UNIVERSITÀ DI SIENA 1240

CGT SAN GIOVANNI VALDARNO

Final dissertation: Master of Science in Geomatics

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Dr. Lorenzo Agostinelli

Definition of an operational protocol for terrestrial laser scanning surveying and orthophotographic restitution of a cycle path

Internship at Monitor The Planet S.R.L.

The project involved the integration of different surveying and data processing techniques, including terrestrial laser scanning, UAV-based photogrammetric surveying, and subsequent post-processing and graphical restitution phases. The analysis of the results focused both on the internal quality of the generated datasets and on their mutual consistency, with particular attention to the limitations related to the absence of ground control points (GCPs).

With regard to the laser scanner survey, despite the use of a high-performance system equipped with a millimetric-precision LiDAR sensor and a survey-grade GNSS/IMU unit, the internal coherence of the point cloud alone does not allow for the evaluation of the absolute accuracy of the model with respect to the real reference system. It is in fact possible to obtain a geometrically continuous, stable, and locally well-aligned point cloud that is globally translated or rotated in space due to residual systematic errors (biases), which may arise from uncertainties in the GNSS solution, lever arm calibration, or inertial unit orientation. In the absence of GCPs, such discrepancies cannot be directly detected, and therefore centimetric absolute accuracies cannot be scientifically demonstrated. Considering the operational conditions and the 1:200 restitution scale, a conservative estimate of the absolute planimetric accuracy ranging between 3 and 5 cm is consistent with technical literature and professional practice.

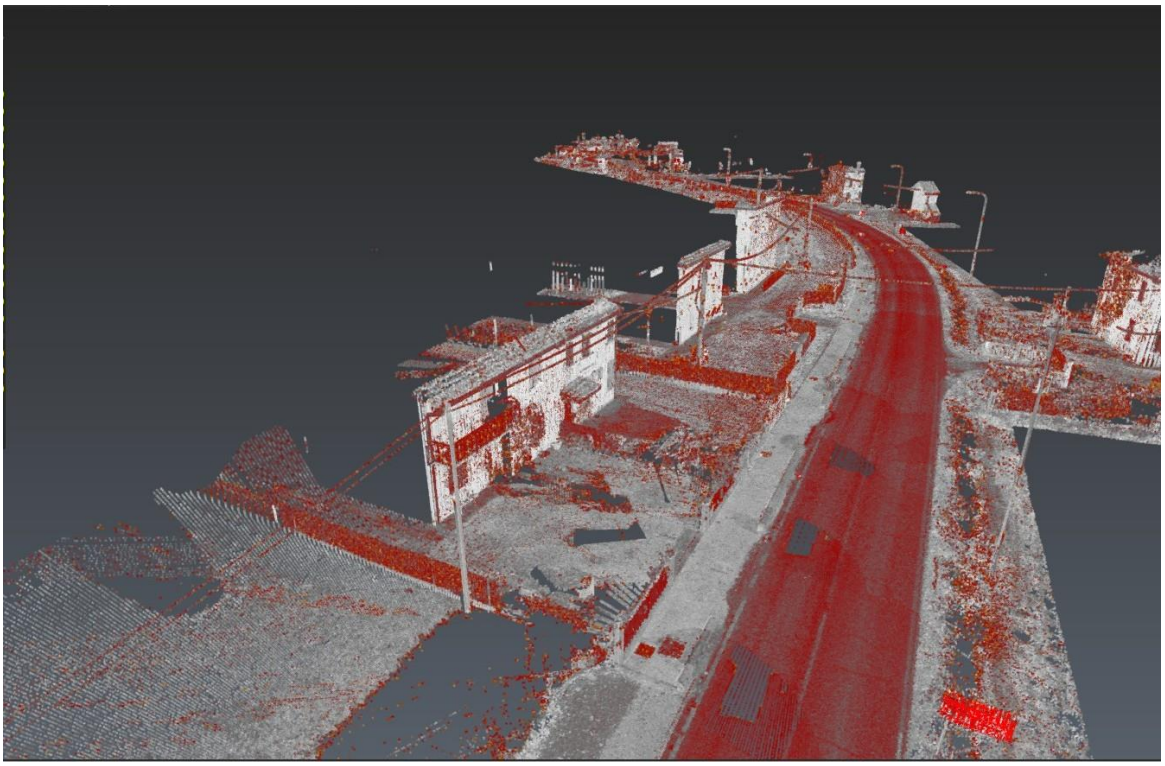
The analysis of inertial measurements highlights a regular behaviour of the IMU, with no significant peaks in acceleration and rotation components along the instrument fixed axes. Similarly, the analysis of the GNSS time series along the North, East, and Up components shows a stable and continuous positioning solution, with physiological oscillations mainly affecting the vertical component, which are consistent with the expected behaviour of GNSS positioning in kinematic mode. The trajectory optimization report confirms the proper convergence of the GNSS/IMU/LiDAR integration model, while not excluding the presence of residual systematic errors in the absence of external control points.

Regarding the UAV-based photogrammetric survey, the processing of the 53 nadir images in Agisoft Metashape produced an internally consistent model, as demonstrated by the low reprojection errors, the high number of tie points, and the stability of the estimated camera positions. The camera calibration shows limited values of radial and tangential distortion parameters, with minimal residuals, confirming the good geometric quality of the model. The resulting orthophoto is correctly georeferenced in relative terms; however, similarly to the laser scanner dataset, its absolute accuracy cannot be reliably assessed without GCPs, making the product mainly suitable for relative analyses and geometric comparisons.

The final phase of the workflow involved data processing and graphical restitution in xPad and AutoCAD environments. The elements affected by the intervention were extracted from the point cloud through the generation of lines and points, subsequently exported in DWG format and refined in AutoCAD. Each element was assigned a dedicated layer and an associated elevation value, in order to improve drawing readability and data organization. The overlay of the vector outputs with the orthophoto highlights a substantial consistency between the two survey sources, despite the presence of local discrepancies of a few centimeters, mainly attributable to the lack of ground control points.

Overall, the adopted workflow enabled the production of an integrated and coherent dataset, suitable for the objectives of the project, namely to provide a reliable visual and informational support for the design of the cycling path widening intervention.

Despite the limitations related to absolute accuracy, the results ensure a high relative quality and a reliable representation of the existing conditions, appropriate for subsequent design phases.

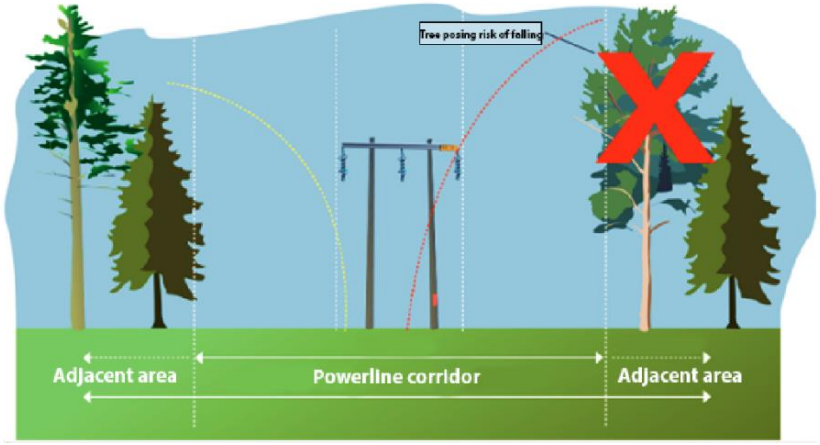


Dr. Gianmaria Brianese

Vegetation Hazard Assessment in Power Lines: from LiDAR to GIS

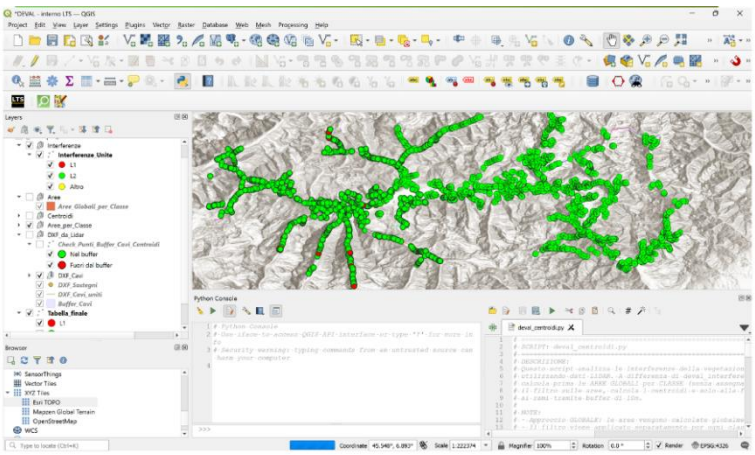
Internship at LTS Land Technology & Services srl

This report documents the methodologies and outcomes of 2 projects focused on automating vegetation hazard assessment along power line corridors, conducted during an internship at LTS Land Technology & Services S.r.l. The work addresses the limitations of traditional manual GIS analysis, which is labour-intensive, prone to operator error, and poorly scalable to networks spanning hundreds of kilometres.



Two distinct, semi-automated PyQGIS workflows were developed to process LiDAR-derived vegetation interference point features for two Italian Distribution System Operators (DSOs). The first, applied to a ~550 km regional grid traversing predominantly flat terrain, implements a span-by-span methodology in which interference point features are assigned to individual spans via a 6 m Euclidean buffer and Spatial Join with predicate CONTAINS. The second, developed for an ~850 km branching Alpine distribution network, implements an object-based geospatial analysis paradigm: approximately 9.5 million individual interference point features are aggregated into ~6,500 discrete vegetation patch objects through morphological buffer-dissolve clustering, which are then assigned to multiple network branches via a one-to-many Spatial Join with predicate INTERSECTS, enabling robust management of hazards at complex junction zones.

The automated pipelines achieved an approximately 70% reduction in processing time, enhanced standardisation, and improved data quality by minimising manual errors. Client-ready deliverables include formatted management tables (XLSX) and KMZ packages for field crew navigation. This work demonstrates the critical importance of adapting automated geospatial analysis to specific geographic, topological, and operational requirements, successfully transitioning from manual, operator-dependent processes to reproducible, scalable data-driven workflows for critical infrastructure management.



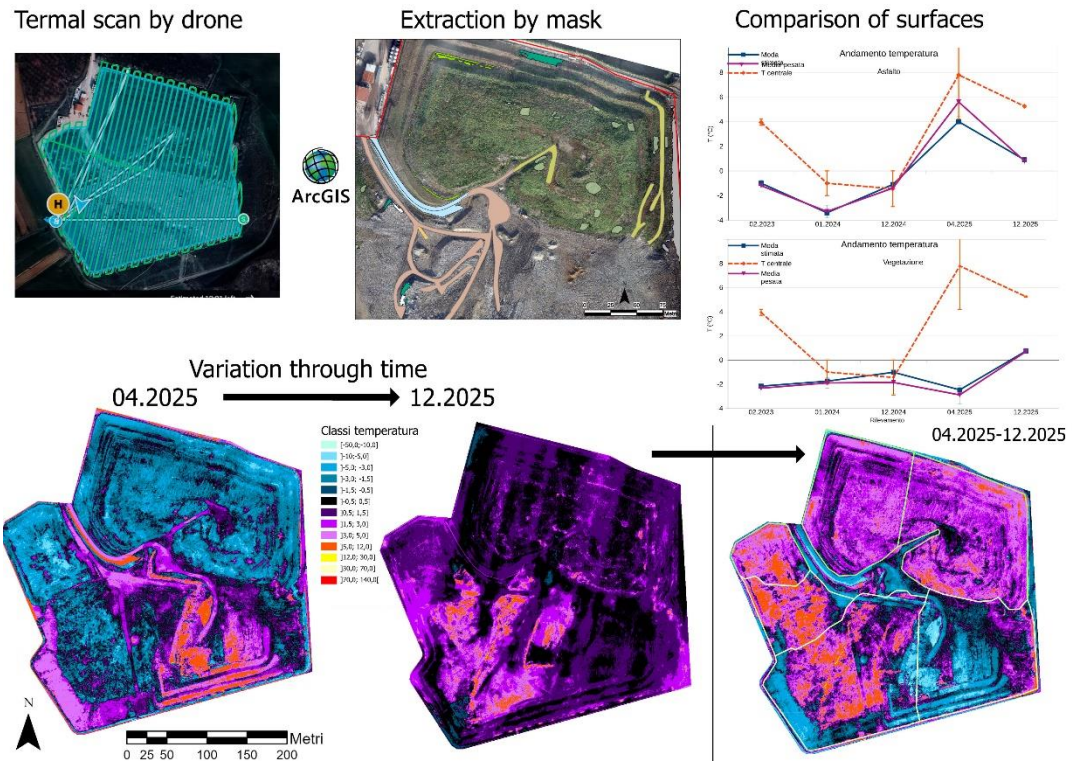
Dr. Marcello Perillo

Time-lapse thermographic analysis using UAVs of the non-hazardous waste landfill in Cerro Tanaro (AT)

Internship at Monitor The Planet S.R.L.

This study analyses the surface thermal behaviour of a landfill site using drone-based thermal surveys, with the aim of identifying anomalies potentially related to the fires outbreak and constructing an interpretative to support future monitoring activities. The analysis of five survey campaigns between 2023 and 2025, complemented by thermal difference maps and weighted statistical indicators, enabled the distinctionbetween anomalies within active basins, linked to waste piles and cover thickness, and recurring perimeter anomalies, independent of waste disposal activities.

The thermal signatures of typical infrastructure elements are clearly distinguishable from critical hotspots through morphological analysis. Sub-optimal environmental conditions influence the interpretation of thermal variations but do not compromise the identification of temperature peaks. The basins exhibit thermal behaviour dependent on their operational status, while the cover surfaces show differentiated responses: asphalt and dirt roads are more sensitive to temperature changes, vegetation has a mitigating effect, and synthetic covers display more stable and consistent behaviour, making them surfaces of particular interest for the identification of potential triggering conditions. Finally, the study highlights the importance of field-testing sampling masks to ensure the reliability of the analysis.



Dr. Davide Rossi

GNSS surveying and GIS processing for mapping Arctic trails: Application in Greenland

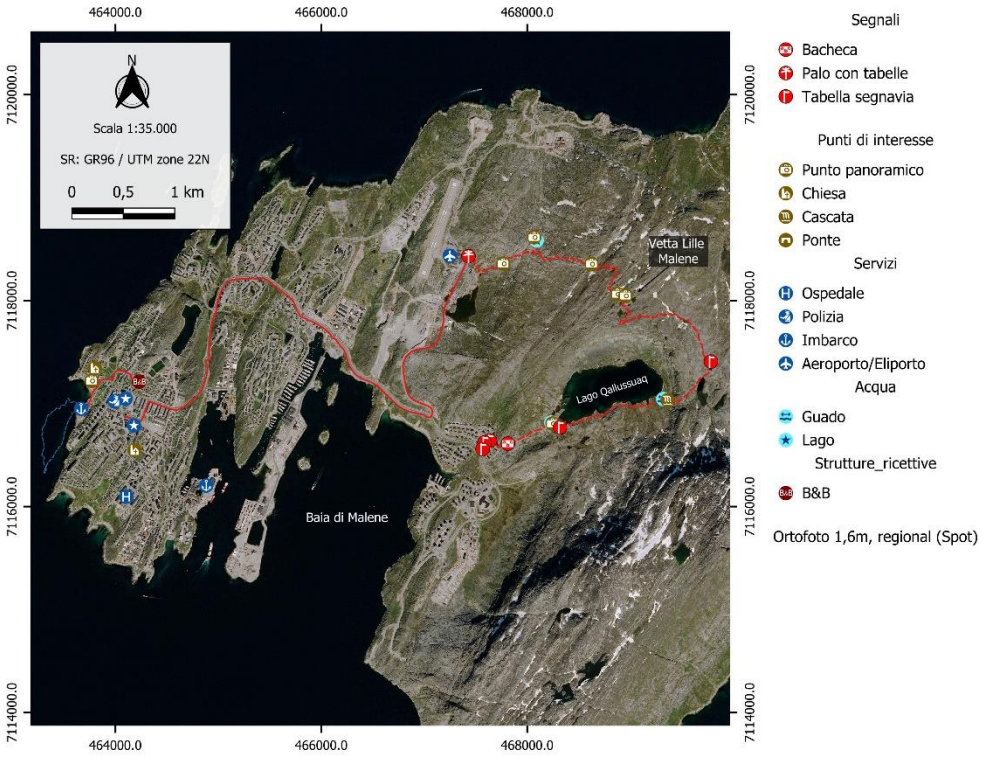
Internship at GPS Brianza

This work documents the methodological workflow for the development of a WebGIS dedicated to hiking trails, based on data acquired during the "ICELAND-GREENLAND 2025" scientific expedition, which was coordinated by Giorgio Meroni of the GPSBRIANZA team, in collaboration with the RIPARTIAMO association.

The main objective of the research was precision surveying in subarctic and arctic environments, aimed to creating a WebGIS for the consultation and dissemination of the data.

The field acquisition phase involved, QField software connected to the Trimble Catalyst GNSS receiver, which allowed the digitization of spatial data directly on mobile devices, ensuring synchronization between GNSS positioning and the specific database created for the expedition. The data was then processed using QGIS software for post-processing of tracks, topological validation, and geographic database management, leveraging the software's analytical capabilities for the integration of raster and vector data.

The final part of the study focused on publishing the results through an interactive WebGIS platform. This step made it possible to share the expedition's routes and surveys, demonstrating the effectiveness of integrating mobile GIS and desktop GIS tools for cartographic documentation in even extreme environmental contexts.



Dr. Francesco Rosso

Development of a WebGIS platform for environmental monitoring and methodological framework for tree inventory from UAV-based multispectral imagery

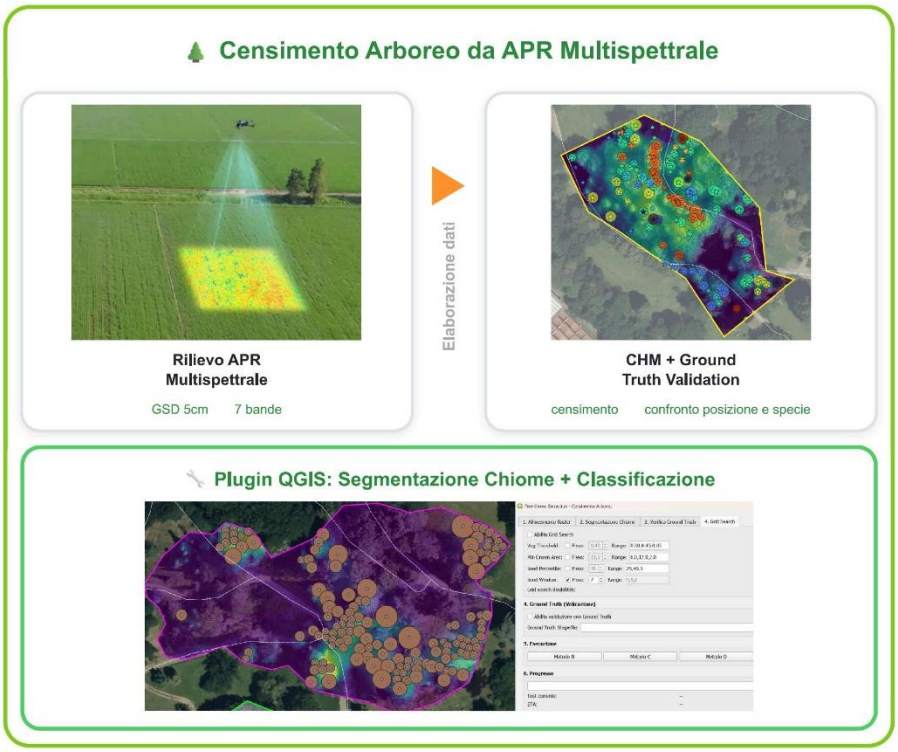
Internship at Co.R.In.Te.A.

This report describes the activities carried out during an internship structured around two complementary projects, both faimed at the development and application of advanced GIS tools for environmental monitoring and land management.

Project 1 – "SMART-GUARD" involved the design and implementation of an integrated digital platform supporting natural hazard management in pilot territorial contexts, with specific focus on wildfire monitoring in the Val di Susa (Piedmont). The system, conceived as a modular Decision Support System (DSS), is based on a multi-component WebGIS architecture developed using Docker stack (PostgreSQL/PostGIS, FastAPI, Nginx), which integrates: (a) automated acquisition of meteorological data from the ARPA Piedmont network via public APIs, with time-series storage; (b) operational computation of the Fire Weather Index (FWI) according to the Canadian Forest Fire Weather Index System, with hazard threshold adapted to the regional context; (c) spatial aggregation of the FWI over the area of interest through multi-criteria weighting (IDW-based spatial contributions, Gaussian altimetric components, qualitative factors); (d) real-time tracking WebGIS for Wildfire Prevention (AIB) volunteers and operational assets, based on GPS acquisition via Bot Telegram and digital channels, including user role management and an administrative dashboard. The platform enables both cartographic and temporal visualization of hazard indices over configurable time windows (24h, 48h, 7 days) and supports future integration with dedicated monitoring networks and fire spread simulation systems (ROS, Rate of Spread).

Project 2 – "Tree Census from Unmanned Aerial Vehicles (UAV)" focused on the automated reconstruction of dendrometric variables at individual tree scale level from high-resolution multispectral UAV surveys (GSD 5 cm), operating in inverse mode with respect to a georeferenced Ground Truth dataset (340 trees, 39 species, 86 features per tree). The workflow integrates Structure-from-Motion photogrammetric products (DSM, DTM, CHM, RGB and 4-band multispectral orthomosaics: Green, Red, RedEdge, NIR) and is implemented in a dedicated QGIS plugin (TreeCrownPlugin) structured into

four functional modules: (1) preprocessing and geometric raster alignment via GDAL Warp; (2) crown segmentation through three alternative data-driven methods (Method B: CHM-based watershed; Method C: radiometric Pseudo-CHM derived from spectral indices and GLCM texture; Method D: RGB-based approach using ensemble colorimetric filters ExG/ExGR/CIVE); (3) weighted multi-criteria taxonomic classification based on five components (spectral similarity 40%, vegetation indices 30%, height 15%, crown diameter 10%, morphometry 5%), including explicit uncertainty management through a confidence threshold (0.60) and an "Unknown" class; (4) quantitative validation against Ground Truth using via nearest-neighbor spatial matching and exhaustive Grid Search for parametric optimization (225 configurations tested per method, adopting multi-area protocol with incremental A→B→C validation to assess geographic transferability).



Results from Project 2 highlight significant performance limitations: the detection module achieved a maximum F1-score of 0.143 (Area B, Method B), well below operational standards (target F1 > 0.60), attributable to a combination of non-uniform CHM quality, suboptimal watershed parameterization, and potentially excessive strictness of the spatial matching criterion. Fine-scale classification into 39 species proved unfeasible using the weighted multi-criteria approach (maximum Overall Accuracy 5.9%), confirming the limited discriminative power of 4-band multispectral sensor information content for high inter-specific discrimination. However, the implementation of a binary Random Forest classifier for Conifer/Broadleaf discrimination demonstrated robust hierarchical separability (Accuracy 88.15%, ROC-AUC 0.927 on an independent test set), highlighting the feasibility of functional classification even with entry-level sensors.

Overall, this work provides: (a) an operational WebGIS system for wildfire risk monitoring integrating FWI integration and AIB tracking, transferable to analogous contexts; (b) a modular, open-source QGIS plugin for UAV-based tree inventories, featuring an extensible architecture and integrated quantitative validation; (c) documented evidence on realistic operational constraints of low-cost multispectral UAV forest remote sensing (critical importance of CHM quality, necessity of hierarchical taxonomic aggregation, Ground Truth sampling requirements), thereby guiding future developments toward evidence-based strategies.