# Update and Quality Assessment of GeoDBs in Urban Areas Based on SLAM Technology

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**Abstract**

The quality assessment and updating of spatial geodatabases (geoDBs) are essential tasks for effective spatial data management. This paper introduces an innovative methodology called Virtual Reconnaissance (VRec), which leverages Mobile Laser Scanning (MLS) systems based on Simultaneous Localization and Mapping (SLAM) technology. VRec aims to support both field reconnaissance and the geometric/semantic validation of GeoDBs. After reviewing the state-of-the-art, a case study in the municipality of Lecco (Italy) is presented, where a portable MLS device was used to acquire high-resolution point clouds. These data were georeferenced using GNSS ground control points (GCPs) and compared with the existing geoDB. Results demonstrate that VRec enables accurate quality assessment within official tolerance thresholds and offers promising capabilities for GeoDB updating, especially in complex urban environments. While data processing still requires skilled operators and significant time investment, future integration with artificial intelligence techniques may enhance efficiency and scalability.

**Keywords:** Mobile Laser Scanning, Quality Assessment, SLAM, Geospatial Database, Updating.

## 1. Introduction

### 1.1 Geodatabase production and assessment

Geospatial Databases (geoDBs) have become a fundamental geographic and semantic basis for the management and analysis of urban environments. Developed across the beginning of the new millennium, they inherited some functions of previous technical topographic mapping products adopted for representation of urban areas (i.e., vector numerical cartography, raster maps, digital orthophotos, digital terrain models) but with the option to apply those methods and techniques derived from the Geographic Information Science. The typical application of these technical topographic products, in general produced at a equivalent scale ranging between 1:1,000 to 1:2,000, is to support urban planning and to control the application of existing plans and rules. Cadastral functions are also important, if not confined to a different mapping set, as it is the case of Italy.
The production process of GeoDBs may follow two alternative pipelines, which depend on the availability of existing data to recover and update:

1. creation of a completely new GeoDB; or
2. update of existing datasets.

In both cases, spatial 3D information can be retrieved from stereoplotting based on aerial imagery acquired by manned aircrafts or drones, LiDAR data, ground-based surveying and field recognition, the latter important for the assignment of the semantic content of each object. Due to the complexity of the urban environments, the role of ground operations is even more important than in the countryside or in open terrain, where aerial data may suffice for the reconstruction.
Quality Assessment (QA) is another crucial task in the production/update of geoDBs. While different projects may entail their own requirements about this task, the comparison between the reconstructed urban model and the real situation is the general approach to assess the geometric and semantic content. Both types of validation need a physical exploration at the ground level by expert operators, to be integrated by some surveying measurements (e.g., based on theodolites and/or GNSS) to check the metric aspects. The large extension of geoDB projects often calls for the selection of samples to be assessed, whose extension and number depends on the global size of the dataset to be validated.
From these considerations, it clearly appears that in mapping projects for the generation and/or update of geoDBs, the role of ground surveying and recognition plays a paramount role for the achievement of a very good final geometric/semantic quality. On the other hand, such field operations are time-consuming, they require the presence of expert people on-site and may largely impact the budget. In addition, unlike the information-extraction from images that can be done at any moment, ground operations must be completed during the mission, with no chance to be integrated later in the office. For the sake of completeness, today the availability of aerial images, realistic 3D models and panoramic imagery (see, e.g., Google OpenStreetView®) gives some chances to look at some semantic content of the urban environment from remote. Anyway, these tools do not allow for accurate metric validation.

### 1.2 Virtual Reconnaissance based on SLAM

In other domains, today the impressive developments of 3D modelling technology at medium-close range (Luhmann et al., 2020) has introduced a new approach to integrate or replace on-site data acquisition. One typical application is in the Geosciences, where it is called as Virtual Geology: 3D point clouds obtained from Structure-from-Motion Photogrammetry or terrestrial laser scanning transfer to the office the extraction of information about rock outcrops and other geological structures. In general, the size and the shape of these sites are suitable for reconstructions based on these techniques, with increasing usage of drones for photogrammetric data acquisition. Recently, the progress in the field of LiDAR UAVs has extended the application of this technique (Mandlburger et al., 2023).
On the other hand, the urban environment has a more complex structure to be modelled by using the same methodologies in a reasonable time and cost. A new solution has quickly developed in the recent years to overcome these limitations. It consists of 3D portable Mobile Laser Scanning (MLS) and imaging systems, which can reconstruct a few centimetre-level point cloud based on SLAM (Simultaneous Localization and Mapping) technology, see Zhang et al. (2024).

In general, portable MLS instruments integrate multiple sensors able to capture a precise point cloud of the surrounding environment in a dynamic way. One or more rotating laser scanning measure 3D points while moving, whose georeferencing is reconstructed by fusing three types of data: (1) IMU (Inertial Measurement Unit) observations; (2) GNSS kinematic relative positioning; and (3) registration of multiple scans/images based on SLAM technology. Some sensors are not provided with GNSS, limiting their usage in indoor environments or requiring the stationing on some ground control points (GCPs) for georeferencing in a geodetic/mapping reference system. On the other hand, imaging sensors (frame or panoramic) may collect data for colouring the point cloud. Images can be also exploited for registration in the SLAM process (Visual SLAM).

The available technology includes several solutions, which have seen an impressive a rapid development in the recent years (see for review Di Stefano et al., 2021; Chen et al., 2025).

The use of portable MLS sensors is still not suitable for completing mapping projects. The time and the amount of collected point clouds would be exaggerated w.r.t. the required geometry of new geoDB to be produced. On the other hand, their application may be successfully envisaged for the QA process, or for the update of existing geoDBs. In both cases, the reconstruction of a virtual model of the real environment gives the chance of extracting geometric and semantic information in the office, limiting the work to complete during the field recognition. This solution has been addressed here as 'Virtual Reconnaissance' (VRec).

Starting from the achievements of some authors who have already reported about experience on the application of this kind of methodology (Subsect. 1.3), in this paper we present the VREc approach in Section 2. A case study carried out to assess the QA of a geoDB in urban areas is presented and discussed in Section 3. Some conclusions are addressed in Section 4.

### 1.3 State-of-the-art

**1.3.1 Quality Assessment (QA) of geoDBs.** This process consists in several tasks mainly focused on:

1. the certification of the quality of the adopted instruments (HD/SW) and procedures, as well as the required skills for the employed personnel;
2. the analysis of technical reports of intermediate operational steps (flight mission, stereoplotting, ground recognition, editing, structuring of geoDB files, etc.), including some checks (exhaustive on the complete datasets or by considering samples); and
3. the assessment of spatial accuracy by selecting some samples to be independently assessed based on ground measurements (absolute point coordinates and relative distances/height differences).

These operations are defined in the technical specification of each project.

**1.3.2 Field recognition for geoDBs.** In either the case of completely new geoDB production or update of already-existing ones, the photogrammetric stereo-plotting cannot suffice by itself to provide all necessary 3D information. This is even more clear in projects for large-scale mapping in the range from 1:1,000 to 1:2,000. To clear some details in densely built urban areas, in courtyards, below arcades, colonnades and overhanging roofs, field recognition is crucial to clarify the buildings' geometry and to assess the usage of constructions. This task is traditionally done by operators who explore critical areas based on direct outputs of stereoplotting, which may report questions and locations to be better understood in the field. In recent years, tablets integrating GNSS sensors and showing digital maps in interactive way have been adopted during field recognition. The operator is guided on those areas to investigate, which can be sketched on the screen and directly sent to the map editor in the office. It is evident how complex and time-consuming this phase may be, leading to the incompleteness (or even the lack) of the related information.

**1.3.2 SLAM technology for geoDB QA and recognition.** MLS systems have been already used for the purpose of (i) the ground recognition of new geoDBs and (ii) for their QA. In the latter case (i), one example has been recently reported during a presentation at the Congress of the Italian Society of Photogrammetry and Remote Sensing (SIFET), organized on June 2025 in Brindisi, Italy. A delegate from the cartographic department of Veneto Region reported about an experience of field recognition during a large mapping project at equivalent scale 1:2,000, where a SLAM system was used. After a preliminary analysis of the area-of-interest (AoI), optimal paths are designed to be captured using SLAM carried by hand or installed on bikes and quads. The speaker reported about the success of this solution, which provided good results in terms of accuracy and object identification in massive applications. As far as the accuracy was concerned, it was possible to integrate in the geoDB objects with average residual errors inferior to 50% of the mapping tolerance (50 cm). As far as the object identification, it was possible to detect areas unreachable by man or covered by vegetation. The availability of RGB images collected by a camera integrated in the SLAM sensor supported the object identification.

Another experience in the use of portable MLS technology for the QA assessment of geoDBs is reported by Matellon et al. (2025). The authors organized a test for the QA of the new geoDB of Friuli Venezia Giulia Region, Italy (Eaglefvg, 2025). A case study including eight selected buildings at equivalent scale of 1:2,000 was chosen in the urban area of Udine Town. The geoDB was structures following the national rules implementing an ISO TC211 compliant GeoUML methodology (Italian Government, 2011). Since these require multiple layers for the representation of different types of objects, the QA concerned two of them: (1) the perimeter of buildings' volumes (2D); and (2) the roofing elements (3D). A SLAM-based MLS system Stonex X120$^{GO}$ integrating a GNSS-NRTK (Network Real-Time Kinematic) module (Stonex, 2025) was adopted for the reference point-cloud acquisition. Before comparing this dataset to the geoDB of the AoI, a preliminary comparison w.r.t. 75 control points (CPs) measured by a theodolite (georeferenced using GNSS NRTK) was carried out for assessing the accuracy of the reference point cloud itself. This provided more than acceptable results for both categories of objects under analysis. Indeed, Root Mean Squared Errors (RMSE) resulted 4.4 cm for planimetry and 2.5 cm for elevation, to be compared with official accuracy thresholds (tolerances) for the geoDB, namely 50 cm for planimetry and 40 cm for elevation, respectively.

The QA was operated by comparing the reference (SLAM) point cloud and the geoDB using three methods:

1. point (geoDB) *vs* SLAM point cloud;
2. line (geoDB) *vs* SLAM point cloud; and
3. line (geoDB) *vs* line (SLAM).

More methodological details about these comparisons can be found in Matellon et al. (2025). Aggregated results from the application of all methods gave RMSEs in the range 30.2 cm – 41.2 cm for buildings' perimeters (2D), in the range 13.5 cm –

17.7 cm for planimetric component, and 11.8 cm – 18.7 cm for altimetric component of roofing elements.
The authors discussed some positive points of the proposed QA methodology:

1. faster data acquisition of reference data w.r.t. standard surveying techniques for the measurement of CPs;
2. easier operation even in small and narrow spaces, limiting the measurement of CPs; and
3. the more comprehensive and detailed 3D representation of the mapped environment acquired by SLAM technology also allows for the assessment of the completeness of the vectorized objects.

On the other hand, the application of comparisons techniques based on the extraction of lines from the SLM point cloud are still time consuming and need further work to become automatic.

## 2. The 'Virtual Reconnaissance' (VRec) method

The methodological proposal of this paper consists in the application of a portable MLS system for the purpose of completing the content (field recognition) and for the final QA of a geoDB. This method continues the idea from Matellon et al. (2025) reviewed at Paragraph 1.3.2. The main concept is to replace the activity in-the-field that is necessary in the production process of large-scale GeoDBs (from 1:1,000 to 1:2,000) based on stereoplotting from aerial photos. Visual reconnaissance and theodolite/GNSS measurements are taken over by the analysis of a point cloud to be operated in the office. For this reason, the new approach is addressed to as 'Virtual Reconnaissance' (VRec).
The VRec methodology is organized in the following steps:

1. *data acquisition* using a portable MLS system;
2. *data integration*, in the case the MLS lacks GNSS for autonomous geolocalization or images from a drone are needed for a view from the top; and
3. *data processing* to extract information for update and/or QA purpose.

These steps will be addressed in the following subsections and later demonstrated in a selected case study (Sect. 3).

### 2.1 Data acquisition

Data acquisition is based on the use of a portable MLS sensor, which may also implement surveying- or navigation-grade GNSS for direct georeferencing (Zhang et al., 2024; Scaioni et al., 2025). Alternatively, if GNSS onboard is not present, some GCPs measured using an independent geodetic GNSS sensor in relative mode should be included. In any case, some GCPs to be used for independent QA of MLS data should be measured, as proposed in Matellon et al. (2025).
The global absolute accuracy of MLS, including geolocation errors, may be roughly estimated under ±5 cm. This accuracy is sufficient for the purpose of updating/assessing large-scale GeoDBs, whose uncertainty is generally in the range of a few tens of centimetres for both position and elevation.
In the case the roofs and the upper parts of constructions are rich of details that cannot be seen from the MLS surveying, a photogrammetric drone mission (see Nex et al., 2022) should be included to reconstruct a high-resolution point cloud describing that area. For the sake of completeness, this solution should be also applied when using standard solutions for update/QA, based on theodolite/GNSS measurements. In the most project, budgetary reasons and the short time schedule result in skipping this task, with consequent lack of reliable information in the upper part of buildings.

### 2.2 Data integration

After data acquisition, different datasets have to be integrated among them and correctly georeferenced in the reference system of the geoDB. This holds either in the case the MLS data acquisition has been organized in multiple subprojects, and in the case of data from different sources (e.g., MLS and drone photogrammetry). Modern technology allows direct georeferencing if differential GNSS correction are available in real-time (RTK) or post-processing (PPK) kinematic modes. In other cases, GCP should be measured using targets or well-defined features in the scene. As already mentioned, an independent check of the coregistration/georeferencing between different datasets should be always considered. The use of other solutions for merging point clouds (Wu et al., 2014) should be avoided in this application.
At the end of data integration, it is important to keep memory of the original data source of each point when multiple point clouds are coregistered. This can be done by using a classification index (see, e.g., CloudCompare, 2025).

### 2.3 Data processing

The first stage of data processing, after georeferencing, is the editing of the point cloud to remove all objects that are not necessary for the purpose of update/QA of a GeoDB: external areas of the AoI, cars, people and mobile/temporary objects. Other objects may not be useful for the purpose of this analysis (e.g., road furniture and road signs) but could be saved in a separate layer for future use. The same for low vegetation and trees, which may prevent the visibility of other objects in the point cloud, but they may also provide information useful for the geoDB. This classification and filtering may be carried out manually, but solutions based on Machine Learning (ML) and Deep Learning (DL) may help to this purpose, see Cao et al. (2022). This aspect will be further discussed in Subsection 3.4.
In general, MLS provides uneven point resolution due to multiple overlaps depending on the viewpoint. For this reason, a general downsampling at a resolution close to the expected accuracy of MLS point cloud should be applied.
The most important stage in data processing consists in the information extraction for update/field recognition and QA of the geoDB. We separately analyze the possible methodologies under the VRec approach in two distinct paragraphs.

**2.3.1 Update/field recognition.** This is the case where the semantic interpretation of the scene is more important. A 3D visualization of the available data may help, which consist of the existing geoDB in the case of updating (i), or in the 3D models reconstructed from stereoplotting in the case of field recognition during the production of a new dataset (ii). In the latter case, the GeoDB is not structured in the final format unless the integration of data from the field recognition is accomplished. Consequently, the 3D vector model (e.g., in a CAD format) should be used at this stage.
Available 3D data need to be compared or overlapped to the MLS point cloud (possibly integrated with data from drone photogrammetry, if any). This analysis would allow to detect missing, changed or wrong objects, to be integrated in the GeoDB under updating or editing.
As reported in the experimental Section 3, working with 3D data in complex scenarios is not an easy task, especially in the case of point clouds which do not include surfaces useful to hide those parts visible from the back. For this reason, the extraction of


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horizontal sections may help data interpretation. Sections may support a more solid reconstruction of the planimetric component, which in general should guarantee a higher reliability because its usage is prevalent (e.g., in cadastral applications, in urban planning or outside urban areas).

**2.3.2 Quality Assessment.** This task has been already widely discussed by Matellon et al. (2025), that also explored and tried different solutions as described at Paragraph 1.3.2. In the VRec approach, we propose a simple technique emulating what happens in the traditional QA process. After selecting those layers/classes of objects) to be checked, a sample of elements is chosen, and corresponding vertices (2D/3D) are considered for assessment. Their values in the MLS point cloud are read and used for metric QA. The relative width of roads or the height of buildings from the ground can be assessed as well. Using this approach, here implemented in a manual, interactive way, we operate in the same modality adopted when comparing points from the geoDB to surveying measurements. Of course, other methods based on comparing more points (i.e., those addressed as 'line (geoDB) *vs* SLAM point cloud' and 'line (geoDB) *vs* line (SLAM)*'* at Par. 1.3.2) provide a more complete assessment of the geometry but suffer from a main problem. Indeed, a geoDB is not a mere downscaling representation of reality, but it is an approximation controlled by the *graphical error*. Consequently, it is difficult to distinguish between approximation and measurement errors, being the former potentially much higher. By considering two typical equivalent scales adopted for large-scale geoDBs in urban areas, namely 1:1,000 and 1:2,000, the graphical error is in the range between 20 cm and 40 cm, respectively, depending on the national regulations (Pasquinelli et al., 2019).

## 3. Experiment

### 3.1 The case study

The case study selected for testing the VRec methodology is related to a geoDB at large equivalent scale (1:1,000 in downtown and highly urbanized areas, 1:2,000 in other areas) of the municipality of Lecco in Northern Italy, close to the homonymous lake (which is part of the largest Lake of Como).
A first version of the geoDB was completed in 2006 based on stereoplotting from aerial images. That project was one of the first geoDB completed in the Lombardia Region, which promoted and coordinated the production of these mapping products, also by issuing guidelines and technical regulations (see Scaioni et al., 2009; Belotti et al., 2021). After the completion of these local projects by following regional guidelines (Regione Lombardia, 2017), geoDBs resulting from local projects are integrated in the regional Geoportal (Regione Lombardia, 2025).
In 2024 the geoDB was updated based on a new photogrammetric mission, which collected aerial images and LiDAR data.
An area of the geoDB has been selected for a test based on the acquisition of a point cloud (referred to as "SLAM Point Cloud") using a state-of-the-art portable MLS instrument Zeb Horizon® by GeoSLAM. In Figure 2, the area of the test is shown, which concerns the old fishermen village of Pescarenico, which now is part of the municipality but still preserve its cultural identity and original urban structure.

### 3.2 Purpose of the test

This test has a twofold aim:

Figure 1. Portion of geoDB regarding the test area in the former village of Pescarenico (on the left); on the right, an orthophoto of the same area is shown (source Regione Lombardia, 2025).

1. how the SLAM Point Cloud can be used for the QA of the geoDB; and
2. how the SLAM Point Cloud can be used for upgrading the geoDB.

In this paper we limit to present some preliminary results related to application (1), but already some useful hints concerning application (2) will be discussed in Subsection 3.4.

### 3.3 Data collection and processing

**3.3.1 Field campaign.** The acquisition of the SLAM Point Clouds was carried out on 27 March 2025 and 2 April 2025 by adopting a Zeb Horizon® MLS by GeoSLAM, Orlando, FL, United States (GeoSLAM, 2025). This instrument implements the SLAM technology (Bosse et al., 2012), which provides a relative accuracy of 1 – 3 cm and a scanning rate of 300,000 points/second up to a range of 100 m. It does not incorporate a GNSS sensor, but it may be easily and accurately positioned on GCPs by using a reference mark on the lower part of the instrument body (see Fig. 2). The basic SLAM sensors can be integrated by a set of tools, which are continuously improved within time, as reported in the technical specifications (GeoSLAM, 2025). Some studies about the experimental evaluation of Zeb Horizon® MLS can be found in the literature, see, e.g., Previtali et al. (2020) and Urban et al. (2024).

Figure 2. Image of the portable Mobile Laser Scanning (MLS) Zeb Horizon® by GeoSLAM adopted at the case study.

The data acquisition resulted in two partially overlapped point clouds (Fig. 3) consisting of 73 Mpoints and 61 Mpoints, respectively. Colours were not recorded to limit the data size to process and since the interest was more on the geometry. If required, the acquisition of images for colouring point clouds can be operated by using an additional 4k high-resolution camera (Zeb Vision®). Data acquisition was operated by walking in the streets of Pescarenico to cover all faces of buildings, road surfaces and gardens, see paths in Fig. 3. It took a total time of 18 minutes. A set of 16 GCPs (see Fig. 3) were measured in correspondence of clear features on the ground by means of a surveying-grade GNSS receiver Emlid Reach RS2®. This was used in NRTK mode by connecting to the regional positioning service (SPIN3 GNSS, 2025). The service directly provides corrections referred to the official datum for the area of the geoDB ('RDN 2008/UTM32 Nord'). The control software Emlid Flow also allows to transform GNSS elevations in orthometric height by applying the national geoid model ITALGEO2005 (Barzaghi et al., 2007; ISG, 2005). Both planimetric and altimetric datums correspond to the ones adopted for the geoDB under evaluation. The estimated theoretical accuracy of GCPs resulted as 1.6 cm in E-N and 1.4 cm along H.

GCPs were used for georeferencing both point clouds and to merge them into a unique SLAM Point Cloud. The residuals in correspondence of GCPs after georeferencing was in the same order of point clouds accuracy. This outcome can guarantee that the intrinsic accuracy of the SLAM Point Cloud, coupled with the georeferencing accuracy, make the total accuracy much better than the one of the geoDB to assess.

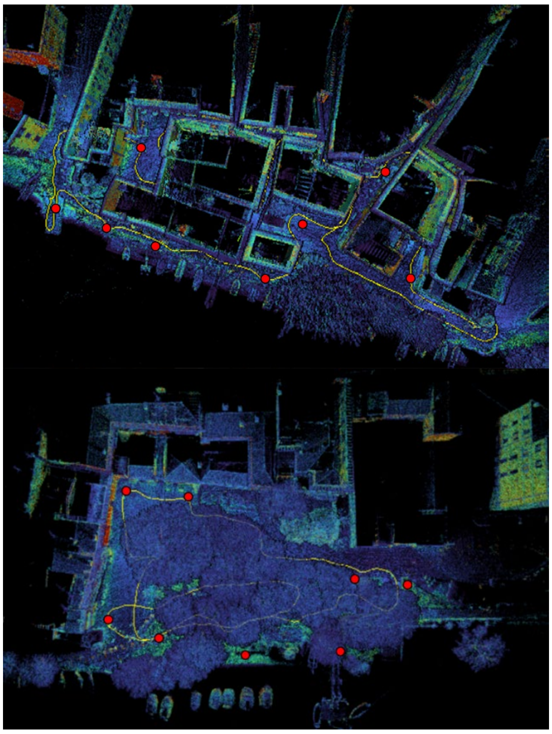

Figure 3. Acquisition of MLS data at the case study. In these planimetric views, both clouds are overlayed with the path of the operator carrying the instrument (yellow lines) and the locations of ground control points (red circles).

**3.3.2 Data processing.** The original SLAM Point Clouds is made up of 134 MPoints. As described in the methodological Subsection 2.3, the first operation in data processing was to clean the point cloud to remove temporary objects and external areas w.r.t. the AoI. Secondly, the numerous trees were filtered out and segmented in a separate class. The latest stable release of CloudCompare software (ver. 2.13.2 'Kharkiv') was used for point cloud processing. In Figure 4, the SLAM Point Cloud after these edits is shown, accounting for a total of 94 MPoints.

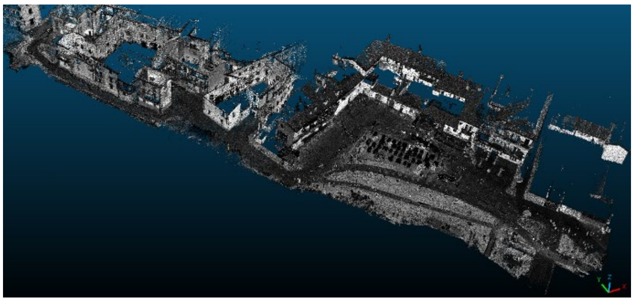

Figure 4. 3D view of the SLAM Point Cloud after editing steps described at Paragraph 3.3.2.

**3.3.3 Quality assessment of the geoDB.** The main category of objects focused during the final QA were buildings. According to the national rules for the GeoDB structure (Italian Government, 2011), buildings are represented in two layers:

1. polygons with the boundary of connected *buildings* (2D), grouping more parts that may feature different relative heights from the ground (Class *020102*); and
2. polygons with the boundary of *volumetric units* (2D), each of them characterized by sharing the same roof (Class *020101*); each volumetric unit is assigned as attribute the average relative height from the ground, which allow a 3D visualization. More volumetric units may belong to the same *building* (Class *020102*), connection given by the presence of a specific identifier in the attribute table. A more detailed representation of the roof geometry may be present in another layer/class, which is often omitted in the regional geoDBs for budgetary costs.

Given this organization for buildings, the QA was carried out on the *volumetric units*, due to the presence of 3D information and since *buildings* (Class *020102*) are derived from them. After selecting a subsample of 7 volumetric units (see maps in Fig. 5) in the Case Study area, two different types of quantities were assessed by comparing data from the GeoDB to the corresponding data from the SLAM Point Cloud:

1. 2D coordinates of the polygon of each *volumetric unit* (Class *020101*); and
2. relative eight from the ground of each *volumetric unit* as stored in the attribute table.

Figure 5. – Location of *volumetric units* (#7) of buildings (Class *020102*) selecting for the Quality Assessment of the geoDB in the Case Study area.


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By applying the VRec method described at Paragraph 2.3.2, the corresponding reference values were read in either the geoDB and the SLAM Point Cloud. Figure 6 shows two examples of reading coordinates of the *volumetric unit*'s contour at ground level and the relative height.

In any assessment, we have always computed the discrepancies of a generic variable $X$ as:

$$\Delta X = \Delta X_{SLAM\ Point\ Cloud} - \Delta X_{geoDB}. \tag{1}$$

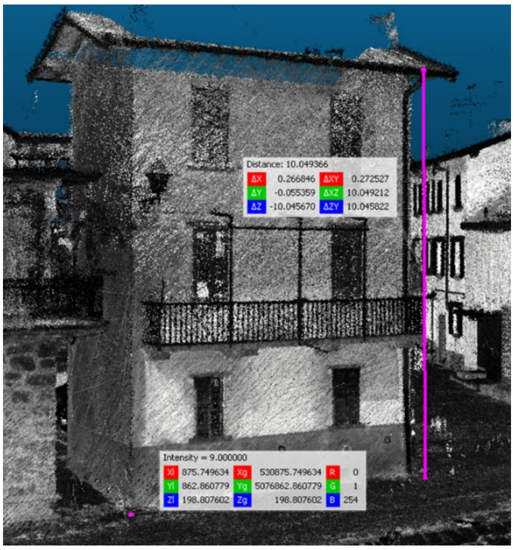


Figure 6. Reading coordinates of the *volumetric unit*'s contour at ground level and the relative height by using the VRec approach and the SLAM Point Cloud.

**3.3.4 Results of the Quality Assessment.** The *assessment of coordinate values of the volumetric units'* contours resulted in mean discrepancies between reference values (from the SLAM Point Cloud) and the geoDB values equal to $\mu_{\Delta E}$ =2.3 cm in Est direction and $\mu_{\Delta N}$ =-3.0 cm in North direction, respectively. Standard deviations of the same discrepancies resulted in term of $\sigma_{\Delta E}$=23.1 cm and $\sigma_{\Delta N}$ =21.2 cm, respectively. No significant differences in both $E$ and $N$ directions are present, while the average values are almost zero. On the other hand, the standard deviations are very close to the limit-of-capture (20 cm) at the equivalent scale for the considered area (1:1,000). This can be explained by the fact that the approximation adopted in computing building contours may have played a predominant role in the error budget. If we derived the corresponding RMSE of these discrepancies by applying the formula:

$$RMSE_{\Delta E,\Delta N} = \sqrt{\mu^2_{\Delta E,\Delta N} + \sigma^2_{\Delta E,\Delta N}}\,, \tag{2}$$

we obtain values equal to 23.3 cm in $E$ and 21.4 cm in $N$. These can be compared to the tolerances to be respected by these geometric elements of the geoDB, namely 40 cm in $E$ and $N$. By looking at the maximum absolute discrepancies, we obtained only 1 coordinate in $E$ ($|\Delta E|_{max}$=56.0 cm) and 1 coordinate in $N$ ($|\Delta N|_{max}$=44.6 cm). The total number of assessed points is 29, ranging from 2 to 6 points per each *volumetric unit*. The out-of-tolerance ratio is then 3.5%, which is compliant with the adopted confidence level of 95%.

As far as the *assessment of the relative eights* is concerned, we extended the sample by including other *volumetric units* to reach a total of 14 elements. In this case, the statistics on the discrepancies according to Eq. (1) resulted in $\mu_{\Delta Z}$ =-0.5 cm, $\sigma_{\Delta Z}$=20.3 cm, and the RMSE (from Eq. (2)) equal to 20.3 cm. The maximum absolute discrepancy is ($|\Delta Z|_{max}$=37.7 cm), which is compliant with the corresponding tolerance. The same considerations about the data quality of the planimetric data can be repeated.

We also included an additional assessment based on the evaluation of some *planimetric distances between road features*, such as width of streets and squares. Ten elements were selected and their values read from the geoDB and compared to the SLAM Point Cloud reference values. In this case, the statistics on the discrepancies (Eq. (1)) resulted in $\mu_{\Delta d}$ =-2.1 cm, $\sigma_{\Delta d}$=14.6 cm, and the RMSE (from Eq. (2)) equal to 14.8 cm. The maximum absolute discrepancy is ($|\Delta d|_{max}$=28.3 cm). No relevant anomalies can be found.

A last point analysed during QA was about the *extension of the green areas*. We only analysed the extension of the main area in the case study (Fig. 7), by comparing its size as represented in the geoDB (Class *060401*) and from the SLAM Point Cloud. We checked five distances ($d_1 – d_5$ in Fig. 7) between vertices of the polygon corresponding to the countour of the green area, and a distance w.r.t. to a building ($d_6$ in Fig. 7). As reported in Table 1, the errors on these distances (Eq. (1)) are quite relevant and they are not compliant with the tolerances of the geoDB. An average bias of -2.31 m can be observed, which is much higher of the standard deviation (1.08 m), corresponding to a larger representation of the green area. A discussion about this result is reported in next Subsection 3.4.

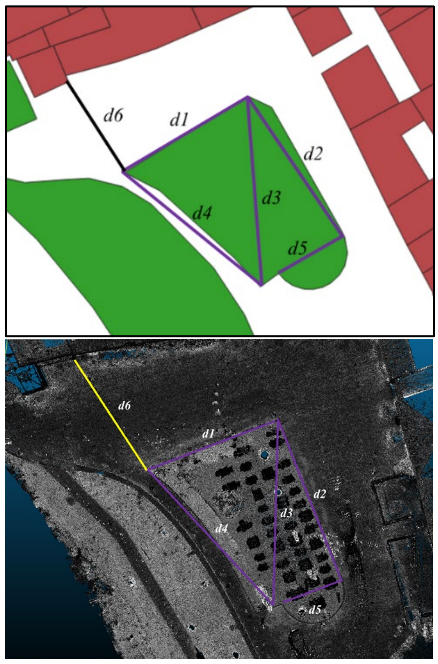


Figure 7. Analysis of the polygon of green area. From top to down: geoDB (Class *060401*); SLAM Point Cloud.

### 3.4 Discussion

**3.4.1 Analysis of the VRec methodology.** In this study we applied the VRec methodology to assess the quality of a small portion of a geoDB from the Lecco Municipality, which is highly representative of this type of spatial data adopted for local and regional land administration in Italy, see Crosilla et al. (2021).

| Distance id | GeoDB [m] | SLAM Point Cloud [m] | Error [m] |
|---|---|---|---|
| *1* | 19.21 | 15.67 | -3.54 |
| *2* | 22.06 | 20.23 | -1.83 |
| *3* | 25.11 | 22.25 | -2.86 |
| *4* | 23.06 | 20.21 | -2.85 |
| *5* | 10.03 | 7.41 | -2.62 |
| *6** | 13.92 | 13.74 | -0.18 |
| | | ***Average distance*** | **-2.31** |
| | | ***Standard deviation*** | **1.08** |

Table 1. Discrepancies computed on distances between vertices of the polygon of the green area (Class *060401*) in Figure 7. Distance *6** is w.r.t. to a building.

The main characteristic of the VRec methodology is to emulate the standard process adopted for the QA of geoDBs based on surveying measurements. The main advantage of deriving information from the SLAM Point Cloud is the larger choice of control points, that are not limited to the ones measured in the field. This allows to assess multiple categories of objects, not only related to buildings as usually happens (see also Matellon et al., 2024). Some comments about this aspect are reported at Paragraph 3.4.2.

Data acquisition with MLS takes a time that is comparable to the one necessary for collecting surveying measurements. In addition, no decisions in the field about control point selections and their documentation (sketches or photos) are required, since this task is postponed to the operator in the office. The use of MLS instrument integrating a surveying-grade GNSS may save time. A contribution to speed up the data acquisition time may be provided by the application of techniques for the optimization of scan planning for MLS (see, e.g., Díaz-Vilariño et al., 2022).

On the other hand, the current implementation of VRec suffers from some operational limits related to the complexity of data processing. Editing of the point cloud (e.g., filtering out vegetation and temporary object) and its interpretation are not yet easy tasks, requiring a large amount of working hours and skilled operators. The recent impressive development of Artificial Intelligence techniques to help point cloud classification may provide a great contribution to this purpose in the future (see Sarker et al., 2024; Yan et al., 2025).

Another possible improvement is related to the application of techniques from the automatic comparison between the 3D vector geometry of the geoDB and the SLAM Point Cloud. Here the main problem is due to the approximation of the geoDB implied by the effective scale of representation, which are difficult to distinguish in automatic procedures (see Matellon et al., 2025). A contribution may be given by using approaches able to recognize the same points in two different types of geospatial data (see Brovelli and Zamboni, 2006).

As the moment the VRec method does not justify its application for QA only. But if the acquisition of the SLAM Point Cloud is also exploited to improve the field recognition of those elements that cannot be derived by stereoplotting, its usage may become more sustainable, at least in those areas where the interpretation of aerial images is difficult.

**3.4.2 Analysis of the specific results on the Case Study.** The QA of the geoDB adopted as case study yielded a positive result, as described at Paragraph 3.3.4. On the other hand, this geoDB was already validated and this result confirmed the expectations, in particular about buildings and their components (*volumetric units*). A more comprehensive analysis should include other classes of objects. About this, it is interesting to comment the negative results about the extension of the *green areas*, whose size is exaggerated in the geoDB. On the other hand, the major efforts in the production of geoDBs and their QA are focused on buildings, roads, infrastructures but less importance is given to urban green spaces, which today have assumed a very important role for improving the quality of our cities. A possible motivation of this problem can be found in the tree coverage of the green area used for testing, see Figure 1. For this reason, the use of the SLAM Point Cloud for QA as well as to accomplish field recognition is another advantage of the VRec approach.

## 4. Conclusions and future developments

In this paper we proposed, tested and discussed the application of Mobile Laser Scanning (MLS) based on SLAM technology to collect point-cloud data for the Quality Assessment (QA) of a geospatial database (gDB in an urban area. The proposed method (called 'VRec') transfers into a digital approach the same procedure applied for the final QA of digital maps, which is based on the use of surveying techniques for measuring a set of check points.

The test demonstrated the technical capability of VRec to operate the QA, but at the current state-of-the-art of the methodology for extracting information from point clouds is note sustainable in terms of time, compared to the traditional methodology. On the other hand, if the VRec method is also used to collect data to be integrated into the output of stereoplotting to help interpretation of those parts that cannot be distinguished in aerial imagery, it may become viable. Forthcoming development in classification of point clouds based on Artificial Intelligence may contribute to make VRec more efficient.

Data from MLS can be integrated by point clouds from drone photogrammetry (Subsect. 2.2), but also by other data sources, such as panoramic images (Cao et al., 2022), UAV-LiDAR (Mandlburger et al., 2023), and thermal infrared images from UAV (Genzano and Colonna, 2025).

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