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# Application of Digital Photogrammetry in Damage Mapping on Facades of Historical Buildings

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***Abstract* – Digital photogrammetry, especially through the use of drones, has proven to be an efficient, accurate, and low-cost alternative for mapping damage on the facades of historical buildings. This paper presents a case study applied to the *Solar do Barão de Itapura*, in Campinas, São Paulo, aiming at the creation of a detailed orthophoto with the identification and classification of pathological manifestations. The methodology includes visual inspection, flight planning, image capture, point cloud processing using Agisoft Metashape Pro software, and analysis of the generated products such as 3D meshes and orthophotos. The results demonstrate the applicability of the technique as an auxiliary tool for identifying and diagnosing pathological conditions in heritage building facades, enabling more well-founded restoration interventions.**

Keywords: Digital photogrammetry; Damage mapping; Historical heritage; UAV; Orthophoto.

## I. INTRODUCTION

The conservation of built heritage requires effective and non-destructive methods for diagnosing pathological manifestations that compromise its integrity. In this context, digital photogrammetry has established itself as a promising technology, capable of producing detailed three-dimensional models from photographic records, allowing for precise analysis of architectural surfaces—especially facades, which often accumulate evidence of deterioration [1], [2].

The use of photogrammetry with UAVs (Unmanned Aerial Vehicles) has stood out as an efficient and widely adopted solution for acquiring images of facades and rooftops of historical buildings [3], [4], [5], [6], [7]. This technology enables the creation of point clouds, textured 3D meshes, and high-resolution, rectified orthophotos that can support the development of damage maps [8]. Several studies demonstrate the applicability of UAV-based photogrammetry in contexts such as the documentation and maintenance of heritage assets [9], topographic and geometric surveys of historical archaeological sites located in coastal environments [10], 3D modeling for documenting and studying the degradation of historical heritage [11], identifying cracks and other pathological manifestations [12], among other applications within the scope of cultural heritage [13], [14], [15].

Proper planning of restoration interventions on historical building facades depends primarily on the identification and mapping of existing pathological manifestations. This initial survey is essential for recognizing different types of damage and defining appropriate conservation strategies [16]. For this purpose, short-range aerial photogrammetry has proven to be efficient, accurate, and low-cost compared to other techniques, such as laser scanning [17].

The objective of this study was to apply digital photogrammetry to obtain a damage map of the facade of the *Solar do Barão de Itapura* (SBI), a 19th-century historical building listed in 1983 by the *Conselho de Defesa do Patrimônio Histórico, Arqueológico, Artístico e Turístico do Estado de São Paulo* (CONDEPHAAT). This paper contributes by presenting a detailed photogrammetric survey method for historical facades, which includes documentation, visual inspection, and solar and climate studies as preliminary steps. It also specifies the parameters and processes for generating point clouds, 3D meshes, and orthophotos. Finally, the mapping of pathological manifestations is carried out, and the damages are identified and classified on the rectified orthophoto.

## II. CASE STUDY: SOLAR DO BARÃO DE ITAPURA

The *Solar do Barão de Itapura* is an example of 19th-century urban residential architecture in Campinas, São Paulo, combining historical, aesthetic, and symbolic values within the context of the São Paulo coffee elite (Figure 1). Built by Joaquim Policarpo Aranha, the Baron of Itapura, the building features a brick masonry construction system and classical compositional elements such as Ionic-order columns. The main facade, in the Italian Renaissance style, is characterized by full arch windows on the ground floor and straight lintels topped with small triangular pediments on the upper floor—

features also present on the left-side facade, facing the *Pátio dos Leões*. Throughout its history, particularly after its adaptation for institutional use by the *Pontifical Catholic University of Campinas* (PUC-Campinas), the building underwent significant changes. These included the construction of bathrooms, the replacement of original wooden shutters with glass windows, and the addition of roof structures over the terraces—interventions that partially compromised its formal integrity [18], [19].

*Fig. 1. Solar do Barão de Itapura*

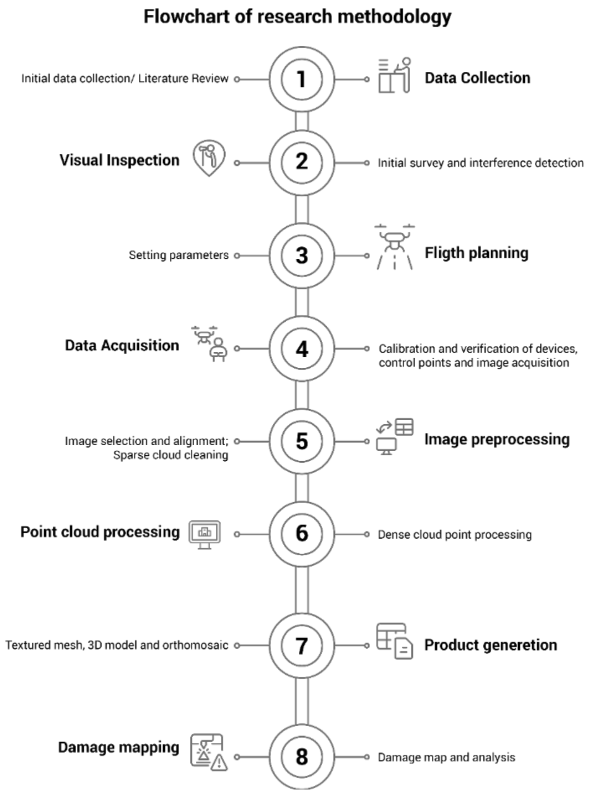
## III. MATERIALS AND METHODS

The use of UAVs to generate point clouds, textured meshes, and orthophotos for damage mapping has significant potential to assist and provide reliable data to multidisciplinary teams specialized in the conservation and maintenance of historical heritage. However, the implementation of this technology requires specific knowledge and care before, during, and after the aerial survey and data processing.

Figure 2 presents a flowchart of the methodology used in this study. Prior knowledge of the steps listed below can help mitigate errors and optimize flight and processing time.

- Step 1: Gathering historical information about the building and previous studies on the topic. This includes climate analysis and a solar chart to define the best time of year and day for the photogrammetric survey.
- Step 2: Evaluation of the site and identification of obstacles that may interfere with the flight plan in aerial photogrammetry.
- Step 3: Definition of equipment, parameters, and flight strategies (altitude, overlap, direction, control points). Power supply, data storage logistics, and required authorizations in restricted areas are also considered.
- Step 4: On-site image collection, including area isolation, control point marking, weather verification, drone calibration, and satellite connection.
- Step 5: Organization and selection of images. Use of Agisoft Metashape to align photos, generate and clean the sparse point cloud, with calibration and configuration of technical parameters.
- Step 6: Creation of the detailed 3D model from depth maps. The application of filters to remove noise caused by visual interference.
- Step 7: The dense cloud enables the generation of: the 3D mesh (triangulated surface), the textured model (realistic appearance of the facade), and the orthophoto (2D image at scale for analysis and vectorization).
- Step 8: All pathological manifestations present on the facade are included in the map, enabling broader analysis of their causes and the extraction of metrics for conservation and restoration work.

*Fig. 2. Flowchart of research methodology*




### *A. Architectural Survey of the SBI Facade*

The aerial architectural survey of the SBI facade was preceded by a visual inspection of the site and its surroundings. During this stage, the presence of front vegetation and lateral buildings was identified, which limited the drone's horizontal and vertical distance from the facade, requiring a slower and more cautious execution of the survey. Despite the limitations imposed by palm trees, measurements conducted during the flight planning phase confirmed the feasibility of maintaining an adequate distance of 5.00 meters from the facade [6], along most of the frontage—except at the lateral extremities, where existing constructions prevented access. The flight plan followed the parameters and definitions in Table 1.

*Table 1. Flight plan parameters.*

| Parameters | Values |
|---|---|
| Height | 16.00 m |
| Distance from the facade | 5.00 m |
| Longitudinal distance | 0.50 m |
| Lateral distance | 1.50 m |
| Longitudinal and lateral overlap | 92%/82% |

In addition to the flight execution plan, a solar study of the building was carried out to determine the best times and seasons of the year to avoid direct sunlight hitting the camera and the facade, thereby minimizing interference, distortions, glare, and excessive shadows. Simultaneously, historical weather and climate data for the area surrounding the SBI were studied, considering wind patterns, rainfall, and solar obstruction.

The data acquisition procedure involved traveling to the site and performing the flight to capture images. Following the solar and meteorological analysis, the image capture was conducted in May 2025 between 9:00 AM and 1:00 PM. After isolating the area, marking the collection points, calibrating the drone's compass, and connecting to satellites, the photographic survey was executed manually using a DJI Mini 4 Pro drone (Table 2). The operation followed the flight planning guidelines and accounted for the limitations imposed by obstacles identified during the visual inspection. For scale referencing, camera correction, and planar positioning of the point cloud and other outputs, direct measurements were taken between three known points, and their distances were determined.

*Table 2. DJI Mini 4 Pro drone specifications*

| Parameters | Values |
|---|---|
| Weight | 249g |
| Dimensions | 298×373×101 mm (L×W×H) |
| Image sensor | 1/1.3" CMOS, Effective pixels: 48 MP |
| Lens | FOV: 82.1°, Equivalent format: 24 mm, Aperture: f/1.7 |
| Maximum image dimensions | 8064x6048 |
| Photo format | JPEG/DNG (RAW) |
| Stabilization | Triaxial mechanical (tilt, rotation, spin) |

After completing the flight and exporting the images from the drone's storage device, the 2349 images captured were organized, analyzed, and selected. Duplicate images due to proximity, those outside the facade scope, or with unsuitable lighting conditions—underexposure or overexposure—were removed. The final selection included 2,335 photos with a resolution of 8064 × 4536 pixels and GSD (Ground Sample Distance) of 0.862 mm/pix. This entire process was carried out manually, based on the operator's visual judgment.

### B. Image processing

The image pre-processing phase, which results in the sparse point cloud, was performed using Agisoft Metashape Professional installed on a machine equipped with a 13th Gen Intel(R) Core (TM) i7-13800H 2.50 GHz processor, 32.0 GB of RAM, and a 64-bit operating system. The image alignment process was initially configured with the following parameters: quality, generic preselection, key point limit, tie point limit, exclude stationary tie points, and adaptive camera model fitting. These parameters determine the resolution level used to match points between images (Highest/High for full or near-full resolution), the speed in identifying overlap between image pairs (avoiding comparison with distant photos), the maximum number of key points to be detected per image (default is 40,000—higher values capture more detail), the limit on real matches used for image reconstruction (default is 4,000—lower values increase precision), and adaptive adjustment of lens parameters to refine automatic calibration. The values used for image alignment configuration are listed in Table 3.

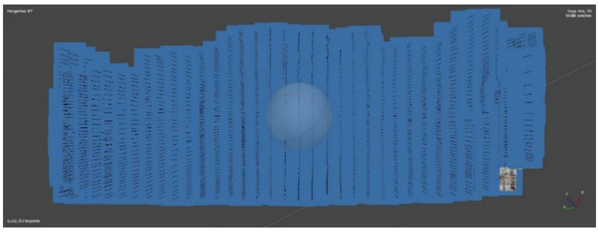
*Table 3. Image alignment configuration.*

| Parameters | Values |
|---|---|
| Quality | High |
| Generic preselection | Enable |
| Key point limit | 60.000 |
| Tie point limit | 0.00 |

| | |
|---|---|
| Exclude stationary tie points | Enable |
| Adaptive câmera model fitting | Enable |

Figure 3 shows the positioning of the photographs for the generation of the sparse point cloud.

*Fig. 3. Photo positions in Agisoft Metashape Pro*

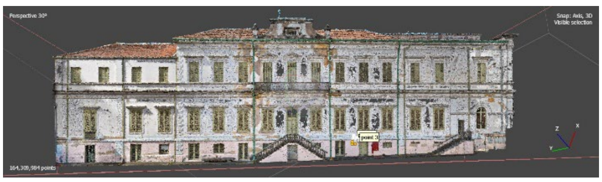


The reconstruction of three-dimensional surfaces from the captured images using photogrammetry technology is part of the dense point cloud generation process. In this step, the software calculates depth maps for each image pair, determining the spatial location and color of the points that make up the cloud. For this calculation, the software requires information on the image quality to be processed, the depth filtering level (a process to remove inconsistent points and noise), and the calculation of RGB colors for each point based on photographs. Table 4 presents the parameter values used during the processing to obtain the dense point cloud (Figure 4).

*Table 4. Dense point cloud processing configuration.*

| Parameters | Values |
|---|---|
| Quality | Medium |
| Depth filtering | Mild |
| Calculate point colors | Enable |
| Calculate point confidence | Enable |

*Fig. 4. Dense point cloud*



After processing the dense cloud, three other outputs were generated: the 3D mesh, the textured 3D model, and the orthophoto. For the creation of the 3D mesh, the depth map was used, as it is more uniform and contains fewer artifacts compared to the dense cloud. Other parameters such as surface type, number of faces, and interpolation for filling data gaps were also configured.

The textured mesh is the step following the construction of the 3D mesh and corresponds to a model that receives the colors and details from the photographs. The configuration for generating this mesh includes setting the mapping mode (how images are mapped onto the mesh), blending mode (how images are combined to generate the texture), texture resolution, gap filling for uncovered areas, and color correction in regions with lighting variation.

Finally, the 3D mesh is used to generate the orthophoto or orthomosaic, a 2D orthorectified and true-to-scale image. Agisoft Metashape Professional requires the following settings to create the orthophoto: projection plane (planar or geographic), base surface (3D mesh, dense cloud, or digital terrain model), blending mode (mosaic or average), gap filling, and color correction. The orthophoto's orientation was also defined at this stage using control points to indicate its projection plan.

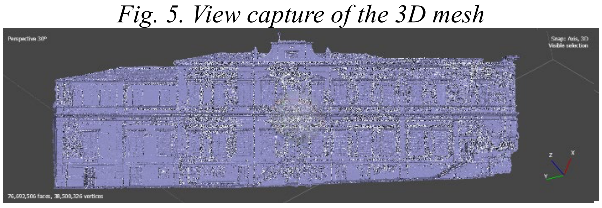
## IV. RESULTS

After processing the dense point cloud, the following outputs were obtained: the 3D mesh (Figure 5), the textured 3D model (Figure 6), and the orthophoto (Figure 7).

### A. 3D Mesh

The 3D mesh consists of a model composed of triangles that connect the points of the dense cloud, forming a solid and continuous element. This product can be exported for the creation of architectural 3D models and volume and shape analyses.

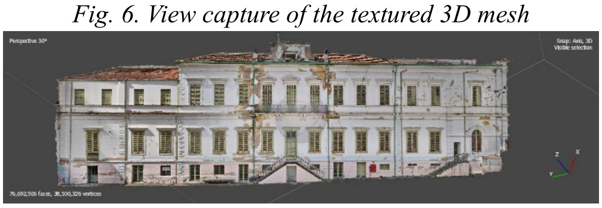
*Fig. 5. View capture of the 3D mesh*



### B. Textured 3D model

This model underwent the process of applying photographic textures, i.e., it received the actual colors and details captured by the images.

*Fig. 6. View capture of the textured 3D mesh*



### C. Orthophoto of the facade

From the mesh and the textured 3D model, orthophotos can be produced, which consist of full-scale 2D models that can be used as photographic floor plans (elevations), for analysis of pathological manifestations and vectorization in CAD (Computer-Aided Design).

*Fig. 7. View capture of the orthophoto*

*D. Mapping of damage to the facade*

Figure 8 reveals, through visual analysis, the presence of several pathological manifestations, namely: detachment of coating and paint, vertical cracks and fissures, moisture stains, biodeterioration, and the presence of small vegetation.

*Fig. 8. Facade damage mapping*


Table 5 shows the number of pathological manifestations found on the facade, the central section of the building.

*Table 5. Number of pathological manifestations.*

| Pathological manifestations | Quantities |
|---|---|
| Water infiltration | 3 points |
| Peeling paint | 44.8722 m² |
| Detachment wall covering | 0.0838 m² |
| Stains | 7.8501 m² |
| Biodeterioration | 1 point |
| Cracks | 128 points |

## V. CONCLUSIONS

This study demonstrated that digital photogrammetry is an effective tool for surveying the facades of historical buildings and identifying pathological manifestations. The application of the methodology to the *Solar do Barão de Itapura* resulted in a three-dimensional model and an orthophoto, highlighting the potential of the technique to support decision-making processes in restoration projects. The proposed approach is unique in that it presents a solution that optimizes and improves the maintenance process of historic buildings, integrating multiple complementary techniques, including solar behavior analysis, drone flight route optimization, and workflows based on three-dimensional modeling. Digital photogrammetry has advantages over traditional measurement methods for obtaining architectural models. This technique has shown that, in addition to the speed of data collection and the reliability of its products, it is possible to detail complex surfaces and integrate more easily with BIM and HBIM flows.

Through the examination of the orthophoto, various pathological manifestations were identified, including detachment of coating and paint, vertical cracks and fissures, moisture stains, biodeterioration (such as fungi and algae), and the presence of small vegetation. In this first study, the identification and classification of pathological manifestations were performed manually.

Furthermore, the importance of a technically and multidisciplinary planned approach is reinforced, ensuring data quality and product accuracy, and contributing significantly to the preservation of cultural heritage.

This work is part of a future and broader research project that will aim to apply machine learning and artificial intelligence techniques to automate the identification of pathological manifestations in orthophotos, enhancing efficiency and objectivity in diagnostics applied to heritage conservation.

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