

Integration of UAV-GNSS-GIS Technologies in a University Extension Project for Religious Cemetery Management: A Case Study at Martin Luther Church (Ibirama - Brazil)

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Abstract

This paper presents a university extension project to improve the spatial documentation of the Martin Luther Church cemetery in Ibirama, Brazil. This was achieved by integrating Unmanned Aerial Vehicle (UAV) photogrammetry, high-precision Global Navigation Satellite System (GNSS) surveying, and Geographic Information System (GIS) mapping. A multi-altitude flight strategy (30 m, 50 m, and 80 m) combined with a network of nine ground control points, enabled the generation of high-resolution orthophotos and a digital surface model. Accuracy assessment using 24 independent checkpoints confirmed compliance with Class A of the Brazilian Cartographic Accuracy Standard (PEC) for 1:250 scale mapping. The highest-resolution orthophoto (1.4 cm Ground Sampling Distance - GSD) was used to manually digitize 1,112 graves, linked to a database containing 1,594 burial records. This study demonstrates a replicable workflow that combines open-source tools and low-cost geospatial technologies to produce precise cartographic outputs for community use.

1. Introduction

University extension is a fundamental pillar of higher education in Brazil, emphasizing the social role of universities by engaging students in community-oriented projects. A 2018 federal resolution mandated that at least 10% of undergraduate curricula must involve extension projects, integrating practical community engagement into academic programs (Conselho Nacional de Educação, 2018). This extension accreditation initiative not only formalizes the inclusion of extension in coursework but also reflects a broader educational vision of forming socially responsible professionals. The project presented in this paper was conducted by fourth-semester civil engineering students at UDESC-CEAVI as part of their “Geomatics 2” course, providing them with hands-on experience while delivering a service to the community through mapping a local cemetery.

Effective management of community and religious cemeteries is greatly enhanced by accurate geospatial data. Many small cemeteries lack up-to-date maps and rely on paper records, which can lead to inefficiencies in plot allocation, maintenance, and record-keeping. By developing a precise geospatial inventory of a cemetery, administrators and the community can ensure better planning and transparency. Digital mapping of cemeteries with GIS allows administrators to gain complete inventory control over plots and plan for future use of space more efficiently. Conversely, the absence of integrated spatial data can result in mismanagement; a study in Malaysia noted that poor data sharing between agencies led to an oversupply of cemetery land beyond actual needs, whereas updating and integrating geospatial information improved inter-agency coordination and transparency (Johar et al., 2019).

In Brazil, the push for accurate geospatial documentation is also driven by legal requirements. Legislation has evolved to require georeferenced spatial records for land administration and regularization purposes. Law 6,015/1973 (the Public Registry Law), supplemented by Law 10,267/2001, introduced mandatory georeferencing for land parcels in official registries (Brasil, 1973). In practice, this means that for properties – including those of religious or communal interest – to be

formally recognized or transferred, their boundaries must be surveyed with high precision coordinates in the national geodetic reference system. This legal framework, originally applied to rural properties, sets a precedent that even community-managed lands like cemeteries benefit from having accurate georeferenced surveys to ensure compliance with regulations and to facilitate any future legal registration or land-use planning.

Modern geospatial technologies have made it feasible to collect such high-precision data efficiently, even in small-scale projects with significant social application. Unmanned Aerial Vehicles (UAVs or drones), Global Navigation Satellite Systems (GNSS), and Geographic Information Systems (GIS) now form an integrated toolkit for detailed spatial data acquisition and analysis. UAV photogrammetry can rapidly produce high-resolution orthophotos and three-dimensional models of a site (Nex and Remondino, 2014), while high-accuracy GNSS receivers provide precise control points and positioning to georeference the maps. The data are then brought into a GIS, where they can be visualized, analyzed, and shared with stakeholders. Utilizing these technologies in a community project not only ensures superior accuracy and completeness of the maps but also demonstrates how advanced surveying methods can directly support societal needs. Such integration requires a multidisciplinary skillset – effective use of drones for mapping demands solid knowledge of geodesy and GIS from the team (Colomina and Molina, 2014) – thereby enriching the educational aspect of the extension project by exposing students to state-of-the-art tools and methodologies.

2. Study Area

The study was conducted in the municipality of Ibirama (figure 1), located in the Vale do Itajaí region in northeastern Santa Catarina, southern Brazil. Geographically, the city lies at approximately 27°03' S, 49°31' W, with an average elevation of 150 m above sea level (IBGE, 2022). Ibirama covers an area of approximately 246.7 km² and is characterized by steep terrain, subtropical Atlantic Forest vegetation, and a riverine landscape shaped by the Rio Hercílio, a branch of the Itajaí-Açu River (Governo de Santa Catarina, 2019; SOS Mata Atlântica, INPE,

2022). The region features a humid subtropical climate with abundant rainfall throughout the year.



Figure 1: Ibirama, Santa Catarina State, Brazil

As of the 2022 census, Ibirama has a population of 19,862 inhabitants, with a population density of around 80 inhabitants/km² (IBGE, 2022). The municipality has a predominantly urban population and a strong cultural identity rooted in German immigration. Founded in 1897 by the Hanseatic Colonization Society of Hamburg, Ibirama was originally named Hansa Hammonia and later renamed during World War II to “Ibirama,” from the Tupi-Guarani language, meaning “region of trees” (Dallabrida, 2003; Prefeitura Municipal de Ibirama, 2023). The German-Lutheran cultural influence is evident in the city’s architecture, language, and institutions. Ibirama’s Human Development Index (HDI) was 0.737 in the most recent report, considered high by Brazilian standards (PNUD, 2022).

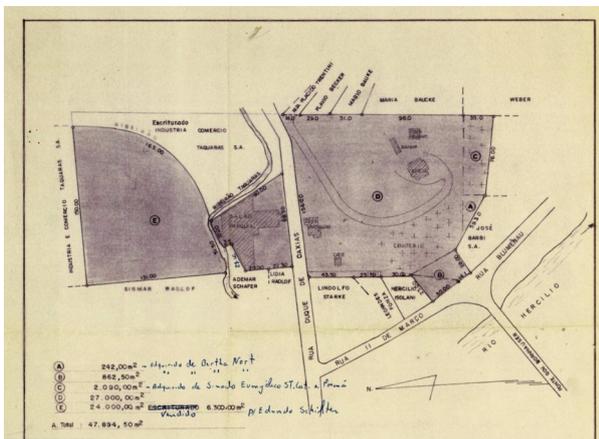


Figure 2: Map of the Lutheran Church property in Ibirama, provided by the local Land Registry Office

A prominent cultural and historical landmark of Ibirama is the Martin Luther Church, built by German immigrants. It is situated on a hilltop with steep slopes overlooking the city, on a parcel of land measuring approximately 27,000 m² (figure 2), according to official registry documentation (Matrícula nº 10699) (Cartório de Registro de Imóveis de Ibirama, 2023). The church’s construction began in 1917, coinciding with the 400th anniversary of the Protestant Reformation, and was completed in 1929 (Aldinger, 1930). Architecturally, the church is unique in Brazil, featuring a cruciform layout with four symmetrical facades and a central square tower topped by a six-sided spire. It

blends elements of Gothic Revival with eclectic influences and serves as a dominant visual feature of Ibirama’s skyline (Prefeitura Municipal de Ibirama, 2023).

The church is surrounded by its historical community cemetery, the focus of this study. This cemetery comprises 1,112 identified graves and 1,594 deceased individuals, distributed across five sectors. It has been in continuous use since the early 20th century and contains family and individual tombs constructed from diverse materials such as granite, marble, and concrete. Located on sloped terrain with limited space for expansion, the site presents challenges for management and preservation. Until this project, the church maintained no georeferenced or digitized map of the cemetery, relying solely on handwritten records and local knowledge. Recognizing its historical and cultural significance, the Martin Luther Church was officially declared a municipal heritage site in 2023 (Jornal de Ibirama, 2023).

3. Materials and Methods

The methodology employed in this study follows a systematic approach integrating UAV photogrammetry, GNSS surveying, and GIS technologies. The workflow began with comprehensive UAV mission planning, where flight parameters and coverage areas were defined to ensure optimal data acquisition. Subsequently, multi-altitude flights were conducted at 30 m, 50 m, and 80 m to analyze the impact of ground sampling distance on mapping accuracy.

Simultaneously, a rigorous GNSS survey establishes a network of ground control points using base-rover configuration and post-processed kinematic (PPK) techniques. The collected aerial imagery was processed photogrammetrically using WebODM software to generate high-resolution orthophotos and digital surface models. Quality assessment follows Brazilian Cartographic Accuracy Standards (PEC) using independent checkpoints to validate positional accuracy.

The validated orthophotos serve as the foundation for GIS development, where cemetery plots are manually digitized and linked to a comprehensive database containing burial records and attribute information. This integrated approach culminates in the delivery of both digital and printed cartographic products to support cemetery management and administrative functions.

3.1 UAV Platform and Mission Planning

Three photogrammetric missions were conducted using a DJI Mavic 3 Enterprise UAV, a platform equipped with a 4/3 CMOS sensor capable of acquiring high-resolution nadir images suitable for mapping and 3D reconstruction. The flights were conducted at three different altitudes – 30 m, 50 m, and 80 m – in order to analyze the impact of Ground Sampling Distance (GSD) on the accuracy of the derived orthophotos.

Each flight was programmed with 80% frontal and 80% side overlap to ensure dense image matching and improve reconstruction quality. Mission planning was executed using DJI Pilot 2, and ground conditions (wind, lighting) were monitored to maintain consistency across flights. Images were captured in JPEG format with geotags embedded from the UAV’s onboard GNSS receiver (DJI, 2022).

3.2 GNSS Survey and Geodetic Control

A total of 33 ground points were surveyed using FOIF A90 dual-frequency GNSS receivers in a base-rover configuration. One receiver (base) was installed over a fixed location and recorded raw observations continuously for four hours. The coordinates of this base point were later determined using the IBGE's Precise Point Positioning (PPP) post-processing service (IBGE, 2023), ensuring high geodetic reliability and consistency. During the same period, the rover receiver was used to survey ground targets throughout the site. All GNSS data were stored in RINEX format and processed using the PPK (Post-Processed Kinematic) technique, applying differential corrections based on the base station's PPP-derived coordinates. No RTK solution or UHF radio link was used in the field survey.

From the total of 33 collected points, 9 were selected and evenly distributed across the cemetery to serve as Ground Control Points (GCPs) during image processing. Another 24 were used as independent Check Points (CPs) for validating the positional accuracy of the final geospatial products. The remaining points were not used due to redundancy or suboptimal location. All valid points were referenced to the SIRGAS2000 / UTM zone 22S coordinate system, and standard surveying practices were applied to minimize multipath effects and vertical deflection errors (Galo and Camargo, 2007).



Figure 3: Spatial distribution of Ground Control Points and Check Points across the cemetery

3.3 Photogrammetric Processing

The images from each mission were processed using WebODM, an open-source photogrammetric platform based on OpenDroneMap. For each flight altitude, the following outputs were generated: Orthophoto (GeoTIFF format), Point cloud (LAS format), Digital Surface Model (DSM), Textured 3D mesh.

The photogrammetric processing pipeline included camera alignment via feature matching, dense point cloud generation using multi-view stereo (MVS), and orthorectification based on the GCPs. The processing configuration followed recommended WebODM parameters with adjustments to resolution and depth maps to accommodate the lower flight altitudes (OpenDroneMap, 2023). Positional accuracy of the outputs was assessed by comparing the CPs with their locations on the orthophotos.

3.4 Accuracy Assessment and PEC Classification

The positional accuracy of each orthophoto was evaluated using independent Check Points, following the guidelines of the Brazilian Cartographic Accuracy Standard – PEC (Padrão de Exatidão Cartográfica) (IBGE, 2015). This standard classifies cartographic products into four accuracy classes – A, B, C, and D – based on the allowable Root Mean Square Error (RMSE) for planimetric accuracy at a given map scale. For example, Class A represents the highest accuracy, requiring a horizontal RMSE of no more than 0.0625 m and a vertical RMSE of no more than 0.125 m. Based on these thresholds, all three flights achieved Class A in horizontal accuracy, qualifying them for high-detail planimetric mapping. In terms of vertical accuracy, only the 50 m flight met the Class A standard, while the 30 m and 80 m flights fell within Class B. However, given the goals of this project – particularly the creation of a thematic map delineating graves and associating cadastral attributes – the elevation component is not essential for the final product.

3.5 Photointerpretation and GIS Development

Once orthophotos were generated, particularly the one with highest resolution (30 m flight), students performed photointerpretation of cemetery plots. The cemetery was divided into five sectors, and each student group was responsible for one. Field visits were conducted to photograph tombstones and gather information on the name of the deceased, birth and death dates, grave number.

Each grave was digitized manually in QGIS using polygon geometry, and attributes were entered into an associated database. A unique tomb ID was assigned to each grave. Attribute tables include the figure reference. The final GIS product was a comprehensive map showing the orthophoto, plot boundaries by sector color, and an attribute index of names.

4. Results

4.1 Orthophotos and Digital Surface Models (GSD & PEC)

Three orthophotos were produced from drone flights conducted at altitudes of 30 m, 50 m, and 80 m. The average ground sampling distance (GSD) for these missions was approximately 1.4 cm, 1.8 cm, and 2.8 cm, respectively. The resulting georeferenced orthophotos were saved in GeoTIFF format, with file sizes of approximately 1.1 GB for the 30 m flight, 980 MB for the 50 m flight, and 920 MB for the 80 m flight. As expected, the imagery captured at lower altitudes offered higher spatial resolution, which was critical for identifying small features such as the boundaries of individual graves, headstones, and surface markings.

In contrast, the orthophoto from the 80 m flight, with a GSD greater than 2 cm, exhibited limitations in distinguishing grave outlines, especially in densely occupied areas, making it less suitable for tasks requiring fine spatial interpretation. These observations were consistent with field photographs taken during ground inspection, which showed that some local features became indistinct in lower-resolution images. Overall, the 30 m flight provided the most visually detailed dataset, becoming the preferred base layer for subsequent photointerpretation and feature digitization within the GIS environment.

4.2 Positional Accuracy Assessment

The positional accuracy of the geospatial products was assessed using 24 independent Check Points (CPs), which were measured in the field and excluded from the photogrammetric processing. For each orthophoto produced from the flights at 30 m, 50 m, and 80 m, Root Mean Square Errors (RMSE) were calculated for both horizontal (X, Y) and vertical (Z) components based on the differences between the measured coordinates and those extracted from the processed orthophotos (table 1). The horizontal RMSE values were 0.04 m, 0.06 m, and 0.09 m respectively, while the vertical RMSE values were 0.14 m, 0.12 m, and 0.16 m. These results were evaluated according to the Brazilian Cartographic Accuracy Standard (PEC), which defines thresholds for four accuracy classes (A, B, C, D) depending on the map scale.

At a 1:250 scale, PEC Class A requires a horizontal RMSE of no more than 0.0625 m and a vertical RMSE of no more than 0.125 m. Based on these thresholds, all three flights achieved Class A horizontal accuracy, qualifying them for high-detail planimetric mapping. In terms of vertical accuracy, only the 50 m flight met the Class A standard, while the 30 m and 80 m flights fell within Class B. However, given the focus of this project on 2D mapping and feature delineation, where the elevation component is not essential for the final product, the superior horizontal accuracy of the 30 m flight was the primary consideration. Therefore, the 30 m orthophoto was selected for use in the grave mapping process. This dataset featured the finest Ground Sampling Distance (1.4 cm) and the highest visual detail, making it the most suitable base layer for photointerpretation and vectorization. Its superior clarity facilitated the precise identification of individual grave limits, which was critical for the accurate cadastral inventory of the cemetery map.

Flight Altitude (m)	Horizontal RMSE (m)	Vertical RMSE (m)	PEC Horizontal Class	PEC Vertical Class
30	0.04	0.14	A	B
50	0.06	0.12	A	A
80	0.09	0.16	B	B

Table 1. Positional accuracy and PEC classification of orthophotos at different UAV flight altitudes (1:250 scale)

4.3 Cemetery Segmentation and Attribute Data

The orthophoto with the highest spatial resolution (1.4 cm GSD from the 30 m flight) was selected as the base layer for photointerpretation. Using QGIS, students manually digitized the perimeter of each grave directly over the orthophoto. The cemetery was subdivided into five quadrants to facilitate fieldwork organization, with each student team responsible for one section. During on-site visits, photographs were taken of every individual grave, documenting visible information such as the names of deceased individuals, birth and death dates, and grave number.

Back in the GIS environment, the digitized grave polygons were enriched with this attribute information. Each grave was assigned a unique identification number created specifically for this project. In total, 1,112 grave polygons were mapped and 1,594 names were recorded, reflecting multiple burials per grave in many cases. A one-to-many relational structure was

implemented in the database to accommodate this, with each grave polygon linked to one or more person records.

The final deliverables to the community included a large-format printed map and digital files containing 1,112 grave polygons linked to 1,594 burial records, enriched with names, dates, and photographic data (Figure 4). A one-to-many relational database model was adopted to associate multiple individuals with a single grave plot, reflecting the real-world structure of the cemetery. This digital system replaced previous handwritten records, significantly improving the accessibility and organization of information.

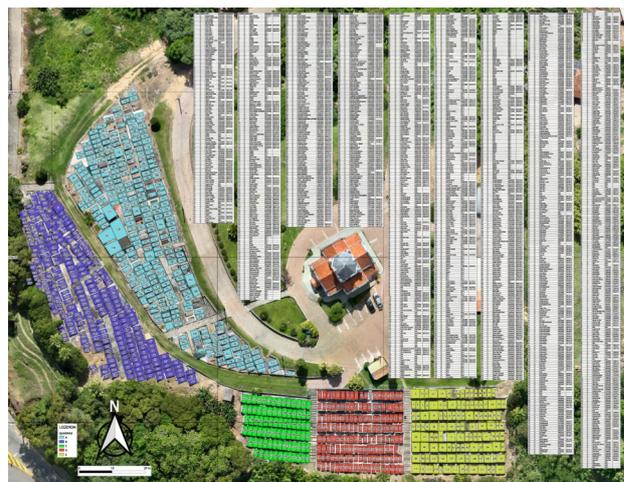


Figure 4: Orthophoto with grave segmentation showing digitized polygons, sector divisions, and tables with the occupants of each grave.

5. Conclusions and Recommendations

The mapping of the Martin Luther Church cemetery using drone-based photogrammetry and GNSS surveying proved to be a highly effective approach for producing a detailed and accurate spatial documentation of a site with significant cultural and community relevance. The integration of high-resolution aerial imagery with geodetic control points resulted in cartographic products that achieved Class A accuracy according to the Brazilian Cartographic Accuracy Standard (PEC) for large-scale maps, confirming the robustness of the methodology applied.

The strategy of employing multiple flight altitudes (30 m, 50 m, and 80 m) was essential in balancing wide coverage with high detail. The orthophoto derived from the 30 m flight, with a GSD of 1.4 cm, offered the sharpest image quality and was selected as the base layer for grave identification. Although the 50 m and 80 m flights yielded acceptable positional accuracy, their lower image resolution (>2 cm GSD) hindered the ability to visually distinguish individual graves, especially in densely arranged or irregular sectors.

The final outputs delivered to the community include a large-format printed map and digital files containing 1,112 grave polygons and 1,594 burial records, linked to geographic and photographic data. A one-to-many relational database was adopted to associate multiple individuals to a single grave plot, reflecting the real-world structure of the cemetery. This digital system replaced the previous handwritten records, significantly improving the accessibility and organization of information.

The impact of this work extended beyond the technical realm. Church administrators reported immediate benefits in daily cemetery operations, such as locating specific graves, planning new burials, and verifying historical records. Training sessions were held using QGIS, enabling the staff to perform basic spatial queries and data updates. However, it is important to note that, at this stage, the system can only be edited or accessed through QGIS on a desktop environment, which may limit broader usability.

Therefore, a key recommendation for future work is to develop user-friendly interfaces, such as web-based maps or custom QGIS plugins, to allow both the community and administrators to access the data via web browsers or mobile devices. Additionally, we suggest the adoption of QField or similar mobile GIS applications for future field campaigns. This would enable real-time data entry in the field—such as recording names, birth and death dates, and photographic documentation—directly into the spatial database, reducing post-processing time and minimizing transcription errors.

Finally, the success of this project highlights the potential for replicating this methodology in other cemeteries or community-managed facilities. It demonstrates the value of university extension projects in delivering practical, socially engaged solutions that bridge academic knowledge with real-world applications in spatial information management.

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