

Proposição metodológica de mapeamento com Aeronave Remotamente Pilotada (ARP) para o planejamento e gestão socioambiental em cidades pequenas

A methodological proposal for mapping using Remotely Piloted Aircraft (RPA) for urban socioenvironmental planning and management in small cities

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Abstract: With technological advancements, it becomes necessary to reflect on their use to promote quality of life, especially in urban areas. In Brazil, small cities still lack technical instruments compatible with their demands and with the required spatial and temporal resolution. In this context, this research proposes a methodological approach to mapping using Remotely Piloted Aircraft (RPA), aimed at urban socio-environmental planning and management in these localities. Methodologically, bibliographic and documentary research were conducted, along with fieldwork and office-based analysis, to define an appropriate workflow. The results indicate that the use of RPA is particularly suitable for small cities: in smaller areas, field time and operational costs tend to be reduced, making its application more feasible despite the high added value of the equipment. On the other hand, there is a lack of technical training among professionals and public managers, which highlights the need for continuous education to enhance the autonomy of local governments.

Keywords: Geotechnologies; Digital Image Processing; Urban Space.

Resumo: Com os avanços tecnológicos, torna-se necessário refletir sobre seu uso para promover a qualidade de vida, especialmente nas cidades. No Brasil, cidades pequenas ainda carecem de instrumentos técnicos compatíveis com suas demandas e com a resolução espacial e temporal necessária. Diante disso, esta pesquisa propõe um caminho metodológico de mapeamento com Aeronave Remotamente Pilotada (ARP) voltado ao planejamento e à gestão socioambiental urbana nessas localidades. Metodologicamente, foram realizadas pesquisas bibliográfica e documental, além de pesquisa de campo e de gabinete, visando definir um fluxo de trabalho adequado. Os resultados indicam que o uso de ARP é particularmente apropriado em cidades pequenas: em áreas menores, o tempo em campo e o custo operacional tendem a ser reduzidos, tornando a aplicação mais viável apesar do alto valor agregado do equipamento. Por outro lado, observa-se carência de formação técnica entre profissionais e gestores, evidenciando a necessidade de formação continuada para ampliar a autonomia das prefeituras.

Palavras-chave: Geotecnologias; Processamento Digital de Imagens; Espaço urbano.

1. Introduction

Geotechnologies constitute essential elements of social practice in the current historical moment, insofar as they influence the way society perceives, analyzes, and represents geographic space (MATIAS, 2005). For this reason, it becomes indispensable to reflect on how such instruments are being mobilized and, above all, in the service of which agent responsible for producing geographic space.

Rosa (2005) defines them as a set of technologies aimed at the collection, analysis, and dissemination of geographically referenced information, involving hardware, software, and peopleware. At this point, it becomes evident that the role of the user (especially the one responsible for processing data and communicating results) is central, since it is through this actor that the quality, scope, and intelligibility of the product are determined.

Among the instruments that compose geotechnologies, Garcia (2016) highlights, among others, digital cartography, topography and geodesy, remote sensing, Geographic Information Systems (GIS), the Global Navigation Satellite System (GNSS), and photogrammetry. Although the author organizes these instruments according to levels of data acquisition, it is relevant to emphasize photogrammetry and, especially, aerial photogrammetry, due to its direct connection with the acquisition of aerial data and its capacity to generate highly detailed products, which expands the possibilities for interpreting and intervening in urban areas.

Brito and Coelho Filho (2007) define photogrammetry as the measurement of terrain through photographs, understood as the science and technique of obtaining reliable information from images captured by digital sensors mounted on terrestrial, aerial, or orbital platforms.

Beyond reducing field activities aimed at the punctual survey of coordinates, photogrammetry enables the three-dimensional reconstruction of locations, articulating image-space (2D) with object-space (3D).

Aerial photogrammetry, in turn, refers to the acquisition of images through sensors mounted on aerial platforms, aimed at the extraction of topographic information. However, since aerial photographs are obtained through central projection, they exhibit radial distortions, which intensify as they move away from the center of the image (ROSA, 2009).

In this sense, the adequate overlap between images, sensor calibration, and flight planning become fundamental elements, since they directly condition the reliability of the generated products.

Despite the dissemination and technological advancement of aerial platforms (SILVA, 2015), aerial photogrammetry procedures are still heterogeneous and poorly systematized, evidencing the need for clearer and more replicable workflows, especially for urban planning in small cities. In this context, Remotely Piloted Aircraft (RPA) stands out due to the generation of orthoimages, three-dimensional models, and digital models — such as the Digital Terrain Model (DTM) and the Digital Surface Model (DSM). These products support socio-environmental and urban analyses (CARMO, 2022; CARMO et al., 2023).

Recent studies highlight this potential by employing DTM/DSM for analyses of vulnerability to floods and inundations in different urban contexts (CARMO; MATIAS, 2024; HANSE et al., 2024). However, differences between operational workflows, such as the adoption (or not) of ground control points for georeferencing, indicate important limitations. Although some procedures are sufficient for visual interpretation, they may not safely meet the technical demands of engineering and planning projects, especially in municipal contexts.

This article aims to systematize and test an aerial survey workflow using RPA technology, employing a Phantom 4 PRO V2, adapted to the reality of municipalities in small cities, integrating legal requirements, fieldwork stages, and Digital Image Processing (DIP), as well as evaluating its technical and operational feasibility in urban areas. To this end, the study is structured into four sections: legal guidelines, organization of fieldwork, data collection dynamics, and data processing.

2. Methodology

The methodological procedures are based on three stages: bibliographic and documentary research, fieldwork, and office activities.

The bibliographic research was carried out through searches in databases such as Periódicos CAPES, Google Scholar, Scopus, and SciELO. This stage supported the definition of the following phases and the analysis of the existing production on the use of RPA in urbanized areas, in addition to guiding the choice of the DIP software (AMARAL, 2007).

The documentary research, based on the analysis of laws, decrees, and plans (FONTANA, 2018), made it possible to understand the guidelines of Brazilian legislation for aerial surveys and to establish flight parameters aligned with national

requirements, especially those of the National Civil Aviation Agency (ANAC) and the Department of Airspace Control (DECEA).

The field research took place in two moments: (I) surveying of ground control points (control and verification) and (II) image recording with a Phantom 4 PRO V2 RPA, carried out in the first quarter of 2022 in the Pinhalzinho neighborhood, in Holambra (SP) (SUERTEGARAY, 2002). The office work focused on DIP in Agisoft Metashape, the stage in which the products described in Carmo (2022) were generated, since this study derives from part of these procedures (Figure 1).

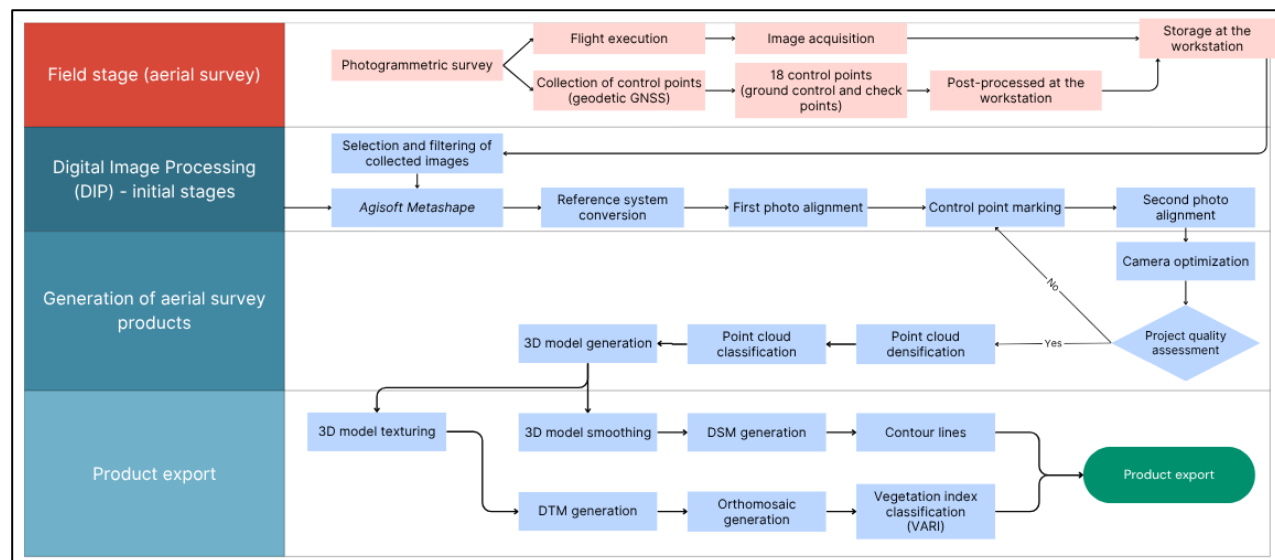


Figure 1 – Workflow for product generation in Agisoft Metashape.

Source: Authors (2025).

The stages in red correspond to image recording, and the ones in blue, to office work. DIP follows a standard workflow: image filtering; coordinate conversion (geographic/UTM); alignment and generation of a sparse cloud; insertion and marking of control points; realignment and camera optimization, with quality checking; densification and classification of the cloud; and generation of the 3D model.

The application of this workflow validated the procedure in its legal-operational and technical-cartographic aspects. The aerial survey with RPA, supported by GNSS points and processed in Agisoft Metashape, generated orthoimages, DTM, DSM, contour lines, and vegetation index with with planimetric and altimetric accuracy compatible with the adopted GSD (Ground Sample Distance).

This set of products indicates operational feasibility and suitability for urban socio-environmental planning and management in small cities, offering a detailed and updatable cartographic base for municipal use.

3. Results and discussion

3.1 Legislation for aerial surveys in urban areas

Given the increasing diffusion of these aircraft and the fact that they operate in airspace shared with other manned aircraft, the legal delimitation of their use has become essential. Aerial survey activities may be carried out by manned or unmanned platforms and involve three main aspects, according to Castilho (2019): (I) they are actions developed in airspace under State domain; (II) they are directly related to cartographic production; and (III) they face gaps and overlaps in Brazilian legislation.

The Brazilian Aeronautical Code (Law No. 7,565/1986) establishes, in Article 21, that no aircraft may carry equipment intended for aerophotogrammetric surveying or prospecting without authorization from the competent body, aiming to safeguard public security. Article 302, on the other hand, classifies the performance of aerial photogrammetry surveys without such authorization as an infraction. Complementarily, Decree No. 2,278/1997 regulates aerial surveys within the national territory, defining them as the phase of data capture and recording by sensors installed on aerial platforms and

determining that, as a rule, the resulting products are not confidential and should support national development, except when there is a risk to State security.

Within the scope of civil aviation, ANAC consolidated specific requirements through Resolution No. 419/2017, which approves the Special Brazilian Civil Aviation Regulation (RBAC-E) No. 94. This regulation establishes that civil RPAs must be registered and have a registration certificate issued by ANAC, in addition to complying with operational requirements, such as the minimum age of the pilot, safety distances in relation to people not involved in the operation, and restrictions on flying over sensitive areas. In addition, Ordinance GM-MD No. 3,703/2021, issued by the Ministry of Defense, defines procedures, deadlines, and risk levels for aerial survey activities, including the mandatory registration of entities in the National Territory Aerospace Survey Registration System (SisCLATEN), the obtainment of Authorization for Aerial Survey – Aerospace Phase (AAFA), and the control of products, which must remain under custody within the national territory.

The legislation also provides specific rules for the participation of foreign entities, whose activities depend on authorization from the President of the Republic, following a request from the Ministry of Defense. On the other hand, some exceptions have been established: Normative Ordinance No. 101/GM-MD waives prior authorization for aerial surveys intended for agroforestry activities on private properties with an area of up to 15 km², which highlights the effort to reconcile State control, population protection, and the encouragement of the applied use of geotechnologies.

3.2 Pre-field procedures for aerial surveys in cities

The pre-field stage is fundamental, as it is during this phase that the flight parameters are defined and the collection of control points that will support post-processing is organized, increasing the precision and accuracy of the generated products. In this study, the planning was structured into four stages: (I) preparation of a checklist; (II) flight planning; (III) planning of the collection of control points; and (IV) equipment calibration.

In the preparation of the checklists, Trello was used as an organizational tool in order to systematize the tasks and reduce operational failures. Three lists were structured (pre-field, field, and post-field) aimed at carrying out the missions with RPA, as shown in Figure 2.

Pré-campo	Campo	Pós-campo
<input checked="" type="checkbox"/> Checklist 0% <input type="checkbox"/> SARPAS/DECEA authorization <input type="checkbox"/> Pilot and aircraft certificate (ANAC) <input type="checkbox"/> Equipment invoice <input type="checkbox"/> Sunshade <input type="checkbox"/> Smartphone with more than 70% battery <input type="checkbox"/> RPA batteries fully charged <input type="checkbox"/> Remote controller charged with at least 50% battery <input type="checkbox"/> USB cable <input type="checkbox"/> Propellers, integrity checked <input type="checkbox"/> Check RPA motors <input type="checkbox"/> Check whether sensors are clean <input type="checkbox"/> Check whether the SD card is in the RPA <input type="checkbox"/> Calibrate the equipment <input type="checkbox"/> Check for firmware updates <input type="checkbox"/> Transfer the flight plan to the smartphone (DroneDeploy)	<input checked="" type="checkbox"/> Checklist 0% <input type="checkbox"/> Calibrate the IMU before going to the field, using the DJI GO 4 mobile app <input type="checkbox"/> Calibrate the drone in DJI Assistant before going to the field <input type="checkbox"/> Remove the gimbal protector <input type="checkbox"/> Connect the USB cable to the remote controller and smartphone <input type="checkbox"/> Check motors — noise and integrity — and connect to the controller <input type="checkbox"/> Check the propellers, placing them according to their colors: black and gray <input type="checkbox"/> Turn on the RPA <input type="checkbox"/> Turn on the remote controller <input type="checkbox"/> Open the DJI GO 4 app <input type="checkbox"/> Check whether there is a GPS signal in the DJI GO 4 app <input type="checkbox"/> Calibrate the compass in DJI GO 4, if the app does not show it on the screen <input type="checkbox"/> Set the home point <input type="checkbox"/> Open the DroneDeploy app <input type="checkbox"/> Execute the flight plan	<input checked="" type="checkbox"/> Checklist 0% <input type="checkbox"/> Turn off the equipment <input type="checkbox"/> Check the integrity of the RPA <input type="checkbox"/> Store the cables <input type="checkbox"/> Remove the RPA battery — never store the RPA with the battery inserted <input type="checkbox"/> Remove the SD card when at the place where the RPA will be stored <input type="checkbox"/> Transfer the images to the notebook <input type="checkbox"/> Check the quality of the images <input type="checkbox"/> Delete the images from the SD card <input type="checkbox"/> Extract the flight log — for DJI RPAs, specific software is required, such as DJI Pilot

Figure 2 – Field checklists for image recording with RPA.

Source: Authors (2025).

In the checklists, special attention was given to the necessary authorizations and documents (SARPAS/DECEA, ANAC certificates, and invoice), to the battery level of the smartphone or tablet, to the integrity of the equipment, and to the

execution and post-field routines. These items seek to ensure operational safety, reducing the risk of accidents involving operators and third parties, as well as damage to the RPA.

The second stage, focused on delimiting the area to be mapped and defining the flight parameters, can be organized in DroneDeploy, provided that the equipment and the GSD have been previously defined. Ferreira (2017) defines GSD as the image pixel size, expressed in cm/pixel, that is, the portion of the terrain represented by each pixel. Thus, it is a parameter directly conditioned, above all, by flight height, focal length, and pixel size on the sensor.

In this study, an RPA from the Phantom line was used (DJI Phantom 4 PRO V2), shown in Figure 3. It is a platform with embedded navigation (GPS/GLONASS) and a camera with a CMOS sensor, suitable for collecting high-resolution images for mapping purposes, provided that it is operated with flight planning and calibration compatible with the required precision.



Figure 3 – RPA used in the field.

Source: Authors (2025).

A relevant point is that the RPA does not have extensive flight autonomy: each battery operates, on average, for approximately 30 minutes. For this reason, depending on the size of the area to be mapped, complementary flight sessions become necessary.

Once the RPA has been defined, the next step is to establish the GSD. Costa et al. (2018) indicate that its calculation is given by [Equation 1]:

$$\frac{f}{h_v} = \frac{d}{GSD}$$

where h_v refers to the flight height, f to the focal length, and d to the physical dimensions of the pixel. The required variables can be obtained from the manufacturer's technical specifications (DJI) and from the flight plan. Thus, to determine d , the calculation presented in [Equation 2] is applied:

$$Tam_{pixel_x} = \frac{Comp_{sensor}}{Comp_{imagem}} = \frac{13,2 \text{ mm}}{5472} = 0,0024128 \text{ mm/pixel}$$

$$Tam_{pixel_y} = \frac{Altura_{sensor}}{Altura_{imagem}} = \frac{8,8 \text{ mm}}{3648} = 0,0024122 \text{ mm/pixel}$$

Considering that the difference between the two results is not significant, the value of 0.00241 mm/pixel was adopted for the variable d . Therefore, the GSD of the aerial survey, to be carried out with a Phantom 4 PRO V2, was calculated as follows [Equation 3]:

$$\frac{3,61 \text{ mm}}{71,1 \text{ m}} = \frac{0,00241}{GSD}$$

$$GSD = 71,1 \text{ m} \times \frac{0,00241}{3,61 \text{ mm}}$$

$$GSD = 71,1 \text{ m} \times 0,00066$$

$$GSD = 0,0469 \text{ mm}$$

Therefore, for an average flight height of 71.1 m and considering the sensor characteristics of the Phantom 4 PRO V2, the estimated GSD was approximately 4.75 cm/pixel. In Agisoft Metashape, the orthoimage was exported with a pixel size of 2.74 cm/pixel, a value lower than the theoretical GSD; however, this refers to resampling during export, which does not increase the geometric resolution, remaining limited to a GSD of approximately 4.7 cm/pixel. Table 1 summarizes the parameters adopted in the aerial survey of this study.

Table 1 – Flight parameters in the Pinhalzinho neighborhood, in Holambra (SP), test area

Parameters	Data
Flight height (m)	71,1 m
Number of images	1.096
Number of batteries	4
Flight lines	34
GSD	0,0469 mm
Estimated flight time	45 min 09 sec
Lateral overlap rate	80%
Frontal overlap rate	80%

Source: Authors (2025).

The flight parameters defined in the pre-field stage may be adjusted during the activity, especially regarding the number of images and battery consumption, depending on possible signal losses between the RPA and the remote controller. Carmo (2022) recommends 80% frontal and lateral overlap to ensure the quality of the products, especially in urban areas, which are marked by greater heterogeneity.

With the parameters defined, the flight plan is prepared in DroneDeploy, as shown in Figure 4.



Figure 4 – Flight plan organized on the DroneDeploy website.
Source: Authors (2022).

Regarding the delimitation of the flight area (Figure 4), a 30 m margin beyond the neighborhood boundary was adopted in order to reduce edge effects in the products, such as so-called “dragging” effects (blurred areas in the image).

After flight planning, the control point planning was defined with the support of Google Earth Pro, seeking to distribute them in a cohesive and efficient manner. Silva (2018) highlights that these points, which must be photo-identifiable in the field, should have x, y, and z coordinates obtained with high precision to ensure better georeferencing of the products.

The distribution should be homogeneous throughout the entire area and planned before the aerial survey. INCRA/DF/No. 02 (2018) establishes a minimum of 20 control points (ground control and check points), properly marked in the field and identifiable in the images. In Figure 5, it can be observed that the distribution occurred homogeneously, covering the boundaries, the central area, and sectors with overlapping flight lines.



Figure 5 – Planning of control points in Google Earth Pro.

Source: Authors (2022).

In Figure 6, the ground control points (HV) are shown in yellow and the check points (CH) in red. As some of them were allocated in grassy areas, EVA foam sheets (black and white) were used for their identification in the field, while lime dissolved in water was used for those positioned on asphalt. The marking followed a checkerboard pattern (Figure 6), with targets measuring 42 cm × 42 cm and squares measuring 21 cm × 21 cm (MATIAS et al., 2015).

To ensure the execution of the field planning, prior calibration of the aircraft was carried out in the laboratory. In DJI equipment, this procedure can be performed using DJI Assistant 2 for Phantom, on a notebook or desktop computer, with sensor calibration and firmware updates, which are recommended at the beginning of each operation.

3.3 Field guidelines for aerial surveys

In the field, it is important to establish a chronological order for the execution of the operation, namely: (I) pre-marking of the control points; (II) collection of control points with a GNSS receiver; (III) field calibration of the equipment (IMU and compass); and (IV) overflight of the area of interest.

The first stage of the operation must necessarily be carried out at the beginning of the process, since the control points must be marked when the overflight stage begins.

The collection of control points with GNSS can be carried out simultaneously with the overflight, which significantly reduces field time. Fagundes (2016) states that the so-called pre-marking of control points consists of artificial marking in the field, which can be viewed in aerial images; its main purpose is to improve the accuracy of point location, which is fundamental in aerial triangulation calculations.

After pre-marking, the aerial survey and the collection of coordinates with geodetic GNSS begin. Monico (2008) distinguishes three main types of receivers: (I) navigation receivers (GPS), with limited precision; (II) GNSS RTK receivers, with base and rover, which generate information in real time; and (III) geodetic GNSS receivers, also with base and rover, intended for high-precision surveys.

The data obtained can reach centimeter-level precision (GNSS RTK) or millimeter-level precision (geodetic GNSS), but they require post-processing on a workstation for error correction (MONICO, 2008). In the field, twenty points were pre-marked; however, due to unforeseen events and losses during processing, eighteen control points remained.

In this research, the equipment used in the field was a pair of L1/L2 GNSS Hiper Lite+ receivers/antennas, manufactured by Topcon. The tracking time of the base station was 5 hours, while the survey station was operated for 15 to 20 minutes for each control point. In Figure 6, it is possible to visualize the base station, as well as the collection of points with the survey station.



Figure 6 – Allocation of the geodetic GNSS base station and collection of control points with the survey station.
Source: Authors (2022).

Once collected, these data are taken to the laboratory to be processed for use in the image georeferencing process, ensuring the precision of the generated products. The aerial survey can be carried out simultaneously with this stage, since the control points have already been pre-marked. In this context, organization is essential, as these points will be used in DIP.

During the aerial survey stage, the RPA and remote controller batteries must be fully charged, and the smartphone must have at least 80% battery charge. The operation uses the DJI GO 4 applications, responsible for system connection and calibration, including the compass, and DroneDeploy, for the execution of the flight plan.

In general, the execution process of the RPA operation is automated. It is relevant for the operator to know how to pilot the equipment in order to ensure greater operational safety, although the process itself is carried out exclusively through the DroneDeploy application.

3.4 Post-field processes, from image organization to Digital Image Processing (DIP)

One of the central elements in the DIP stage is the hardware available for processing. In this research, a workstation was used — an Avell notebook with x64 architecture, Intel Core i7 processor (8th generation), 16 GB of RAM, 500 GB SSD, 1 TB HD, and NVIDIA GeForce GTX 1050 Ti GPU, operating on Windows 11 Home (private license). With this configuration, the full processing of the project, composed of 1,096 images, required approximately 72 hours, including the processing stages and the export of the products.

The post-field activities, carried out in the office, focused on the treatment of the coordinates collected with geodetic GNSS, on the DIP of the aerial images, and on the generation of cartographic products. The post-processing of the coordinates was performed through fast-static processing, using the SPC1 station of the RBMC/IBGE as reference, in the TopconTools software, resulting in planimetric and altimetric data.

The data obtained are presented in Table 2, organized into ground control points (HV) and check points (CH), used in the DIP of the images to ensure the positional quality of the products.

Table 2 – Flight parameters in the Pinhalzinho neighborhood, in Holambra (SP).

Ground control points	Coordinate E (m)	Coordinate N (m)	Altitude (m)	Sd plan	Sd alt
CH1	286438,930	7491271,173	541,832	0,002	0,004
CH2	286505,881	7491460,132	542,716	0,002	0,004
CH3	286680,377	7491606,308	550,415	0,001	0,002

CH4	286794,705	7491449,929	556,932	0,001	0,001
CH5	287084,234	7491476,634	556,667	0,003	0,008
HV1	286457,524	7491289,892	541,748	0,002	0,003
HV2	286438,655	7491242,781	541,436	0,001	0,002
HV3	286533,486	7491065,919	544,410	0,002	0,005
HV4	286487,210	7491340,493	541,636	0,001	0,003
HV5	286603,196	7491599,145	543,189	0,001	0,002
HV6	286788,023	7491595,217	559,460	0,001	0,002
HV7	286761,074	7491523,130	556,468	0,001	0,001
HV8	286623,694	7491344,538	541,297	0,001	0,002
HV9	286738,339	7491388,367	550,307	0,006	0,010
HV10	286795,333	7491250,209	541,294	0,001	0,002
HV11	286937,023	7491538,146	564,349	0,001	0,003
HV12	286896,155	7491468,723	561,076	0,001	0,002
HV13	287236,928	7491451,193	541,630	0,007	0,014

Source: Authors (2022).

The coordinates presented in Table 2 correspond to the data used in the DIP, ensuring the reliability of the products. All coordinates are in UTM and, when imported into the processing software, the SIRGAS 2000 reference system was adopted.

The DIP was carried out in Agisoft Metashape, with an educational license provided by the DEGET/UNEMAT research group — Sinop campus — and the cartographic products were prepared in ArcGIS Pro, with an educational license provided by UNICAMP.

To assess the quality of the project, the principle proposed by Graham and Koh (2002) was adopted, according to which planimetric and altimetric accuracy is considered adequate when it remains around 2 to 3 times the GSD size indicated in the DIP report. In the project used as reference in this research, the GSD was 2.93 cm/pixel and, as shown in Table 3, the results obtained remain within this limit.

Table 3 – Data from the DIP report, based on check points.

Number of points	Axis error X (cm)	Axis error Y (cm)	Axis error Z (cm)	Axis error XY (cm)	Total error (cm)
5	1,6575	0,901599	1,78212	1,88684	2,5954

Source: Data derived from the processing report generated in Agisoft Metashape software, organized by the authors (2022).

The remaining products generated in Agisoft Metashape are derived from the 3D model and follow two workflows, as indicated in Figure 1. Among them, the distinction between DSM and DTM stands out: the former incorporates elements above the surface, while the latter represents only the terrain. For this reason, point cloud classification becomes necessary.

In addition, it is possible to generate vegetation indices, such as VARI (GITELSON et al., 2002; SCHNEIDER et al., 2008), which considers atmospheric influence and allows targets to be distinguished, indicating whether developing vegetation remains within expected patterns. Gitelson et al. (2002) emphasize that the index reduces atmospheric effects by subtracting the band corresponding to the blue channel, as shown in [Equation 4]:

$$\text{VARI} = \frac{\text{Green} - \text{Red}}{\text{Green} + \text{Red} - \text{Blue}}$$

Based on this equation, it is possible to identify areas with higher or lower vegetation density. At the end of the processing, the vegetation index, orthoimage, DSM, DTM, and contour lines were exported and subsequently imported into ArcGIS Pro for layout organization and product dissemination.

Based on the generated products, it was possible to identify, in the study area, distinct patterns of urban land use and occupation, with a concentration of impervious surfaces in central areas and greater presence of vegetation cover in peripheral sectors. The integrated analysis of the DTM and DSM also made it possible to recognize topographic variations associated with potential surface runoff areas, indicating sectors more susceptible to flooding. These results demonstrate that, beyond technical validation, the products derived from aerial surveys with RPA enable analyses applied to urban planning, supporting territorial diagnoses and decision-making at the municipal level.

3.5 Geotechnologies, urban socioenvironmental planning and small cities

Geotechnologies, as a technical-scientific mediation of the (re)production of urban space, play a strategic role in socio-environmental planning, especially in small cities marked by data scarcity and institutional fragility. In these contexts, the lack of updated cartographic databases, dependence on low-resolution images, and the limited technical qualification of municipal teams restrict the capacity for diagnosis and intervention (CARMO et al., 2023).

Within the scope of municipal management, products derived from aerial surveys with RPA can be incorporated into urban planning routines. High-resolution orthoimages allow cadastral updating and the identification of irregular occupations; digital models (DTM and DSM) support drainage analyses and the mapping of areas susceptible to flooding; contour lines assist in infrastructure planning and land subdivision; and vegetation indices allow the monitoring of green areas and soil sealing. Thus, the proposed methodological workflow goes beyond data generation and is consolidated as an instrument to support decision-making in urban socio-environmental planning in small cities.

At the same time, there is a forced fitting of traditional planning instruments, designed for medium-sized and large cities, which do not always correspond to local needs (SANTORO; NASCIMENTO NETO, 2023). Added to this is the fact that, within the scope of Brazilian urban policy, the Municipal Master Plan (PDM) has been consolidated as the main instrument of territorial ordering, but its legal requirement linked to municipalities with more than 20,000 inhabitants ends up leaving a significant portion of small cities underserved, contributing to problems such as environmental degradation, real estate retention, and deficits in urban and social infrastructure (CARNEIRO; FAÇANHA, 2015).

In this sense, products derived from aerial surveys with RPA, such as high-resolution orthoimages, DSM, DTM, contour lines, and vegetation indices constitute a concrete alternative to overcome historical gaps, expanding analytical precision and the monitoring of urban socio-environmental dynamics. Carmo et al. (2023) emphasize that free orbital images generally do not meet the demands of small cities, while the use of RPA offers greater spatial and temporal resolution. Carmo (2022) demonstrates applications such as the delimitation of permeable areas, land use classification, identification of areas vulnerable to flooding, and recognition of irregular occupations, in addition to the three-dimensional reconstruction of urban and rural areas.

Despite the diversity of applications, the use of geotechnologies in urban planning is still generally limited to inventories and diagnostic maps, with little incorporation of more robust modeling and spatial analyses (BUGS, 2014). This reveals a gap between the technical sophistication available and its effective appropriation by municipal governments in small cities, restricting the capacity for socio-environmental planning and management.

For this reason, the discussion cannot be restricted to technical potentialities: it must consider the limits and political-institutional implications of the use of geotechnologies. Göçmen and Ventura (2010) identify central barriers to adoption, such as training of technical staff, funding for hardware and software, and data availability. This framework is also reflected in Brazil, with restrictions both in the supply and in the quality/resolution of data, in addition to municipal base cartography that is often nonexistent or limited to general products, such as those from IBGE, which conditions restricted analyses.

Geotechnologies influence the way geographic space is perceived and represented, guiding socio-spatial (re)production. In this sense, it is important to reflect on their uses and on the agents that guide their application, since they can both reinforce inequalities and contribute to quality of life and social justice (MATIAS, 2005). By proposing and testing a methodological workflow for aerial surveys with RPA adapted to small cities, this article contributes to this second perspective, bringing high-resolution cartography closer to urban socio-environmental planning. Even so, its adoption depends on continuing education, funding, and democratic territorial management.

4. Conclusion

The article systematized and tested a methodological workflow for mapping with RPA aimed at the reality of small cities, articulating legal requirements, field stages, and digital image processing. The results demonstrate that it is possible

to generate high-resolution cartographic products suitable for socio-environmental planning and management, with a good relationship between cost, operation time, and level of detail.

Although the method becomes costly when applied to large areas, in small cities aerial surveys with RPA present themselves as an especially promising alternative, allowing the production of updated data compatible with local demands. The use of software with intuitive interfaces facilitates the adoption of the workflow by technical teams that already have some contact with geotechnologies, even if they are not specialists in photogrammetry.

As a limitation of the research, it is worth noting that the application of the methodological workflow occurred in a single study area, which restricts generalization to other urban contexts. However, the results obtained indicate potential for replicability in other small cities, provided that their socio-spatial, institutional, and technical specificities are considered. It should be emphasized that the proposed methodological workflow has already been applied in other studies developed by the author, which reinforces its consistency and its capacity for adaptation to different realities.

On the other hand, the lack of trained teams and minimum infrastructure in many municipal governments still limits the appropriation of this technology. In this sense, the consolidation of continuing education processes and basic investments in equipment and software are necessary conditions for protocols such as the one proposed here to be effectively incorporated into the institutional routines of urban socio-environmental planning and management in small cities.

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