21. Integrated UAV LiDAR–RGB Accuracy Assessment under Reduced Ground Control: A Pilot-Scale Framework

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The integration of UAV-mounted LiDAR, RGB imaging, and RTK positioning has significantly expanded the capabilities of high-resolution 3D mapping. However, nominal positioning accuracy alone does not guarantee geometric reliability in heterogeneous built environments. This study presents a pilot-scale methodology for assessing UAV LiDAR–RGB products under reduced ground-control conditions, tested in a heterogeneous built environment at the University of Calabria campus using NRTK observations and static GNSS measurements. Five GCPs were used for photogrammetric control, and three points were retained for independent validation. The LiDAR point cloud was independently checked against static GNSS and used as a spatial benchmark. Five RGB photogrammetric scenarios were processed, combining nadir and oblique imagery, reduced GCP configurations, and low-altitude oblique imagery to enhance façade reconstruction. Validation integrated independent checkpoint residuals, pavement cloud-to-cloud comparisons, planar façade point-to-plane distances, and full-façade LiDAR-to-photogrammetric proximity metrics. Moving from the nadir-only configuration to the nadir-plus-oblique configuration reduced vertical checkpoint RMSE from 66.46 cm to 15.03 cm and pavement mean cloud-to-cloud distance from 53.83 cm to 5.27 cm. The RTK configuration with three GCPs further reduced vertical RMSE to 3.16 cm and pavement discrepancies to about 2.2 cm. The five-GCP configuration supplemented with low-altitude oblique imagery achieved a 2.50 cm vertical RMSE, 2.71 cm façade-normal RMSE, and 2.95 cm median full-façade distance, with 92.92% of LiDAR façade points having a photogrammetric neighbor within 10 cm. Under the investigated conditions, image geometry and limited ground control provided complementary benefits, supporting efficient and reproducible UAV survey design in complex built environments.