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INTEGRATION OF UAV-BASED LIDAR, PHOTOGRAMMETRY, AND SLAM TECHNOLOGIES FOR THE COMPLETE ABOVE AND BELOW GROUND MAPPING OF MOUNTAINOUS HYDRO-TECHNICAL INFRASTRUCTURE

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Abstract

The comprehensive mapping and inspection of both underground and above-ground terrain in mountainous environments pose significant challenges for engineering projects, particularly those involving legacy infrastructure. This study presents an integrated geospatial methodology for the rehabilitation and modernization of the Tomesti micro-hydropower station in Timiș County, Romania. By combining GNSS-based control networks, UAV photogrammetry, airborne LiDAR, and handheld SLAM scanning, the project achieved high-resolution data acquisition across complex topographies and inaccessible subsurface structures. Ground control points were established using total stations to ensure millimetric precision and consistent georeferencing of all datasets. The workflow delivered orthophotos, digital surface and terrain models, detailed topographic plans, and 3D reconstructions of the interior hydro-technical gallery. These outputs formed the foundation for updated technical documentation and supported engineering analyses for structural rehabilitation and eco-friendly water intake systems. The results confirm that modern geomatics, when anchored in classical surveying practices, provides a robust framework for accurate assessment, design, and environmental integration. This case study underscores the value of multi-sensor approaches in repurposing abandoned infrastructure for sustainable energy production and demonstrates their practical relevance in mountainous terrain.

Key words: *3D, LiDAR, SLAM, topographic mapping, UAV.*

INTRODUCTION

Accurate land surveying is a cornerstone of complex engineering projects, especially in rugged or inaccessible terrain (Sestras et al., 2025). Infrastructure and energy development rely on precise topographic data, spatial modelling, and georeferenced planning to minimize risk, control costs, and ensure environmental sustainability. This becomes even more critical in projects involving legacy infrastructure or underground features, where outdated or missing data can cause technical and environmental issues (Langhammer et al., 2018). In response, modern surveying integrates advanced technologies, GNSS, UAV LiDAR, photogrammetry and SLAM, that have reshaped terrain analysis, rehabilitation strategies, and design processes (Nap et al., 2023). These tools not only support but significantly enhance the resolution, speed, and precision of early-stage decision-making.

This study centers on the revival of the Tomesti micro-hydropower station in Timiș County, Romania, combining geospatial innovation with sustainable energy goals. Initially launched before 1989, the site includes upstream intakes, an underground gallery, and a partially built hydroelectric cavern. Work was halted, leaving behind incomplete and poorly documented infrastructure. With renewed emphasis on renewable energy and national energy security, reassessing and completing this project using modern technical and environmental standards has become a strategic priority.

To guide the design, rehabilitation, and environmental compliance of this complex project, a comprehensive geospatial survey was carried out. The methodology integrated total stations and GNSS-based control networks for spatial accuracy, UAV-based LiDAR for detailed surface modelling, and SLAM technology for high-precision scanning of underground tunnels (Liu et al., 2024). These combined approaches produced orthophotos, DSM/DTM models, topographic plans, and 3D reconstructions of the subterranean system, forming the technical foundation for feasibility assessments and future planning.

While geospatial technologies like UAV photogrammetry, LiDAR, and SLAM have advanced rapidly, classical instruments such as GNSS receivers and total stations remain essential in complex terrain (Sălăgean et al., 2019; Sestras, 2021). Their precision is unmatched when defining geodetic control networks - critical for survey accuracy. GNSS, particularly in RTK or PPK mode, enables fast, accurate 3D positioning across large areas, while total stations offer high angular accuracy in areas with limited satellite visibility, such as valleys or forested regions.

Classical surveying instruments are essential in establishing Ground Control Points (GCPs) and Independent Check Points (ICPs), which are critical for georeferencing UAV imagery and validating products like orthophotos, DSMs, and DTMs (Stöcker et al., 2020). Regardless of technological advancements, airborne systems depend on precise ground data for calibration and accuracy. UAV and SLAM outputs achieve their full potential only when tied to a solid geodetic network established via GNSS and total stations.

As highlighted in both the literature and the present methodology, relying solely on aerial or mobile sensors can lead to positional drift, systematic errors, or reduced accuracy in dense vegetation or occluded zones. Total stations and GNSS provide consistent benchmarks and validation points across the survey area, mitigating these limitations.

Given the complexity of terrain in engineering surveys, no single method suffices in isolation (Bilașco et al., 2021). A multi-sensor approach, especially combining UAV-based LiDAR and photogrammetry, proves far more effective in achieving full spatial coverage and accuracy.

Structure-from-Motion (SfM) photogrammetry reconstructs 3D surfaces from drone-captured images (Khanal et al., 2020), excelling in open areas with visible features like buildings or roads. It offers affordability, high visual detail, and easy interpretation. However, in vegetated areas, it struggles to capture ground surfaces (Popescu et al., 2024). LiDAR, by contrast, penetrates vegetation to provide accurate terrain data, even in low-light conditions (Oniga et al., 2023). Still, it may miss finer architectural elements and demands more advanced equipment and processing (You & Lee, 2020).

By integrating LiDAR and photogrammetry, surveyors harness the strengths of both systems while mitigating their individual limitations. LiDAR accurately captures terrain beneath vegetation, whereas photogrammetry excels at rendering visible structures. Combined, they offer a more complete and balanced view of the landscape (Sestras et al., 2025a).

This integrated approach is especially valuable for infrastructure projects like hydropower development, where natural topography and built features must be mapped with precision. Generating detailed topographic outputs, 3D models, and full site documentation facilitates improved decision-making, risk evaluation, and design planning (Coroian et al., 2024).

Simultaneous Localization and Mapping (SLAM) has become a crucial technology in areas where GNSS or total stations are less effective (Chio & Hou, 2021). Using LiDAR sensors and inertial units (IMUs), SLAM continuously tracks scanner movement while generating accurate 3D point clouds. Its portability allows surveyors to collect data in confined, GPS-denied spaces like underground infrastructure, interiors, or dense forests (Keitaanniemi et al., 2021).

In our case study, SLAM was essential for mapping the abandoned hydro-technical gallery in Tomesti. The underground sewer system, unreachable by GNSS and unsuited for static scanning, was navigated on foot with a handheld SLAM unit. This enabled both 3D data collection and real-time video inspection, producing a reliable model of the tunnel's condition and revealing critical information for structural evaluation.

The application of SLAM in rugged environments highlights its value in engineering projects where complex geometries, poor visibility, and restricted access make traditional surveying difficult (Urban et al., 2024). In this project, integrating SLAM data with UAV-derived surface models and geodetic networks created a seamless spatial database, essential for feasibility studies and rehabilitation planning. SLAM emerges not merely as a complementary tool, but as a key technology in multi-sensor surveying, enabling accurate and efficient mapping in the most challenging conditions.

The combined use of photogrammetry and LiDAR greatly improves the quality and flexibility of modern surveys, especially in difficult terrain (Rogers et al., 2020). While these technologies increase coverage and speed, classical instruments like GNSS and total stations remain vital for providing the precision needed for georeferencing and validation. This hybrid approach ensures high-resolution, standards-compliant data that supports reliable infrastructure planning and environmental assessment.

The Tomesti project exemplifies how outdated hydro-infrastructure can be revitalized through a balanced mix of advanced geomatics and traditional methods. It addresses both technical demands and broader goals like sustainable energy and responsible land use in mountainous regions. This case stands out for its interdisciplinary methodology, reliance on accurate data, and strong potential for replication. The following sections outline the geospatial workflow, equipment used, survey results, and how this integrated strategy informs rehabilitation and energy planning.

MATERIALS AND METHODS

Study area and desideratum

The study focuses on a hydro-technical site in eastern Timiș County, within the administrative boundaries of Tomești commune, Romania (Figure 1). Timiș is Romania's largest county, covering about 8,696.7 km² or 3.65% of the national territory. Located in the historical Banat region, it borders Hungary to the west and Serbia to the southwest. The county's capital, Timişoara, situated on the Bega River, is the main urban and administrative centre.

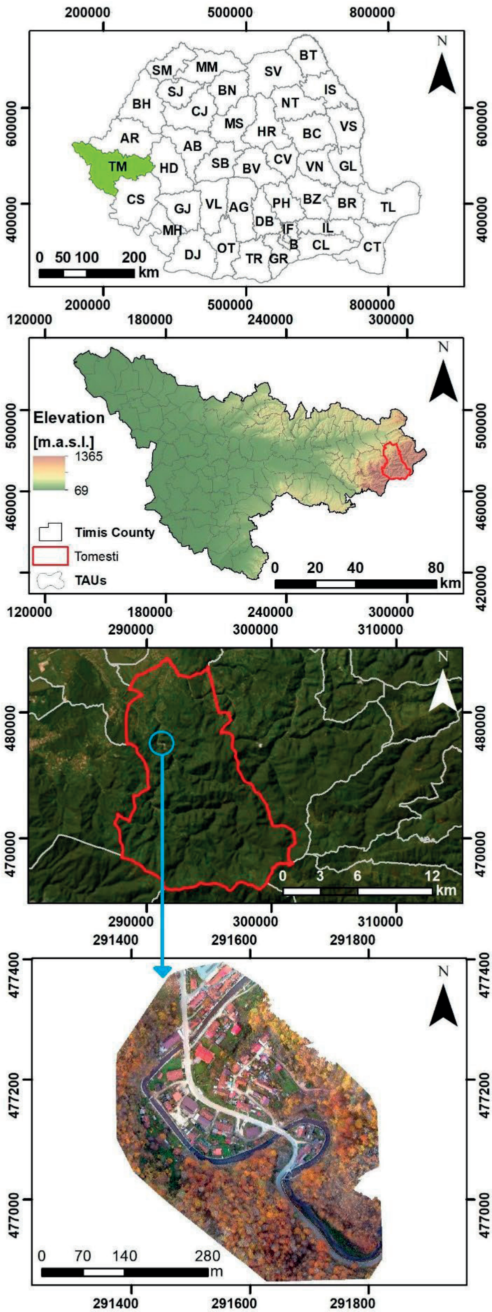

Figure 1. Location of the study area in Timiș County, Romania, showing elevation context, satellite view, and orthophoto of the Tomești micro-hydropower site

Tomești commune lies on the northern slopes of the Poiana Ruscă Mountains, covering 140.94 km² and comprising six villages, including its namesake seat. As of the 2021 census, the population totals 1,879, continuing a declining trend. The area features steep, forested terrain shaped by the upper Bega River and its tributaries, which provide favourable conditions for hydro-technical development due to the region's geomorphological and hydrological profile.

This site was part of a larger hydropower initiative begun during the communist era, which included partial construction of a 9.4 km underground tunnel, two water intakes, and a cavern for a micro-hydropower station. Abandoned before completion, the infrastructure has since deteriorated without maintenance.

The current investment project aims to modernize and finalize the original development using advanced surveying and design tools. Given the complex terrain, outdated documentation, and limited access, technologies such as GNSS, UAV-based LiDAR, and SLAM scanning are essential for georeferencing, surface modelling, and underground inspection.

Aligned with Romania's renewable energy strategy, the project seeks to sustainably harness the site's hydropower potential while ensuring all planning and design stages are based on precise geospatial data. This initiative not only supports technical feasibility and environmental evaluation but also demonstrates how modern methods can breathe new life into legacy infrastructure.

Methodological framework

This study presents an integrated methodological framework for the accurate mapping and inspection of both surface and subsurface components of a previously abandoned micro-hydropower project in Tomești commune, Timiș County. Due to the site's challenging terrain, partial hydro-technical infrastructure, and renewed national focus on renewable energy, the campaign aimed to develop a high-resolution spatial and technical database to support the project's redesign and revitalization.

The need for intervention stems from the deteriorated and outdated state of the original infrastructure. Initially planned before 1989, the project includes two upstream concrete intakes on Bega River tributaries, an underground gallery, and a partially excavated hydroelectric cavern. With no recent surveys or technical evaluations, these structures have experienced extensive environmental and structural degradation. The adopted workflow is outlined in Figure 2.

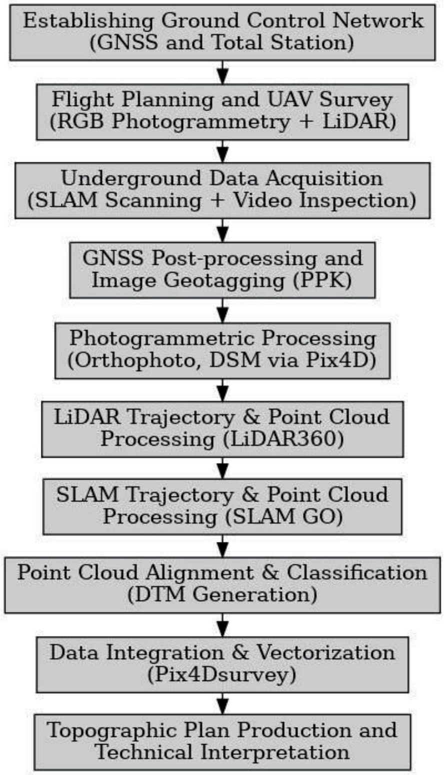

Figure 2. Methodological workflow

To address the complex demands of this project, the methodological framework combined traditional geodetic surveying with advanced remote sensing and 3D scanning techniques. Initially, a ground control network was established using GNSS receivers and total stations, forming a stable reference system for all subsequent data collection and ensuring spatial consistency across datasets.

UAV-based photogrammetry was then performed using drones with high-resolution RGB cameras to produce orthophotos and digital surface models (DSM). These were refined using LiDAR sensors mounted on UAV platforms, which provided detailed elevation data, even in vegetated or inaccessible zones, enabling the generation of accurate digital terrain models (DTMs) for hydrological and engineering analyses.

To map the underground gallery and associated structures, SLAM (Simultaneous Localization and Mapping) technology was employed. A handheld SLAM unit enabled the collection of 3D point clouds in GPS-denied tunnel environments while also capturing video for visual inspection of structural conditions such as cracks, sedimentation, or collapses.

This hybrid methodology produced robust deliverables tailored for engineering and environmental applications, including:

- High-resolution orthophotos;
- Precise DSMs and DTMs;
- Cross-sectional terrain and tunnel profiles;
- Integrated 3D models;
- Video records of underground conditions.

By providing reliable spatial data, this approach supports feasibility and safety assessments for completing the hydroelectric project in alignment with Romania's energy policy. The method also offers a replicable model for other complex or partially completed infrastructure projects.

Surveying instrumentation and equipment overview

In the Tomești micro-hydropower station rehabilitation project, a suite of advanced surveying instruments was deployed to ensure high-precision data acquisition across diverse terrains and structural challenges. These technologies enabled comprehensive spatial analyses essential for design and planning.

■ GNSS Technology: UniStrong G10 Receiver

To establish the Stereographic 1970 projection, the UniStrong G10 GNSS receiver was used in both static and RTK modes. Supporting GPS, GLONASS, BeiDou, and Galileo constellations, the G10 ensures high positional accuracy. Its tilt compensator auto-corrects based on pole orientation, and its cloud capabilities offer real-time monitoring, updates, and triple data storage for secure acquisition.

■ Total Station: Leica TS16P

In mountainous zones with poor satellite visibility, the Leica TS16P robotic total station was used to densify the control network. This self-learning instrument auto-adjusts to site conditions, offering high-accuracy measurements, a 5-inch touch display, and AutoHeight functionality for automated instrument height reading. It also includes LOC8 technology for remote locking and tracking.

■ UAV-Based Surveying

A DJI Matrice M200 drone with a Zenmuse X4S camera and TOPODRONE 200+ LiDAR system captured aerial data (Figure 3). The LiDAR system, based on the Hesai XT32M2X sensor, offers 200 m range, triple return mode, and 3–5 cm XYZ accuracy. Its built-in 200 Hz IMU and GNSS receiver enable precise georeferencing. Flight planning was performed via Map Pilot Pro, maintaining a steady altitude of 120 m AGL for optimal coverage.

Figure 3. UAV system and GNSS

■ SLAM Technology: Feima SLAM100 Handheld Imaging LiDAR Scanner

The complex water intake structure, which includes underground components, required additional scanning using Simultaneous Localization and Mapping (SLAM) technology (Figure 4). The Feima SLAM100 handheld LiDAR scanner was used for mobile mapping in GNSS-denied environments like tunnels, delivering high-resolution 3D point clouds critical for evaluating the geometry and condition of subterranean infrastructure.

The strategic integration of these advanced surveying instruments ensured the acquisition of precise and comprehensive data, necessary for the effective rehabilitation of the Tomesti micro-hydropower station. Each technology addressed specific challenges posed by the project's diverse terrains and structural intricacies, collectively contributing to a robust geospatial framework for informed decision-making.

Figure 4. SLAM and TS mapping; video inspection

Geospatial Data Processing and Integration

Following field data acquisition, a structured processing workflow was implemented to ensure data accuracy and integration across UAV photogrammetry, airborne LiDAR, and mobile SLAM sources. Each dataset was processed independently, followed by a unified integration and vectorization stage to produce final deliverables.

UAV imagery was first geotagged using TOPODRONE Post Processing, which synchronized GNSS trajectories with image metadata for high-precision PPK georeferencing. Images were then processed in Pix4Dmapper using a Structure-from-Motion (SfM) pipeline, including alignment, sparse and dense point cloud generation, and surface modelling. The result was a high-resolution orthophoto mosaic accurately referenced to the national coordinate system.

Airborne LiDAR data was refined through several stages to reconstruct the sensor's trajectory and generate a georeferenced 3D point cloud. Using TOPODRONE LiDAR Post Processing, GNSS and IMU data were merged to define the flight path (Figure 5), while the Cloud Generation module converted raw data into spatial coordinates.

To correct internal misalignments, boresight calibration was performed in GreenValley LiDAR360. Manual adjustments of Roll, Pitch, and Heading were made via Stepwise Geometric calibration, using cross-sectional analysis of overlapping flight lines. This was followed by automated strip alignment through least-squares matching for improved spatial coherence.

Ground classification was completed using the Cloth Simulation Filter (CSF), effectively separating terrain from vegetation and infrastructure, resulting in a reliable Digital Terrain Model (DTM).

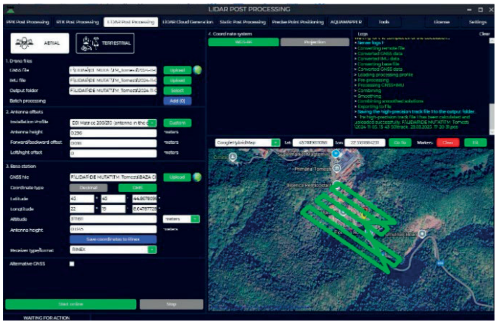

Figure 5. LiDAR postprocessing

SLAM (Simultaneous Localization and Mapping) was performed using the Feima SLAM100 handheld scanner, equipped with a Hensai XT16 LiDAR sensor offering 360° horizontal and 270° vertical coverage. This was essential for mapping the hydro-technical gallery's interior, where GNSS was unavailable. Georeferencing was achieved by aligning SLAM data with Ground Control Points (GCPs) previously measured via total stations, ensuring consistency with the national coordinate system.

Raw SLAM data was processed in SLAM GO software for trajectory reconstruction, noise filtering, and initial alignment. The resulting point cloud was imported into LiDAR360, where the Cloth Simulation Filter (CSF) algorithm classified ground and non-ground points to extract underground terrain and structural elements. All datasets, LiDAR, photogrammetry, SLAM, and total station measurements, were integrated in Pix4Dsurvey, enabling vector extraction and cross-validation. This harmonized geospatial environment allowed accurate digitization of infrastructure features, later exported to AutoCAD for engineering design.

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The fusion of classical surveying tools with advanced scanning technologies ensured precise documentation of both surface and subsurface structures, supporting the rehabilitation planning of the Tomesti hydro-technical system.

RESULTS AND DISCUSSIONS

Integrated survey outputs and geospatial products

The integrated survey campaign carried out for the Tomesti micro-hydropower station rehabilitation produced a comprehensive suite of geospatial deliverables essential to the project's technical and environmental planning. These outputs include orthophotos, digital terrain and surface models (DTM/DSM), dense point clouds, topographic layouts, and detailed cross-sections, each contributing to a deeper understanding of both surface and underground conditions.

Figure 6 illustrates a detailed three-dimensional topographic rendering of the Tomesti site, showcasing elevation through dense contour lines. The layout captures the steep and complex terrain of the valley, essential for hydrotechnical planning. Superimposed vector elements such as roads, hydro-technical structures, and land parcel outlines are integrated into the model, allowing for precise spatial analysis and elevation profiling. This visualization supports slope analysis, infrastructure alignment, and drainage assessment, forming a key tool in the rehabilitation planning process of the micro-hydropower system.

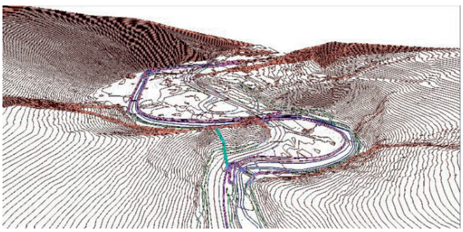

Figure 6. 3D terrain representation with contour lines

Figure 7 presents a high-resolution Digital Elevation Model (DEM) of the Tomesti study area, visualized using a hue-saturation-value (HSV) shader to depict elevation changes. The colour gradient, from red (higher elevations) to blue and green (lower elevations), clearly outlines the valley's terrain morphology, built structures, and hydrological features. The DEM was derived from UAV-based LiDAR data, offering fine detail necessary for slope analysis, hydrological modelling, and infrastructure planning. This product is essential for understanding elevation variability and guiding technical designs within the hydropower rehabilitation project.

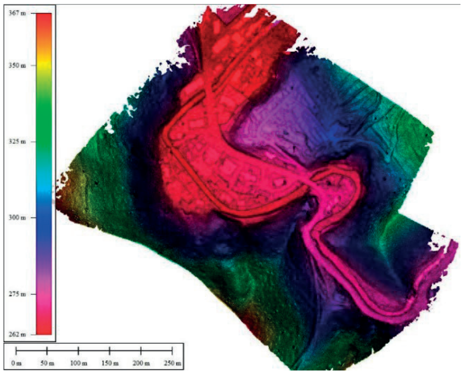

Figure 7. Digital Elevation Model (DEM) with HSV Shading

Figure 8 illustrates a Triangulated Irregular Network (TIN) model overlaid with vector data and geospatial control points. The TIN surface, derived from LiDAR and photogrammetric inputs, represents detailed terrain morphology through irregular triangle meshes. Superimposed vector lines denote features such as roads, hydrological networks, and infrastructure elements, while coloured pins mark field-verified geospatial targets or control points. This combined visualization supports 3D terrain analysis, infrastructure alignment, and engineering planning within the Tomesti hydropower site.

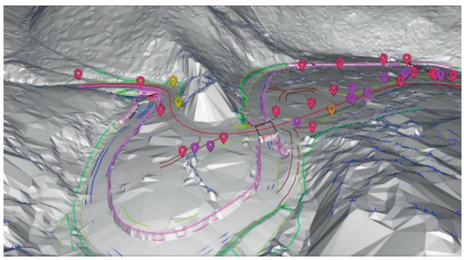

Figure 8. TIN surface with vector overlay and markers

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Figure 9 presents a cross-section profile extracted from LiDAR data, corresponding to the yellow transect line shown on the elevation-coloured orthophoto. The upper image provides spatial context within the Tomesti site, while the lower section displays elevation values along the transect. The profile distinctly captures both surface terrain, including road infrastructure and vegetation, as well as the outline of the underground hydrotechnical tunnel. This dual-layer representation offers valuable insights into the vertical spatial relationships between above-ground features and subsurface infrastructure.

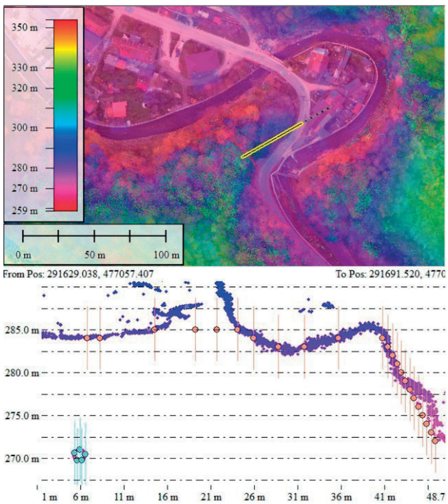

Figure 9. LiDAR and SLAM derived cross-section profile

Figure 10 displays a high-resolution UAV-derived orthophoto of the Tomesti site, overlaid with the traced alignment of the underground tunnel.

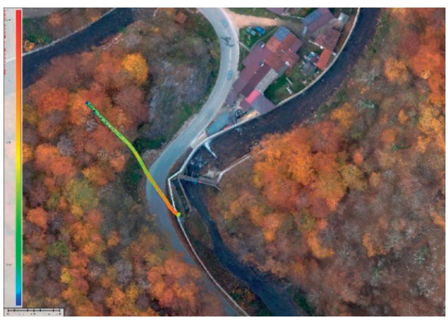

Figure 10. Orthophoto with tunnel overlay

The tunnel path is color-coded by elevation, allowing clear visualization of its trajectory beneath the terrain and infrastructure. The overlay facilitates precise spatial correlation between the subsurface gallery and surface features, proving essential for engineering assessment and future rehabilitation planning.

Topographic mapping and layout plan

Topographic plans are essential tools in civil engineering, infrastructure development, and environmental management. These scaled cartographic outputs accurately represent terrain through elevation contours, hydrography, vegetation, and man-made structures such as roads or utilities. They are critical for understanding slope dynamics, drainage paths, construction feasibility, and site access, particularly in mountainous terrain like the Tomesti study area.

Beyond visual representation, topographic plans integrate data from GNSS, total station, UAV photogrammetry, and LiDAR to provide georeferenced context for all design and modelling efforts.

In modern workflows, these plans are derived from dense point clouds and processed in platforms such as Pix4Dsurvey or AutoCAD Civil 3D, allowing precise integration with engineering and environmental analyses. Their role extends from initial assessment to ongoing monitoring, making them a central deliverable in multidisciplinary survey projects.

The Topographic Plan (Figure 11) marks the culmination of the Tomesti survey campaign, merging LiDAR and photogrammetric data with vector features derived from total station observations. It depicts both natural and built elements, offering a comprehensive layout for hydrotechnical assessment and design. Contour lines extracted from the DTM illustrate slope variations and elevation changes crucial for hydrological planning and infrastructure layout. The alignment of the underground gallery, catchment structures, forested zones, roads, and open terrain are all vectorized and overlaid on an orthophoto mosaic, enabling precise visual correlation with real-world imagery.

This detailed and multi-layered plan provides the spatial foundation for modelling, engineering design, and environmental evaluations, supporting the informed rehabilitation of the Tomesti micro-hydropower system.

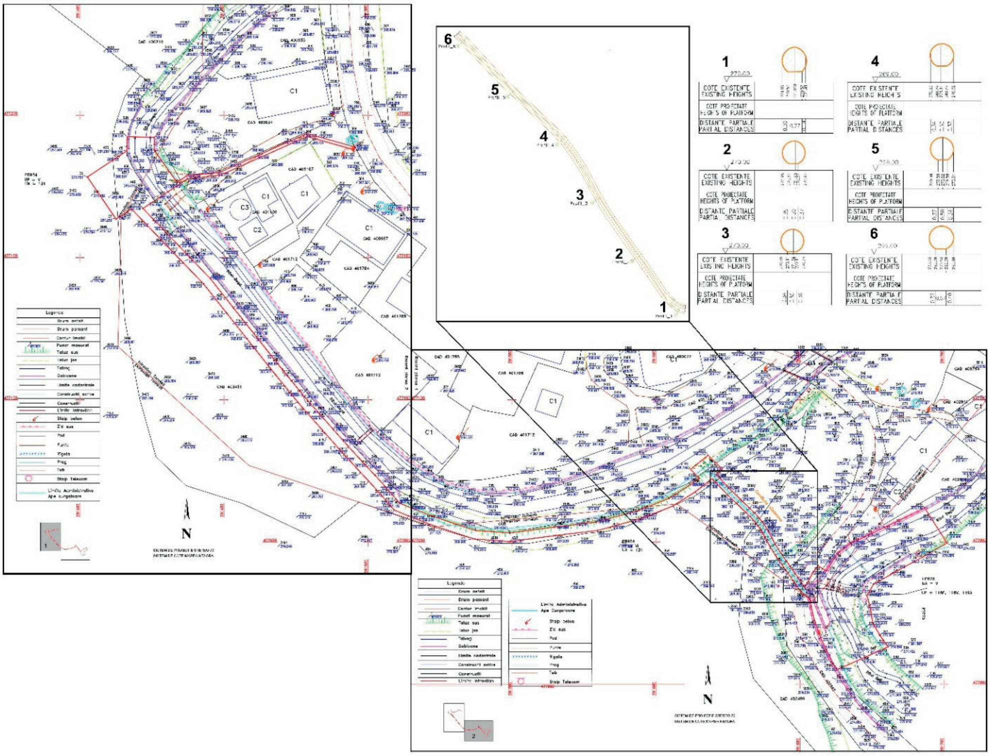

Figure 11. Topographic plan of Tomesti study area with integrated elevation, hydrography, and infrastructure data

SLAM data accuracy assessment and control point validation

Accuracy assessment is a critical element in geospatial data acquisition, especially when merging outputs from multiple sensors like SLAM and total stations (Figure 12). In complex engineering projects, spatial precision underpins reliable design, structural analysis, and implementation. While SLAM excels in GNSS-denied environments such as tunnels, it is prone to positional drift and trajectory errors from motion instability and sensor noise. To ensure spatial integrity, SLAM point clouds must be validated against high-accuracy control points, best obtained using total stations, which offer millimetric precision in areas where GNSS is ineffective. Comparing SLAM outputs with total station-derived control points allows for the identification and correction of spatial discrepancies, ensuring the dataset is accurately aligned within the project's coordinate system. This process is essential for hydrotechnical rehabilitation, where accurate underground alignment and modelling are vital. Ultimately, such accuracy checks enhance the reliability of final products and support confident, data-driven decisions.

Figure 12. SLAM point cloud with GCPs (G6–G11) used for spatial alignment and accuracy validation in the national coordinate system

The table presents an accuracy assessment comparing SLAM (Simultaneous Localization and Mapping) data with control point coordinates measured via total station. It includes six control points (G6 to G11), showing both coordinate sets to evaluate SLAM's spatial precision in inaccessible environments. For each point, residual errors in X, Y, and Z axes are provided (Table 1), with D_{XY} representing horizontal deviation and D_Z the vertical difference. D_{XY} errors range from 0.021 to 0.052 m, while D_Z values remain below ±0.02 m, indicating strong vertical consistency.

Table 1. Residual errors for each GCP, with overall accuracy assessment

Control point (m)				Measurement Coordinates (m)			Residual Error (m)			
GCP Name	East X	North Y	Up Z	Measurement X	Measurement Y	Measurement Z	DX	DY	DXY	DZ
G 8	291671.593	477060.581	272.453	291671.570	477060.582	272.473	0.023	-0.001	0.023	-0.020
G 9	291653.152	477030.348	274.453	291653.147	477030.320	274.469	0.005	0.028	0.029	-0.016
G 10	291664.952	477032.59	272.710	291664.900	477032.587	272.712	0.052	0.003	0.052	-0.002
G 11	291691.226	477045.855	271.724	291691.207	477045.884	271.727	0.019	-0.029	0.034	-0.003
G 7	291661.634	477099.282	270.974	291661.625	477099.263	270.997	0.009	0.019	0.021	-0.023
G 6	291637.355	477123.85	270.088	291637.383	477123.871	270.087	-0.028	-0.021	0.035	0.001
Mean Error							0.013	0.000	0.032	-0.010
RMSE							0.027	0.020	0.034	0.014

Also included are the mean error and Root Mean Square Error (RMSE), with an RMSE of ~0.027 m, validating the system's high accuracy, remarkable for a GNSS-denied, subterranean environment. This confirms SLAM's ability to achieve centimeter-level precision when anchored to total station benchmarks. For the Tomesti project, SLAM delivered reliable 3D documentation that met engineering standards for structural evaluation and design planning.

Rehabilitation strategy and hydro-technical design proposals

The revitalization of the Tomesti micro-hydropower station represents a strategic fusion of modern geospatial technologies and sustainable energy objectives. Originally planned decades ago but left incomplete, the site remains viable due to its existing underground infrastructure and favorable hydrological context. The current project outlines a full rehabilitation strategy, aligning with present-day technical, environmental, and policy standards.

Based on high-resolution topographic and 3D mapping using GNSS, LiDAR, and SLAM, the proposed works address both surface and underground hydro-technical components. This geospatial data provided accurate terrain models, structural detail, and precise spatial alignment to guide engineering analysis and updated documentation.

Rehabilitation efforts focus on the adduction gallery and water intake systems. The pre-existing tunnel, though unused, was digitally reconstructed via SLAM scanning, allowing for condition evaluation and targeted actions such as consolidation, alignment correction, and sealing, ensuring long-term functionality under varying flow regimes.

At the surface, the intake structures on Bega River tributaries will be redesigned to meet modern hydropower standards. The updated system integrates ecological flow control, sediment handling, and durability improvements, using adjustable sluices and fish-friendly features to guide water safely into the rehabilitated gallery.

Further downstream, the incomplete power cavern will be fitted with automated turbines and linked to the national grid. The upgraded facility aims to deliver efficient, low-impact renewable energy, contributing to local sustainability goals.

The 3D rendering of the intake structure illustrates the planned upgrades derived from our integrated survey campaign (Figure 13). Key rehabilitation targets include degraded concrete components such as the overflow weir, sluice niches, retaining walls, and loading chamber. These will be cleaned and reinforced using mesh and sprayed concrete to restore structural integrity.

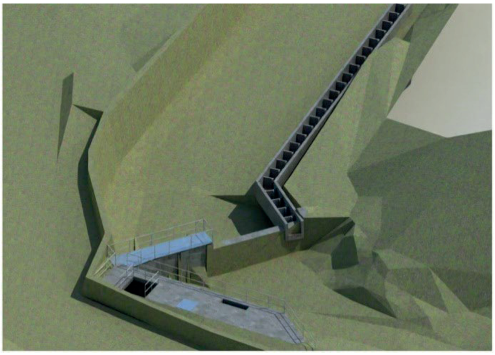

Figure 13. 3D rendering of the rehabilitated water intake structure, designed based on topographic and LiDAR measurements, showing the restored weir, retaining walls, and access elements integrated into the terrain

Interior and exterior reinforcements will be connected to enhance cohesion (Figure 14). The proposed design aligns precisely with terrain data extracted from UAV photogrammetry and SLAM scans, ensuring accurate positioning and minimal landscape alteration.

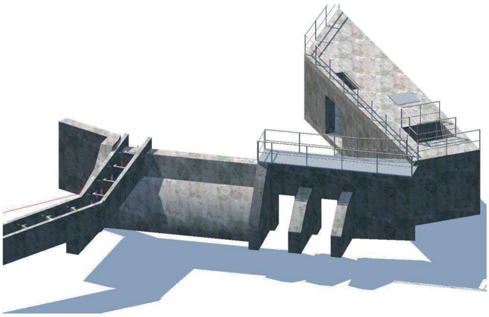

Figure 14. Detailed 3D model of the rehabilitated intake structure, highlighting spillway elements, intake gates, and access platforms, reconstructed based on precise geospatial data

Crucially, all interventions are designed to comply with national energy and environmental regulations. The project embraces a low-impact philosophy, reusing existing structures, minimizing deforestation, and preserving the visual integrity of the mountainous landscape. As such, the Tomesti initiative illustrates how legacy hydro-infrastructure can be repurposed using contemporary tools, offering a replicable model for future sustainable energy projects in similar terrains.

CONCLUSIONS

This study demonstrates the critical importance of integrating modern geospatial technologies with traditional surveying methods for complex infrastructure projects situated in rugged, forested, and geologically challenging environments. The revitalization of the Tomesti micro-hydropower station, a legacy project abandoned decades ago, required not only technical innovation but also methodological precision and environmental sensitivity. Through the combined use of GNSS-based control networks, total station measurements, UAV photogrammetry, airborne LiDAR, and SLAM scanning, a comprehensive spatial dataset was generated, one capable of supporting both engineering design and environmental compliance.

The resulting geospatial products, including orthophotos, DSMs, DTMs, 3D tunnel reconstructions, and a detailed topographic plan, provide a unified spatial framework for decision-making and technical validation. Accuracy assessments between SLAM-derived outputs and total station control points confirmed the reliability of the multi-sensor workflow, with sub-decimetric residuals ensuring confidence in the datasets used for design.

The case of Tomesti highlights how modern geomatics can breathe new life into dormant infrastructure by bridging outdated documentation with current spatial realities. The proposed rehabilitation, grounded in this high-fidelity survey campaign, encompasses both structural restoration and environmentally conscious hydrotechnical design. If implemented, this initiative will not only contribute to local renewable energy production, but also serve as a replicable model for similar projects across Romania and other mountainous regions. This work underlines the evolving role of geomatics in sustainable development, where multi-sensor integration, precision mapping, and terrain intelligence converge to enable resilient, future-ready engineering solutions.

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