGETATION AREA

4. Conclusion and perspectives

High-precision LiDAR and laser scanning have become structuring tools in modern environmental engineering workflows. The applications presented in solar energy planning, flood-risk management and biomass estimation show that these technologies go far beyond simple cartographic production. They now constitute fundamental building blocks of environmental modelling chains and territorial decision-support systems. By transforming precise measurements into actionable environmental information, surveyors play a central role in building smarter and greener territories.

The continuous improvement of LiDAR sensors and data-processing techniques opens new horizons for three-dimensional environmental representation. Today, high-density LiDAR acquisitions already enable detailed 3D reconstruction of terrain, vegetation, buildings and even small urban objects such as street furniture and roof structures. For the first time, surveyors can provide complete and accurate three-dimensional descriptions of territories, forming the geometric basis for advanced spatial analyses.

These high-fidelity 3D datasets support increasingly sophisticated simulation environments. Detailed LiDAR-based models enable realistic simulation of water flows over complex urban surfaces, dynamic flood propagation and sediment transport. Similarly, accurate 3D urban geometry allows simulation of telecommunication wave propagation to optimise the deployment of 5G and future networks.

The examples presented in this paper show that the value of LiDAR does not lie solely in the density or precision of point clouds, but in the ability to transform raw data into environmental indicators directly exploitable by decision-makers.

Whether optimising photovoltaic panel layout, improving flood-risk maps or quantifying biomass stocks, LiDAR acts as a quality multiplier for existing environmental models. It reduces uncertainties, improves simulation robustness and makes it possible to move from decisions based on coarse assumptions to choices grounded in faithful three-dimensional representations of reality.

In this context, the role of the surveyor is evolving towards that of an architect of environmental spatial data, guaranteeing not only geometric accuracy, but also the coherence, traceability and decision-making value of the information produced.

Beyond individual simulations, LiDAR-derived 3D models will form the backbone of digital twins of cities and natural environments. These digital twins will integrate real-time sensor data, environmental models and infrastructure information, enabling continuous monitoring, predictive analyses and scenario testing. Such developments will transform LiDAR from a mapping technology into a central component of next-generation intelligent territorial management systems.

These perspectives confirm that LiDAR is not only a high-precision measurement tool, but also a key enabler of next-generation simulation and decision-support platforms for smart and resilient territories.

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BIOGRAPHICAL NOTES

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