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Aerial Photogrammetry using Low-Cost RPA and Free Software: A Case Study in Urban Communities of Simões Filho-BA

Aerofotogrametria utilizando RPA de baixo custo e software livre: Um estudo de caso em comunidades urbanas de Simões Filho-BA

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Abstract: This study evaluates low-cost aerial photogrammetry using open-source software (DTM/ODM) for collaborative mapping in peripheral areas of the municipality of Simões Filho, Bahia, Brazil. A DJI Air 3S remotely piloted aircraft (RPA) was employed, and the results obtained from image processing were compared between Agisoft Metashape (commercial software) and DTM/ODM (open-source platform), using the same image dataset as input. The main objective was to assess the methodology for community-based initiatives, focusing on data availability and the democratization of access to geoinformation. The results indicate that DTM/ODM is an efficient and viable alternative for generating orthomosaics, achieving positional accuracy compatible with a 1:5000 scale (PEC-PCD), suitable for territorial planning and diagnostic applications, even in the absence of ground control points (GCPs). The resulting products were made available on the OpenAerialMap platform, expanding public access to geospatial data.

Keywords: Aerial Photogrammetry; RPA; Free Software.

Resumo: Este estudo avalia a aerofotogrametria de baixo custo com softwares livres (DTM/ODM) para mapeamento colaborativo em áreas periféricas do município de Simões Filho-BA. Para tanto, foi utilizado um RPA DJI Air 3S, onde foi realizada a comparação dos resultados dos processamentos realizados no Agisoft Metashape (comercial) e no DTM/ODM (aberto), tendo como entrada de dados o mesmo conjunto de imagens. O objetivo foi validar a metodologia para iniciativas de base comunitária, focando na disponibilização de dados e acesso democrático à geoinformação. Os resultados indicaram que o DTM/ODM é uma alternativa ágil e viável para gerar ortomosaicos, com precisão posicional relativa à escala de 1:5000 (PEC/PCD), indicada para planejamento e diagnóstico territorial, mesmo sem o uso de pontos de controle terrestres. Os produtos resultantes foram disponibilizados no OpenAerialMap, ampliando o acesso público a dados geoespaciais.

Palavras-chave: Aerofotogrametria; RPA; Software Livre.

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1. Introduction

A significant portion of urban growth in Brazilian cities has occurred in vulnerable areas. Recent data from MapBiomas indicate that areas occupied by favelas and urban communities increased from approximately 53.7 thousand hectares in 1985 to about 146 thousand hectares in 2024, evidencing a substantial expansion of these territories over the period. A considerable share of this total is located in areas susceptible to socio-environmental risks, reinforcing the relationship between informal urbanization and territorial vulnerability (MapBiomas, 2026).

At the same time, there is a lack of reference mapping and outdated cartographic data precisely in these areas, a common condition in developing countries such as Brazil, where there is a strong need for updated and reliable geospatial data to support urban planning. This demand is also highlighted by Sustainable Development Goal 11 – Sustainable Cities and Communities, which establishes, in its target 11.1, the commitment to ensure universal access to safe and adequate housing and the upgrading of informal settlements by 2030 (UN, 2015).

The demand for adequate housing, combined with the search for access to services and opportunities concentrated in urban areas, primarily affects low-income populations (Silva & Oliveira, 2022). This dynamic imposes challenges on municipal management, particularly in the formulation of public policies that integrate territorial planning with social inclusion (Rolnik, 2015), as well as in the promotion of land regularization processes and the updating of cadastral systems that support efficient territorial management (Nascimento & Lima, 2021).

In parallel, demands for public participation remain, as established by the Brazilian City Statute (Federal Law No. 10,257/2001, Art. 2, II and XIII; Arts. 43–45, Brazil, 2001). The statute establishes democratic urban governance and mandates the involvement of the population in the development and revision of master plans, urban programs, and public policies through councils, debates, public hearings, consultations, conferences, and citizen-led legislative initiatives. In this context, vulnerable areas that expand on the margins of public knowledge and assistance present a particular demand for expedited mapping processes, enabling communities to actively participate in the production of geospatial information and supporting inclusive and sustainable urban planning policies.

However, technological advances in geosciences have expanded access to tools for collecting, analyzing, and representing spatial data. Currently, Remotely Piloted Aircraft (RPA), commonly known as drones, are widely used in these processes (Silva et al., 2021), as well as in more recent studies such as Salim et al. (2023), Oliveira et al. (2024), Ramos et al. (2025), Schmidt et al. (2025), and Teh et al. (2026).

According to Hackney and Clayton (2015), RPA systems have developed significantly in recent decades. They operate remotely as small platforms equipped with cameras and, for most applications, are available as vertical takeoff and landing (VTOL) aircraft with four, six, or more rotors. As noted by Tziavou, Pytharouli, and Souter (2018), these systems are equipped with Global Navigation Satellite System (GNSS) receivers and other sensors that enable positioning, such as inertial measurement units.

The primary application of RPAs is mapping, including visualization and three-dimensional (3D) modeling, contributing to applications such as topographic surveys, structural monitoring, disaster assessment, archaeological mapping, agriculture, and forestry. These data are further analyzed in Geographic Information Systems (GIS), which have been recognized since the early 2000s as fundamental tools for understanding territorial phenomena and supporting more effective and sustainable public policies, as highlighted by Câmara and Monteiro (2001).

These technological developments have contributed to reducing operational costs and expanding access to mapping techniques, allowing users to conduct surveys with acceptable levels of accuracy for various applications, such as urban mapping, precision agriculture, and environmental monitoring (Silva et al., 2021). However, distinguishing between adequate and inadequate geospatial products still requires specialized technical training, which is essential to ensure the reliability of information used in analysis and decision-making processes.

Examples of such processes include recent studies demonstrating the potential of RPAs as tools for inclusion and community mapping, as evidenced by Virgens et al. (2024). Gomes and Pedrassoli (2018) conducted analyses in the Alto das Pombas community in Salvador, Bahia, producing maps and digital models of the region. In the study by Li et al. (2023), participatory mapping was integrated into indigenous communities, producing the first dataset of infrastructure and resources for an indigenous community in southwestern China, enabling the community to better understand its territory, fire risks, the preservation status of historical buildings, and potential economic resources.

These initiatives are consistent with Soares et al. (2022), who state that low-cost RPAs have revolutionized the mapping and monitoring of vulnerable areas. The use of accessible technologies in territorial dynamics promotes collaborative mapping as an important tool for participatory social inclusion, aligned with local realities and demands (Quintanilha, 2021). However, it is important to emphasize that these approaches do not replace conventional methodologies but rather complement them, expanding the scope and efficiency of mapping practices.

In this context, RPAs serve as tools that enhance traditional processes such as classical photogrammetry, especially in outdated areas, community territories, or regions historically neglected by cartographic investments. Nevertheless, although data acquisition is relatively straightforward, data processing for the generation of cartographic products remains challenging due to the computational tools required. Additionally, processing demands specialized computers and software, often associated with high licensing costs, which may limit their use in certain contexts. Furthermore, the involvement of qualified professionals is essential, as the proper handling, processing, and evaluation of cartographic products depend on specific technical knowledge, which is crucial to ensure the quality and reliability of results.

Based on this context, OpenAerialMap (OAM), launched in 2007 and revitalized in 2015 by the Humanitarian OpenStreetMap Team (HOT), has established itself as a collaborative platform for sharing high-resolution aerial imagery, expanding access to geospatial data and strengthening participatory mapping. In an integrated manner, OpenStreetMap (OSM) uses these images as a reference for extracting and updating cartographic features. By accessing editors such as iD or JOSM, users can overlay imagery from OAM or commercial providers, allowing them to identify and delineate buildings, roads, and other elements with greater precision, as well as assign tags more consistently. Studies show that the availability of such imagery improves geometric accuracy, increases editing frequency, and encourages community engagement, especially in urban areas and frontier regions (Mandourah & Hochmair, 2024).

Within this ecosystem of open platforms, the Drone Tasking Manager (DTM) stands out as an open-source tool developed by HOT in partnership with the Nepalese company NAXA. DTM enables the collaborative planning and coordination of flight missions by dividing areas of interest into optimized tasks for multiple operators, avoiding overlap and ensuring efficient coverage. The platform integrates with OpenDroneMap for image processing and allows the direct submission of orthomosaics to OpenAerialMap, establishing a complete and accessible workflow for the collection, processing, and publication of geospatial data (Drone Tasking Manager, 2025).

Thus, the main objective of this research is to evaluate the effectiveness of using low-cost RPAs associated with free photogrammetric processing software, taking as a reference the open-source DTM (Drone Tasking Manager, 2025), aiming at the generation of orthomosaics. In this context, the study seeks to compare the cartographic quality, technical characteristics, and visual aspects of orthomosaics generated by the DTM software with those produced by Metashape, whose methodology is widely recognized in the field. Additionally, the research aims to analyze the advantages and limitations of DTM in photogrammetric processing and to assess the feasibility of replicating the adopted methodology in other collaborative mapping scenarios in vulnerable communities.

2. Methodology

2.1. Study Area

The study area comprises the communities of Marielle Franco and Alto da Conquista, located in the municipality of Simões Filho, in the Metropolitan Region of Salvador, Bahia, Brazil (Figure 1). The area is part of the Periferia Viva Residências program, an initiative of the Ministry of Cities aimed at the urbanization of peripheral areas, focusing on improving basic infrastructure, environmental restoration, land tenure regularization, and the strengthening of social initiatives (Brazil, 2025).

The study area, covering approximately 25.7 hectares, was selected due to ongoing projects and partnerships with the Residency in Architecture, Urbanism, and Engineering (RAU+E) at the Federal University of Bahia (UFBA), which facilitated the development and continuity of the activities.

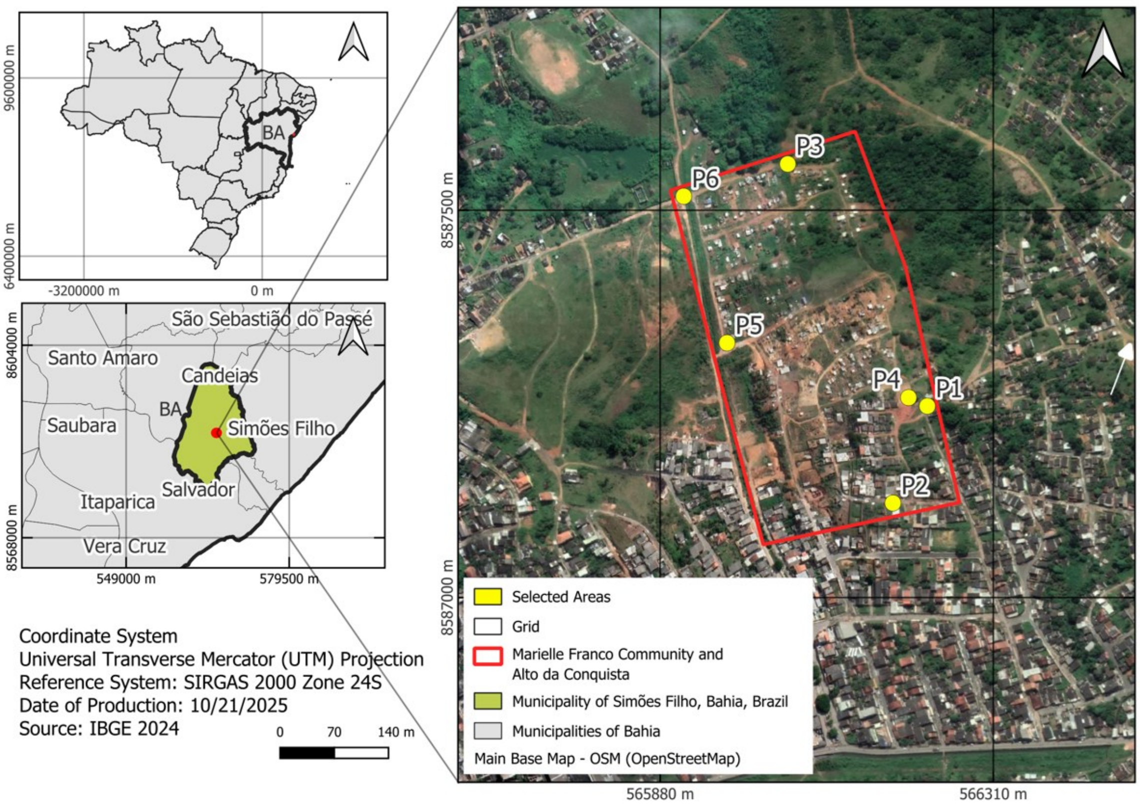

Figure 1 – Marielle Franco and Alto da Conquista settlements.
Source: The authors (2026).

2.2. Methodological Workflow

The methodological workflow (Figure 2) was structured into six stages. The first stage consisted of flight planning using the DJI Air 3S drone, in which the study area, check points, equipment, and technical parameters required for efficient coverage were defined. It is important to highlight that Ground Control Points (GCPs) were not used for georeferencing the products. In the second stage, an automated flight was carried out, along with the surveying of check points using a Trimble DA2 receiver and a Trimble TDC6 data collector, which were essential for the validation of the cartographic products.

The third stage involved image processing in two photogrammetric environments: the widely used commercial software Metashape and the free web-based platform DTM, which was employed comparatively to assess the quality of the orthomosaics. In the fourth stage, the results were validated using the GeoPEC software (GEOPEC, 2025) through comparison with the check points. Subsequently, in the fifth stage, a comparison was conducted between the products generated in the different environments.

Finally, the sixth stage corresponded to the application of the results in the context of collaborative mapping, with the publication of the orthomosaics on the OAM platform, integrating them into OSM. This stage contributed to the democratization of access to geospatial information in vulnerable areas.

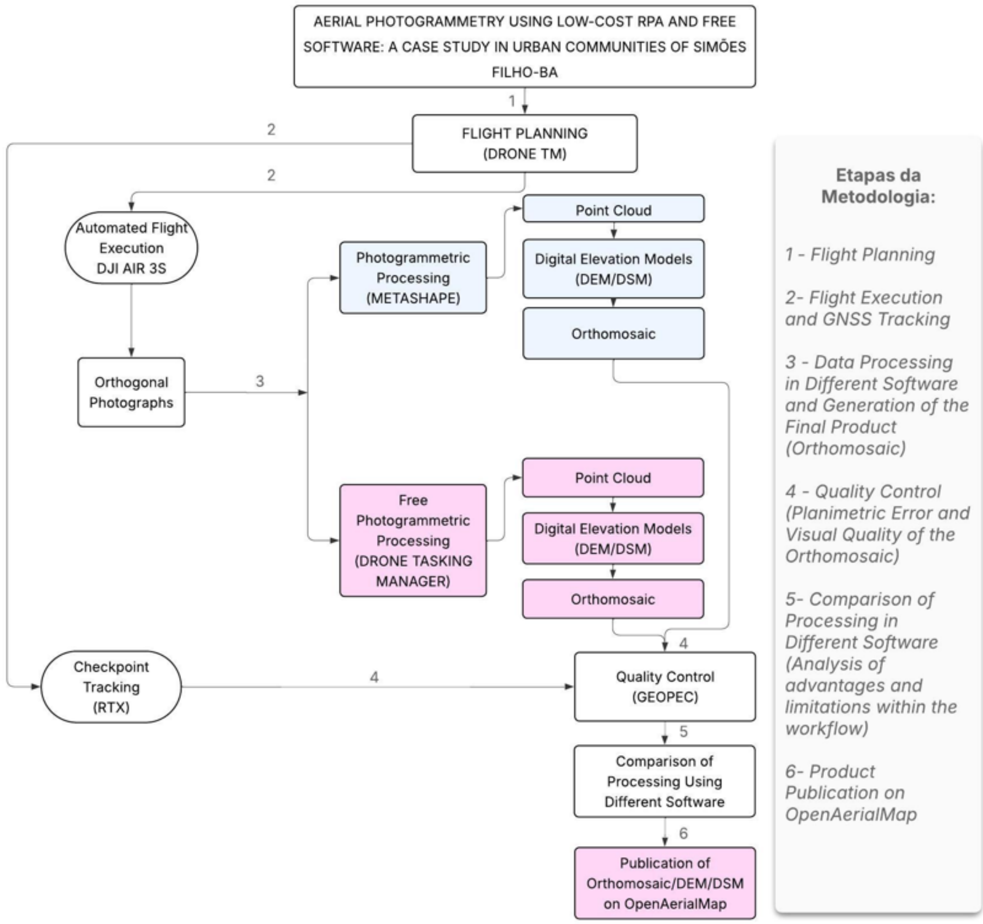

Figure 2. Methodological workflow.
Source: Authors (2026).

2.2.1 Equipment Used

For the mapping, a DJI Air 3S RPA, released in 2024 by Shenzhen DJI Sciences and Technologies Ltd., was used. The equipment has a mass of 724g and a flight autonomy of up to 45 minutes, being classified as a mid-range model with good cost-effectiveness (approximately USD 1,600–2,200).

The surveying of check points was carried out using a Trimble DA2 GNSS receiver coupled with a Trimble TDC6 data collector. The system is compatible with the GPS, GLONASS, Galileo, BeiDou, and QZSS constellations, achieving centimeter-level accuracy when integrated with the Trimble RTX real-time correction service via the Catalyst platform.

2.2.2 Flight Planning

In this study, flight planning was carried out using the free web-based platform Drone Tasking Manager (DTM). This tool enabled the creation of routes based on waylines, which is essential for the equipment used, as it does not have native software dedicated to aerial mapping. According to its developers, DTM was designed to facilitate the division and collaborative management of areas to be mapped, based on user-defined parameters (Drone Tasking Manager, 2025).

Initially, the boundary of the study area was imported. Subsequently, essential mission variables (Table 1) were defined, such as image overlap, flight altitude, aircraft speed, camera angle, and flight line orientation, ensuring the quality of the photogrammetric data obtained.

Table 1 – Flight technical specifications.

Tipo	**Valor**
Side overlap	70%
Forward overlap	80%
Flight speed	8 m/s
GSD	2.3 cm
Flight altitude	120 m

Source: Authors (2026).

2.2.3 Flight Execution

For the flight execution (Figure 3A), the low-cost DJI Air 3S drone was used, with automated planning and control carried out through the free DJI Fly application. In addition, GNSS check points were collected using high-precision receivers, ensuring the positional quality control of the data.

(A) (B)

Figure 3. (a) Photogrammetric survey; (b) Check point acquisition.
Source: Authors (2026).

Fieldwork was conducted on May 14 and August 2, 2025.

2.2.4 Check Point Surveying

The validation of the positional accuracy of the cartographic products was carried out based on the surveying of six check points, uniformly distributed across the study area (Figure 3B). The use of the Trimble RTX correction system proved to be suitable for the survey conditions in the Marielle Franco community. According to Trimble (2025), this technology applies orbital and clock corrections via geosynchronous satellites, providing centimeter-level real-time accuracy with high reliability.

2.2.5 Data Processing

Data processing was carried out in two stages. First, Agisoft Metashape, a widely established software in photogrammetry, was used. The data were processed at three quality levels Low, Medium, and High in order to evaluate the impact of point density on the generated products. The Low setting prioritized processing speed and lower resource consumption, producing models with less detail; the High setting used the maximum available information, resulting in denser and more accurate models, albeit with higher computational demand; and the Medium setting represented a balance between level of detail and processing time.

In the second stage, the same dataset was processed using the Drone Tasking Manager (DTM), a free web-based platform that integrates flight planning and photogrammetric processing through OpenDroneMap (ODM). DTM automatically executes the entire reconstruction workflow, eliminating the need for advanced parameter configuration.

According to Hartwig et al. (2023), ODM follows a structured pipeline consisting of image alignment, sparse and dense point cloud generation, and the derivation of products such as Digital Surface Models (DSM), orthomosaics, and textured 3D models. In this study, processing was performed using default parameters, ensuring uniformity and reproducibility of the results. This integrated approach allows maintaining the technical consistency of the products even without advanced manual adjustments.

2.2.6 Quality Control

The positional accuracy of the cartographic products was evaluated by comparing coordinates extracted from the orthomosaics generated in the DTM and Metashape software with check points collected in the field, using the free GeoPEC software (GEOPEC, 2025). This procedure was applied identically to both orthomosaics, namely those produced in Metashape and those generated in DTM/ODM, allowing for a direct comparison of the software performance in reproducing the actual position of the measured targets.

The GeoPEC software (GEOPEC, 2025) follows the standards established by the Brazilian Army Directorate of Geographic Service, which defines the Technical Specification for Quality Control of Geospatial Data (CQDG) as a reference for positional accuracy assessment (DSG, 2016). Based on this procedure, positional errors were quantified and classified according to their suitability for the intended use (Santos et al., 2016).

2.2.7 Processing Quality Comparison

In this stage, following quality control and the acquisition of results, a comparative analysis of the products generated in two processing environments was carried out: the commercial software Agisoft Metashape and the open-source software OpenDroneMap (ODM), accessed via DTM. The comparison considered technical criteria and final product quality, including: covered area, orthomosaic resolution (GSD), processing time, point cloud density, mean reprojection error, GPS RMS, interface, computational requirements, and visual quality.

The visual assessment of the orthomosaics was performed using a regular grid created in QGIS 3.38 (QGIS Development Team, 2024), with cells measuring 70 × 70 m. The Random Selection tool from the MMQGIS plugin was used to randomly select three cells, which served as the basis for comparison between the orthomosaics processed in DTM and Metashape, analyzed at a fixed scale of 1:200. This step allowed the identification of differences in sharpness, distortions, and the representation of urban and natural features.

Finally, the advantages and limitations of each software were analyzed, focusing on evaluating the potential of the DTM platform for photogrammetric processing.

2.2.8 Processing Quality Comparison

To promote open access to the generated data, the cartographic products were made available on the OpenAerialMap platform (Humanitarian OpenStreetMap Team, 2025). The use of this tool has shown a significant impact on data editing and updating practices in projects such as OpenStreetMap (OpenStreetMap Contributors, 2026), contributing to the democratization of access to geospatial information and strengthening community mapping initiatives (Mandourah & Hochmair, 2024).

3. Results and Discussion

3.1. Quality Assessment and Control

According to the Federal Geographic Data Committee – United States (1998), a minimum of 20 check points is recommended for positional accuracy analysis. However, due to operational constraints, only six points were used, which allowed the estimation of the Root Mean Square Error (RMSE) for the generated products. The process was conducted using the GeoPEC software (GeoPEC, 2025), following the methodology proposed by Santos et al. (2016) and the limits established by the PEC-PCD standard (Decree No. 89,817/1984) for the 1:5,000 scale.

For the DTM, the obtained RMSE was 2.3958 m, a value compatible with Class C (EP ≤ 2.5 m), classifying the product as accurate within the requirements of this category. This result indicates that, although it meets regulatory standards, DTM presents greater dispersion in discrepancies when compared to the orthomosaic.

For the orthomosaic generated in Metashape, using medium processing settings, the total RMSE found was 1.2255 m, meeting the threshold for Class B (EP ≤ 1.5 m). This performance demonstrates higher positional accuracy, indicating lower variation in the absolute discrepancies of the evaluated points.

The direct comparison between the products revealed that the Metashape orthomosaic presented better positional accuracy, being classified as Class B, while the DTM product, although of lower quality, remains within the acceptable parameters of Class C. Thus, both products are considered accurate; however, the Metashape orthomosaic stands out for providing the highest precision among the analyzed data.

3.2. Technical Comparison of Orthomosaics

The main results obtained from the two processing environments are presented in Table 1, allowing a direct comparison between the performance of Metashape and the Drone Tasking Manager in the generation of cartographic products.

Table 1. Results of photogrammetric processing.

Criterion	DTM	Metashape (Low)	Metashape (Medium)	Metashape (High)
Covered area	0,2125 km²	0,267 km²	0,271 km²	0,267 km²
GSD	2,3 cm/pixel	2,16 cm/pixel	2,18 cm/pixel	2,18 cm/pixel
Total processing time	1h 02m	17m	1h 45m	3h 03m
Point cloud	15.876.047	12.227.165	52.189.861	212.632.898
Mean reprojection error	1,66 pixel	2,78 px	1,72 px	1,27 px
RMS accuracy	1.25 m (X: 54,4cm / Y: 51,8cm / Z: 1.12m)	80,13 cm (X: 30,07 cm / Y: 23,99 cm / Z: 70,29 cm)	54,92 cm (X: 32,66 cm / Y: 27,24 cm / Z: 34,74 cm)	78,42 cm (X: 35,54 cm / Y: 28,35 cm / Z: 63,89 cm)
Interface	Web-based and accessible	Greater technical control	Greater technical control	Greater technical control
Computational requirements	Cloud-based processing	Local software, 7.7 GB RAM, i5 CPU, integrated GPU		

Source: Authors (2026).

The comparative analysis shows that the processing performed in DTM presents technical performance close to that obtained in Metashape under its Medium quality configuration, as evidenced in Table 1. Among the main indicators, the number of reconstructed points stands out: DTM generated 15,876,047 points, a value higher than that of the Low configuration in Metashape and representative of a consistent processing, although lower than the 52,189,861 points obtained in the Medium configuration.

The spatial resolution achieved by DTM (2.3 cm/pixel) is also close to the values obtained in Metashape Medium and High (2.18 cm/pixel), indicating its capability to generate orthomosaics with a high level of detail. In terms of geometric consistency, DTM presented a mean reprojection error of 1.66 pixels, slightly lower than that of Metashape Medium (1.72 pixels), demonstrating stability in the photogrammetric adjustment.

Processing time is another distinguishing factor, with DTM completing the entire workflow in 1 h 02 min, demonstrating good operational efficiency.

Thus, the results indicate that DTM delivers products comparable to those of Metashape at Medium quality, combining technical performance, accessibility, and ease of use, while also standing out for its efficiency in terms of processing time and computational requirements.

3.3. Visual Comparison of Orthomosaics

The initial analysis of the orthomosaics reveals visual differences between the products generated by the two platforms. Metashape exhibited higher sharpness and better definition of urban features, allowing clear identification of rooftops, roads, and vegetated areas. In contrast, the orthomosaic produced by DTM/ODM showed more regular edges and lower geometric distortion, indicating a more consistent boundary delineation at the edges of the processed area.

These differences reflect the distinct performance of the mosaicking and photogrammetric adjustment algorithms employed by each software, directly influencing the final appearance of the product. Figure 4 presents the orthomosaics generated by DTM/ODM (A) and Metashape (B).

(A) (B)

Figure 4. Results: (a) DTM; (b) Metashape.
Source: Authors (2026).

To further deepen the visual comparative analysis between the generated orthomosaics, three areas of the original image were selected based on a sampling grid previously constructed in QGIS (Figure 5). Three cells were randomly chosen and clipped from the orthomosaics produced both in the Drone Tasking Manager (DTM) and in Metashape using the medium processing configuration and a fixed scale of 1:200.

The qualitative analysis of the orthomosaics (Figure 6) demonstrated a high visual similarity between the products generated by the web platform (DTM) and the proprietary software. Only minor visual artifacts were identified in the DTM product. In comparison (1), a slight distortion was observed in a wall; in comparison (2), a minor distortion was identified at the boundary of a property; and in comparison (3), distortions were observed in two walls representing plot boundaries.

These discrepancies are associated with the geometric displacement of vertical features, a common characteristic of conventional orthophotos, in which the apparent position of elevated features depends on the image acquisition angle and the geometry of the photogrammetric reconstruction. In this context, such distortions do not necessarily represent processing errors, but rather inherent limitations of the surface-based orthorectification model (DSM-based).

It should be emphasized that a more rigorous evaluation of the geometry of these features would require the use of true orthophotos, which incorporate more detailed three-dimensional modeling and occlusion-handling algorithms, enabling the correct projection of vertical objects. Since this type of processing was not adopted in this study, the visual analysis should be interpreted within the limitations of conventional orthophotography.

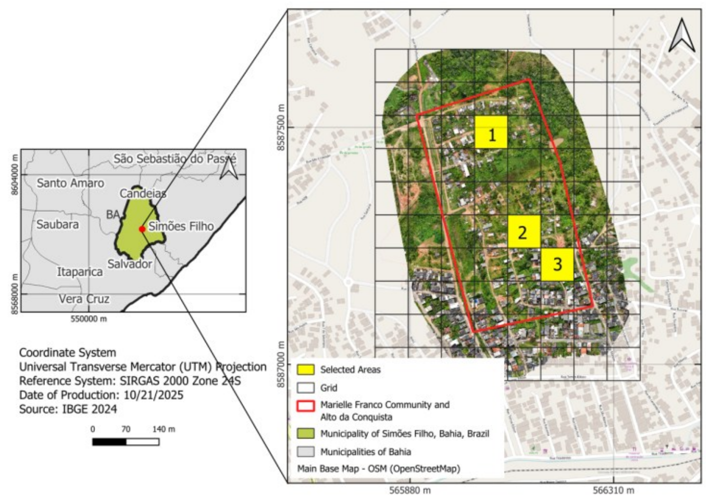

Figure 5. Illustration of selected areas for visual comparison.
Source: Authors (2026).

These results indicate that the products generated by DTM, despite minor distortions, maintain the ability to faithfully represent the main landscape features. Thus, their application in collaborative and participatory mapping initiatives is validated, especially in contexts with limited access to proprietary software.

(A) (B)

(A) (B)

Figure 6. Visual comparison of orthomosaics: (a) DTM; (b) Metashape.
Source: Authors (2026).

3.4. Advantages and Limitations

The Drone Tasking Manager (DTM) stands out for operating entirely in a web-based environment, eliminating the need for robust hardware and proprietary licenses, which broadens access to flight planning and photogrammetric processing through a free and low-cost platform. Its processing time proved to be competitive compared to Metashape, even when executed locally, demonstrating good operational efficiency. DTM achieved a spatial resolution of 2.3 cm/pixel, similar to that of Metashape (2.18 cm/pixel), and presented a mean reprojection error of 1.66 pixels, slightly lower than Metashape (1.72 pixels), indicating satisfactory geometric consistency.

During flight operations, the Waylines mode provided greater stability by adopting continuous trajectories and reducing the data load on the remote controller, in contrast to the Waypoints mode, which experienced freezes during longer missions.

However, DTM presented limitations regarding positional accuracy, with a total RMS of 1.25 m, higher than that obtained with Metashape (0.55 m). This difference is mainly due to the absence of ground control points in the processing, restricting its use for products requiring certification according to the ET-CQDG standard. Additionally, DTM offers less control over technical parameters and produces orthomosaics with slightly reduced sharpness compared to Metashape. Although this difference does not compromise visual interpretation, it limits applications requiring higher positional accuracy.

3.5. Publication on the OpenAerialMap Platform

The final stage consisted of making the orthomosaics available on the OpenAerialMap (OAM) platform, with the aim of promoting open access to data and fostering collaborative mapping in vulnerable communities. The process involved uploading the orthomosaic and essential metadata (location, date, and project information), integrating the product into the public repository of high-resolution aerial imagery. This initiative reinforces the principles of geospatial information democratization and expands the practical reach of the results, enabling their application in spatial analyses and community-based projects. The result can be accessed at: OpenAerialMap Browser

4. Conclusion

The results demonstrate the technical feasibility of the proposed methodology, showing that the Drone Tasking Manager (DTM), combined with OpenDroneMap (ODM), enables the generation of accurate and accessible cartographic products even in contexts with limited infrastructure. The resulting orthomosaic was classified as Class C (1:5,000 scale) according to PEC-PCD (ET-CQDG), confirming the suitability of the data for medium-accuracy applications and validating the potential of the method for collaborative mapping and community-based territorial planning.

Although Metashape presents better technical control and visual quality, its dependence on advanced hardware and paid licenses limits its use in budget-constrained contexts—precisely where ODM/DTM proves more advantageous by democratizing access to cartography and promoting territorial autonomy.

The achieved accuracy (Class C, 1:5,000) is sufficient for urban diagnostics, risk area identification, local planning, and emergency actions, consolidating DTM as an efficient tool for social and extension-based applications. For future work, the following recommendations are made:

a) evaluate lower-altitude flights (50–70 m) to assess the impact on resolution and accuracy;
b) test cross-flight patterns to increase point cloud density and orthomosaic sharpness, including evaluation using true orthophotos;
c) incorporate ground control points (GCPs), with a minimum of 20 points and/or explore references addressing optimal sample size for validation, in order to investigate the methodology's potential at larger scales and higher accuracy classes (A or B), expanding its applicability to technical cadastral mapping and official georeferencing;
d) extract cartographic features and compare them with reference cartography at a scale of 1:1,000 or larger;
e) Test other open-source photogrammetry software available.

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