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Damages mapping of façade using Aerophotogrammetry and Thermography Inspection: Zoroastro Artiaga Museum – Art Deco in Brazil

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ABSTRACT

Inspecting historic buildings with non-destructive techniques can contribute to obtaining information about the in-service status of a given building without damaging its parts. Damages map prepared by digital photogrammetry and the application of façade Thermography assessment are non-destructive techniques and possible due to technological advances. The present work aimed to apply non-destructive inspection techniques of the façade on the Zoroastro Artiaga Museum, of Art Deco Architecture, using two techniques: generation of damages map by orthoimage created from Aerophotogrammetry and the method of Damage Factor, and application of the thermographic image analysis technique. For the generation of damages map, the relevance of using UAV was observed, since for this technique it is essential to use this equipment to capture images perpendicular to the plane of the façade, when thinking about using the method by Dense Stereo Matching. The damages map generation and the analysis of the Damages Factor allowed the quantification of the incidence of pathological manifestations. The analysis of thermographic images made it possible to understand which factors contributed to the emergence of pathological manifestations, such as the possible presence of excess moisture, favoring, for example, the formation of efflorescence. It is concluded that the application of these techniques can be safely used for inspection and prior diagnosis and that the Thermography was important to identify non-visible damages to the façade, such as moisture extensions, since it was not possible to visually delimit the entire existing area of moisture through damages map generated by Aerophotogrammetry.

Keywords: Art Deco Architecture; Non-destructive techniques; Aerophotogrammetry; Thermographics images; Damages map.

1. INTRODUCTION

Tirello and Correa [1] point out that the damages map is an effective and suitable method for planning and actions aimed at restoring historic buildings, as well as an instrument applicable to preventive conservation monitoring. These authors explain that the damages maps are representative elevations of façades added to graphic overlays (lines, hatches, colors, numbers, etc) that are intended to represent pathological manifestations (efflorescence, cracks, dirt, paint detachment and others), belonging to one of the non-destructive inspection techniques applied to historical heritage buildings.

Concerning the works developed with the purpose of identifying and quantifying the damage to building façades, the works developed by Flores-Colen *et al.* [2], Flores-Colen [3], Gaspar [4], Bauer *et al.* [5], Bauer *et al.* [6], Tirello and Correa [1], Melo Júnior and Carasek [7], Souza *et al.* [8] and Bauer *et al.* [9] can be cited. These researches have scientific importance as they contribute with the understanding of the aspects that involve the phenomena of deterioration of façades.

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The technological advances have contributed to façade inspection work, facilitating the work of professionals to obtaining information representation in damages map [10]. In this context, Digital Photogrammetry emerges as a method that eliminates tedious work, such as measuring using the tape measure, thus allowing professionals to prepare accurate drawings of buildings for maintenance or restoration work. Improvements in algorithms for DSM (Dense Stereo Matching) have facilitated access to this technology, mainly by allowing the use of digital still cameras and personal computers for non-complex work.

For the use of photographic images in digital photogrammetry by automatic correspondence programs (DSM), the images must be captured close to the perpendicular of the façade plane, and the Unmanned Aerial Vehicle (UAV) emerge as a new tool for this purpose, in addition to making it possible to reach the highest areas of large buildings, which makes it possible to even see hidden parts or pathological manifestations that are difficult to see at ground level, such as cracks. The UAV facilitates the inspection of larger façades in relation to other conventional techniques that employ scaffolding, and one must be aware of the regulations established by the National Civil Aviation Agency (ANAC). The photogrammetric method that uses aerial images is called Aerophotogrammetry.

As well as photogrammetry, Freitas, Freitas and Barreira [11] explain that non-destructive inspection techniques can be adopted in building inspections aiming at a quick diagnosis, citing, as an example, Infrared Thermography. These authors state that many parameters must be used in this technique and that pathological manifestations can become visible when there is solar radiation or a heat source. Riggio *et al.* [12] used non-destructive techniques to evaluate the wooden structures of the roof of Giotto's Bell Tower in Florence (Italy) and one of the techniques used was Infrared Thermography, which proved to be very efficient when combined with another damage inspection technique. Solla *et al.* [13] used the Infrared Thermography technique to identify the presence of moisture on façades because they claim that it can be an important starting point for decision making.

Art Deco Architecture was born inspired by abstractions from the industrial world, based on geometric shapes and aerodynamics of machines in motion [14]. The city of Goiânia, Goiás – Brazil, has twenty-two buildings Art Deco belonging to historical heritage and, among the studies on the creation of a damages map of property from this period of architecture, one can mention the work developed on the Clock Tower Monument, in this city, developed by Borges, Carasek and Cascudo [15]. This relevant study sought to present procedures used in the inspection and elaboration of a damages map of the external faces of this tower in washed plaster, as well as trying to explain the causes and possible solutions for restoration.

From the above, this work aims to apply methods to identify damage to the façade of the Zoroastro Artiaga Museum, with Art Deco architecture, located in Goiânia. The methods applied are the generation of a damages map through Aerophotogrammetry and vectorization of pathological manifestations in a CAD program and Thermography, which is also a non-destructive test technique used in the inspection of façades. From this work, it was intended to demonstrate that the two techniques used are a starting point for diagnosing damages in façades of historical heritage buildings without physical intervention, highlighting the use of imaging techniques.

2. BIBLIOGRAPHIC REVIEW

This item is a brief review of the literature on non-destructive techniques that consider digital images captured through Aerophotogrammetry and thermographic images to identify damage to the façade.

2.1. Processing to develop models by DSM

The computer science evolution, and especially in the field of computer vision, has enabled the advancement of photogrammetry and, therefore, the achievement of the current phase called Digital Photogrammetry. According to Amorim [16], this evolution has simplified processes due to the possibility of deploying systems with a high degree of automation and the reduction in costs due to the non-necessity of photogrammetric instruments replaced by computers.

Photogrammetric products are the result of processing steps: Dense Stereo Matching (DSM) or stereo matching (sparse point cloud), dense point cloud and mesh construction. In the stereo matching step, the corresponding points (smart matches) are found in two or more images. It is important to highlight that for the 3D reconstruction, it is necessary to exist at least two images of the same scene taken from different positions, that is, from different projection centers, ensuring the overlapping of scenes [17].

The overlap between images for processing can be guaranteed through Equation 1 [18].

$$R = \frac{B}{L} \tag{1}$$

where:

R = range of 0.1 < R < 0.5,

B = distance between the stations position in the photograph (m) and,

L = distance from the stations to the photographed object (m).

Like the need to ensure overlapping between photographs, surfaces with random textures, that is, without repetitive patterns or uniform coloring, favor the DSM technique, because the repetitive patterns difficult the search for corresponding points in photographs.

As a result of the point matching, a sparse point cloud is obtained. After the construction step of the sparse point cloud, there is the construction of the dense point cloud in which most of the object's geometric details are built (Figure 1) [19].

Transforming point cloud data into meshes is the cloud vertex clustering procedure. Mesh is the most common way to represent a surface model, which is characterized by a spatial arrangement of adjacent polygons [20].

2.2. Orthorectification

Orthorectification is the way of repositioning each pixel of the image according to its orthogonal projection, generating the orthoimage, that is, object-space coordinates (X,Y,Z), which are part of the digital model, are transformed into coordinates of the image-space (X,Y). Thus, orthoimages are two-dimensional photogrammetric products obtained by the orthorectification of geometric models, obtained in the exporting surface models steps and, thus, allow capturing the effective form, i.e., all types of problems arising from life in service [21].

Figure 2 shows, among others, the orthoimage of one of the UnB Central Library façades, from studies carried out by Melo Júnior *et al.* [21]. The processing type of PhotoScan program is automatic.

Some programs have been used to generate models from automatic matching algorithms, such as: Apero Micmac (IGN, France), Eos Photomodeler (Eos System Inc., Canada), Pix4D Mapper (EPFL, Switzerland) and Agisoft PhotoScan (Agisoft LLC., Russia) [10]. This work used the Agisoft PhotoScan program for the generation of orthoimages, based on other researches that consolidate it as adequate for the purpose and there was no objective to compare the results between other existing programs [22].

2.3. Photos capture for automatic processing of digital images (PDI)

Groetelaars and Amorim [23] mention that two aspects of camera positioning must be considered for the automatic process (DSM) of photogrammetry: the parallelism between their positions and the perpendicularity to the plane of the façade, as shown in Figure 3. The authors also emphasize that each part of the façade must be viewed in at least 3 photographs, ensuring its overlap so that the coordinate identification in the object-space occurs (X, Y, Z).

Thus, these aspects are important to maximize the procedures related to the automatic correlations of the DSM technique.

In the photographic registration stage, photographing the highest parts of a building is one of the challenges to obtain suitable images to be used in the DSM technique, making the photographic registration perpendicular to the plane of the façade. The use of UAV (Unmanned Aerial Vehicle) appears as a proposition to obtain these photographic records, that is, photographs of the highest parts of façades.

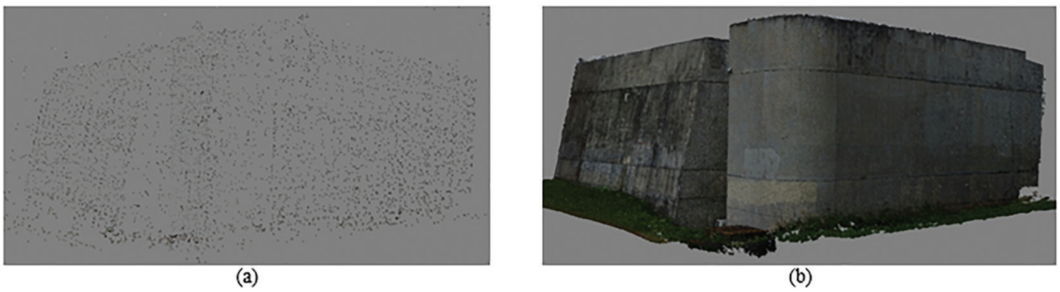

Figure 1: Model 1 of the Central Library of UnB generated by PhotoScan program, from 65 photographs. (a) sparse point cloud. (b) dense point cloud.
Source: Melo Júnior *et al.* [21].

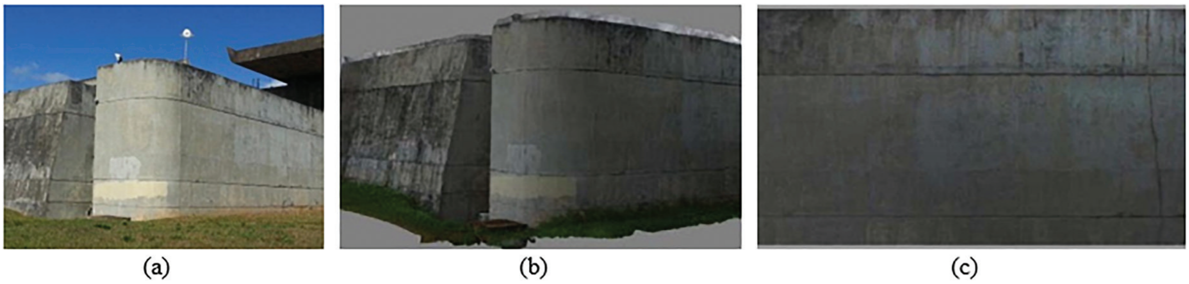

Figure 2: UnB Central Library: (a) Photography; (b) Geometric model; (c) Orthoimage.
Source: Melo Júnior *et al.* [21].

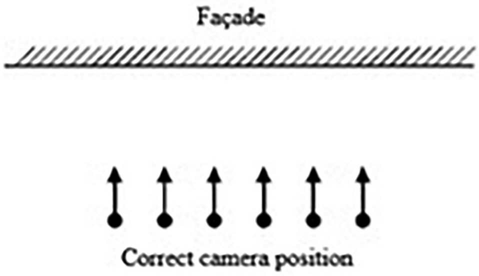

Figure 3: Camera positioning for acquiring façades photographs.
Source: Agisoft [24].

Regarding the damages map, the images captured by an UAV can be used in photogrammetric processes and, therefore, in the generation of orthoimages. Another relevant aspect is that orthoimage features the effective form of the building as a characteristic, that is, the current representation at the time of the photographic record, which may present, for example, its pathological manifestations.

When it comes to images captured by UAV aimed to be treated by photogrammetry programs, this technique is called Aerophotogrammetry, also used in other purposes, such as planialtimetric terrain survey.

Some researches have been using Photogrammetry and Aerophotogrammetry techniques to generate façade damages map, such as the works by Costa and Amorim [25], Melo Júnior *et al.* [26], Melo Júnior *et al.* [21], Ballesteros and Lordsleem Junior [27] and Ballesteros *et al.* [28].

In the work carried out by Melo Júnior *et al.* [21], it was found that it was important to use UAV to capture photographs perpendicularly to the plane of the façade, especially for the highest parts of the building, since the images must be recorded as close to the perpendicular to generate the photogrammetric model by DSM. The program used in this research was PhotoScan by Agisoft, which presented satisfactory results.

2.4. Thermography

Infrared Thermography is a non-destructive testing technique also used in the inspection of façades. This technique is considered qualitative when it is based only on the identification of hot and cold spots in the thermographic image, in others words, when the analysis consists of comparing the images with standards. This type of study is normally used in the diagnosis of anomalies and restoration of historic buildings [29]. On the other hand, quantitative Thermography is used when the objective is to classify the importance of the defect and the greatest concern is the accuracy of the temperatures obtained, because, when very accurate, they can result in thermograms suitable for the analysis of important characteristics of the pathological manifestations identified [30]. It is important to highlight that, for the use of Infrared Thermography in façade inspection, attention should be paid to the main factors that strongly influence the temperature of the façade surface, as well as thermographic images, which are: the characteristics of the materials that make up the façade, solar radiation and infrared radiation from the environment [31].

Depending on the intensity and direction of the heat flow that crosses the façade, it is possible, using this technique, to visualize different types of pathological manifestations. The presence of anomalies modifies the rate of heat transport in the material, which generates temperature differences that can be detected on the material's surface [32]. In this way, several anomalies can be identified, either as warmer or colder areas, compared to nearby or surrounding regions. Important pathological manifestations can be detected by thermographic inspection, such as: detachments, blisters, cracks, moisture, presence of other materials, among others [33].

Detachments and paint blistering, due to the relatively small thickness of most coating materials and the presence of air between their layers as a result of the loss of adhesion with the substrate, are two of the aspects that enable the study of this phenomenon. The presence of air near the surface generates temperature differences if compared to a neighboring area under normal conditions, which allows the identification of this pathology [34]. Several studies, such as Bauer *et al.* [35], Edis, Flores-Colen and Brito [36], Edis, Flores-Colen and Brito [37], have proven the effectiveness of this technique in the identification and evaluation of detachments in ceramic and mortar coverings [4] [38].

The evaluation of cracks, with Thermography, has been viable in cases of surface cracks in external coatings, mainly in mortars or concrete elements. The layer of air trapped in the crack and the narrow crack geometry facilitate the study of this pathology. When heat penetrates or leaves the crack, this region does not heat up in the same way as the fully exposed surface, which generates differences that can be detected in thermographic inspection [34]. The presence of cracks, when confirmed, and the evaluation of their thermal behavior has been the object of study by several authors [39] [40] [41].

Moisture detection with Infrared Thermography is possible because gain or loss of heat in building materials (concrete, mortar, bricks, blocks) is slower in the presence of water in these materials. The increase in the heat capacity of the wet material is the factor that causes surface temperature changes. Thus, areas with high moisture content are hotter or colder in relation to neighboring regions [42]. This temperature difference can be observed with Infrared Thermography. In several research, it has been possible to validate the Thermography's ability to detect moisture problems, both visible and not visible on visual inspection, in problems related to capillary absorption in walls and water infiltration in floors and roofs [43] [44] [45] [46] [47].

The identification of hidden materials or elements is possible by differences in the thermal resistance of construction materials. Depending on the direction and intensity of the heat flow, it is possible to visualize the presence of hidden materials or elements in the thermogram, because of changes in the heat flow [33]. In the context of façades, the main studies related to the detection of hidden materials and elements are dedicated to identifying the presence of hidden structures, whether concrete [48] or wood [49].

The use of UAV with thermographic camera for building façade inspection has been used frequently. This method is challenging as it leaves the thermographic câmera subject to vibration and unwanted movement. To reduce this unwanted movement, it is necessary to use video stabilization techniques together with an appropriate methodology. Pant *et al.* [50] evaluate video stabilization techniques as an auxiliary tool in the post-processing of thermograms obtained through Infrared Thermography boarded in UAV, pointing out that despite the variables involved it is possible to effectively apply these methodologies to identify surface defects. However, infrared cameras in a fixed position present greater accuracy, since the distance and resolution of the camera are necessary to evaluate the pathological manifestation.

Thus, the feasibility and potential of Infrared Thermography in the evaluation of pathological manifestations on building façades can be verified, both in the detection and evaluation of the main pathological problems, as a main or complementary technique in inspections.

3. METHODOLOGY

In this item, the main characteristics and information about the Zoroastro Artiaga Museum are presented, as well as the processes adopted in Aerophotogrammetry, consequently in the preparation of the damages map and analisys of thermographics images.

3.1. Characterization of the study object

The Zoroastro Artiaga Museum, as can be seen in Figure 4, is named after its founder, Professor Zoroastro Artiaga, who was a professor, lawyer, geologist and historian, and the institution's first director. The museum is located at Praça Cívica in Goiânia-Go, located at the geographic coordinates 16.67° South Latitude and 49.25° West Longitude. In Goiânia, the seasonal tropical climate predominates, with two well-defined seasons: a rainy season, from October to April, and a dry season, from May to September. The studied façade is oriented at azimuth 279º W (clockwise from the North axis) defined as the west façade, represented in Figure 4, highlighted in red.

The building was designed by Polish architect Kazimiers Bartoszevsky, in Art Deco style, and built between 1942 and 1943. Initially, it served as the headquarters of the Press and Propaganda Department (DIP in Portuguese) and, in July 1946, it became a museum. This building is part of the administrative complex of Goiânia and was listed as State Architectural and Historical Heritage by Decreet-Law n. 4943, of August 31, 1998, then listed by IPHAN in 2002 [52]. The museum has various collections related to the region of Goiás, such as: mineral geology, fauna, archeology, documentary, architecture, chemistry, manufactured industry, fossils, flora, agriculture, livestock, anthropology and indigenous people of Goiás [53].

Figure 4: Indication of the studied façade of the Zoroastro Artiaga Museum.
Source: adapted from Google Earth [51].

Figure 5: Aerial image of the Zoroastro Artiaga Museum.

Regarding the constructive characteristics used and reports of renovation interventions in the building, there are few records. The most cited record refers to a wide institutional and museographic restructuring, from 1999 to 2003. On that occasion, the museum's façades, roofs, gutters, and hydraulic installations were restored with improvements in ventilation and light control [53].

The building is made of reinforced concrete, with slender pillars along the main façade (west façade) and thick walls. The façade is covered in plaster with a high presence of mica, typical of buildings from that period [54]. Today, the façade is gray painted, but it is suspected that this had a "washed plaster" appearance, which also resulted in a gray colored façade. According to Unes [55], platbands are characteristic elements of Art Deco Architecture, used to hide roofs (Figure 5). It should be noted that these platbands can provide greater retention of rainwater on their surfaces.

3.2. Aerophotogrammetry

The creation of the orthoimage of the Artiaga Museum by Dense Stereo Matching (DSM) covered the stages of planning, photographing, and processing, which will be presented below.

3.2.1. Planning for photographic record

For the technique of obtaining point cloud models by photographs, the images of the façades needed to be captured with the camera positioned as close to the perpendicular position to the façade as possible. For the highest parts of the museum, it was necessary to use the UAV which allowed the parts that could be hidden by other elements of the façade, such as projections from marquees, to be photographed.

It is relevant to analyze the surroundings of the building to capture images by UAV, because possible obstacles (vegetation, electrical wiring, and other buildings) can limit or make impossible the flights and photographic records. This analysis was carried out, finding out that it was feasible to inspect the Artiaga museum façade.

Figure 6: Phantom 4 Pro flying over the façade of the Zoroastro Artiaga Museum.

Table 1: Parameters used in photographing.

PARAMETERS	
Diaphragm opening or f-number scale	f/4,5
Exposure time	1/100 s
ISO sensitivity	ISO-200

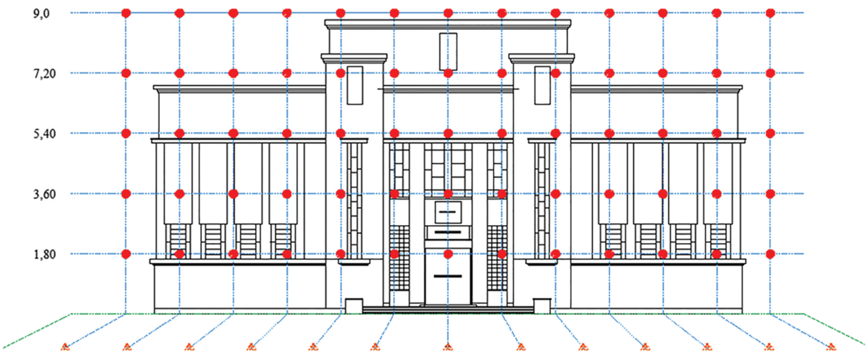

Figure 7: Points of photographic shots on the main façade of the Zoroastro Artiaga Museum.

3.2.2. Photos capture

The UAV used was the Phantom 4 Pro (Figure 6), from DJI, which has a FC6310 camera with a 1-inch sensor and 20 megapixels, manually adjustable opening from F2.8 to F11, resolution of 5,472 × 3,648 pixels and 20 MP of effective pixels.

Manual exposure was adopted, and parameter values were important to ensure that the images guaranteed acceptable depth of field and minimized the diffraction phenomenon that can be generated by the objective lenses. Thus, the parameters presented in Table 1 were adopted.

The images were photographed between 9:00 am and 10:00 am on December 5, 2018. The dry bulb temperature at 9 am was equal to 21.7 °C and at 10 am it was equal to 23.1 °C. The relative humidity in this period was equal to 90%. On the summer solstice, the West façade receives direct sunlight from 12:00 pm onwards. It is important to highlight that the images for processing by DSM must be made in the minimum amount of time, so that there is no variation in light between the photos. Another relevant aspect is, if possible, the photos should be taken on cloudy days to reduce shadows on the façades.

For photographing the façade of the Zoroastro Artiaga Museum, a minimum of 13 vertical flights with approximately 1.80 m were required, with photographic records at each maximum of 1.80 m (Figure 7) to ensure the overlap between 60% and 80% of the images and, in this way, guarantee the processing by DSM. The distance from the UAV camera to the building façade was 6.00 m, which guaranteed an R equal to 0.3, within the range specified by Pierrot-Deseilligny *et al.* [18].

It is noteworthy that Figure 6 presents the optimal scenario for taking photographs, but when the UAV control is in manual mode, that is, without programming for the automatic recording of photographs, the positions of these records vary according to the pilot skill and precision.

3.2.3. Processing steps for the photogrammetric model

The processing for the generation of photogrammetric models was performed using the PhotoScan program from Agisoft LLC. The computer used for image processing has the following configuration: Intel (R) Core (TM) i7-2670 processor 2.20 GHz CPU, 8 GB of installed memory (RAM) and 64-bit operating system.

The PhotoScan program performs the internal orientation or calibration (obtaining the metric parameters of the camera) automatically, having very defined steps and a practical interface regarding the operation, which follows the steps: image alignment and reconstruction of the sparse point cloud (align photos); construction of the dense point cloud (build dense cloud); construction of the triangular mesh (build mesh); and application of texture (build texture).

In the alignment of the photos (or images), some parameters can be defined, such as precision (accuracy), being the stage in which the construction of the sparse point cloud occurs simultaneously. In the construction of the dense point cloud, where the geometric details are constructed, the quality of the model can be defined. The higher the quality required, the higher the computational cost.

The last steps are mesh construction and texture application. In the mesh construction stage, it is possible to choose its construction from the sparse or dense point cloud, noting that the dense cloud provides a greater detailing of the object because it has more points.

After the construction of the photogrammetric model, the orthoimage generation can be carried out. Some programs, such as PhotoScan, allow you to export orthoimages after performing absolute external orientation. This orientation consists of, from measurements taken from the building, forming an X and Y axis, referencing the plane and the position in which you want to generate the orthoimage.

3.3. Damages map

A damages map was produced from visual inspection and orthoimage data, in which the phase of generation of the damages map was based on the method developed by the Material Testing Laboratory of the University of Brasília – LEM/UnB [56] [57]. The documental investigation and laboratory tests phases were not the purpose of this study. It should also be noted that no relationships were established between the typology of each pathological manifestation and the type of constructive component affected and its respective severity.

The damages map was generated in AutoCAD software, allowing the identification of the essential elements of the façade. A 20 cm × 20 cm mesh, equivalent to 0.04 m², was superimposed on the orthoimage of the façade, to accurately map each damage. From this overlapping, the pathological manifestations were graphically registered in their respective positions and identified by colors and hatching.

The use of this methodology facilitated the accounting of areas affected by pathological manifestations and, consequently, the measurement of the damage factor.

3.4. Thermographic evaluation

The thermographic evaluation of the building's façade aimed to use another method of image inspection, thus adding more information about the pathological manifestations identified in the damages map.

The images thermographics were photographed between 9:00 am and 10:00 am on December 5, 2018, the same day and hourly of photos capture to Aero Photogrammetry. It is worth highlighting that at this hour, and because the façade is at west, there was no direct incidence of sunlight on the windows, avoiding radiation reflection from window glass.

The thermographic images were captured at ground level at a distance of 4.5 m from the façade, without the use of UAV and, for the application of this method, four regions of the façade with more accentuated pathological manifestations were recorded. Figure 8 shows the regions evaluated and studied using Infrared Thermography.

Thermographic recordings were performed in the morning, starting at 9 am. As the façade faces west, at the time of inspection it did not receive direct sunlight. For thermographic inspection, a Flir E40 model camera was used with a resolution of 160 × 120 pixels, temperature range from –20° to 250 °C, with accuracy of ± 2 °C and thermal sensitivity < 0.07 °C, following the routine described below:

- Measurement of air temperature and humidity at the test site;
- Positioning the thermographer to acquire emissivity and reflected apparent temperature data;

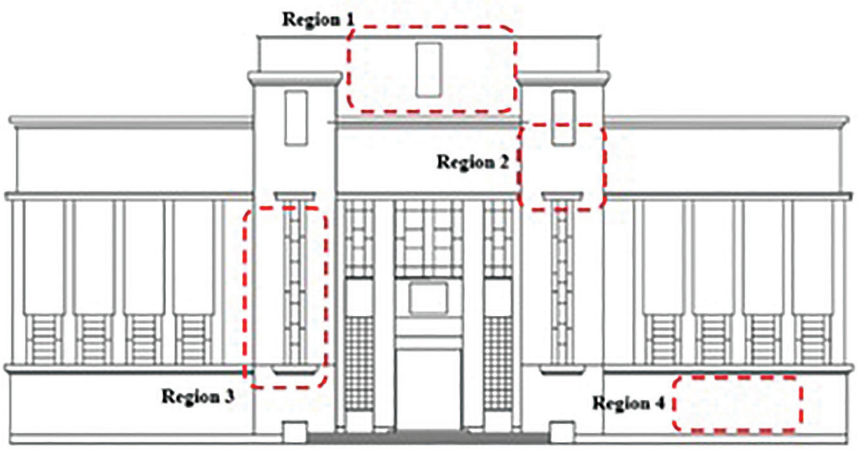

Figure 8: Regions evaluated with Infrared Thermography of the façade of the Zoroastro Artiaga Museum.

- Determination of the emissivity value, according to the standard tape method described in ASTM 1933-99 [52];
- Determination of the reflected apparent temperature, according to the reflector method described in ASTM E1862-97 [53];
- Capture of thermograms in the façade study regions after entering the ambient temperature, humidity and reflected apparent temperature data.

After inspection, in the Flirtools software, the thermograms were processed, and the regions with the presence of pathological manifestations were identified and compared with orthoimage based on the damages map.

4. RESULTS AND DISCUSSIONS

The results and discussions related to orthoimage generation, damages mapping and inspection by Infrared Thermography are presented below.

4.1. Orthoimage generation

Figure 9 shows some of the images captured by the UAV, which were used in the photogrammetric model generation step and, later, in the orthoimage generation. For processing, a larger number of photos was used in relation to the number estimated by Pierrot-Deseilligny *et al.* [18] relation: 109 photos.

Figure 9: Images from the Artiaga Museum captured by the UAV.

Table 2: Input data for the photogrammetric model.

ALIGN PHOTOS – BUILD SPARSE POINT CLOUD	
Accuracy	Low
Pair preselection	Disable
Sparse point cloud	16.627 points
BUILD DENSE POINT CLOUD	
Quality	Lowest
Depth filtering	Mild
Dense point cloud	473.791 points
BUILD MESH	
Surface Type	Arbitrary
Face count	947.710
BUILD TEXTURE	
Mapping mode	Generic
Blending mode	Mosaic
Texture size/count	4.096

The input parameters adopted for the photogrammetric model in PhotoScan in the stages of align photos, build dense cloud, build mesh, and build texture are presented in Table 2.

To reduce the computational cost, in the steps of alignment of photos and construction of the dense cloud, low accuracy and lowest quality of the dense point cloud were chosen, respectively. As presented by Melo Júnior *et al.* [21], selecting these options does not reduce the quality of the model and becomes viable for computers with lower performance configurations. The processing time was less than 24 minutes and the file size was 45.6 MB.

When the geometry of the scene is complex, with small details on the plane, mild mode is recommended for depth filtering, still in the dense cloud construction stage.

In the mesh construction stage, the arbitrary option was chosen in surface type, which is used to model any object, including buildings.

When applying texture, mapping mode determines how the texture will be applied to the object and the generic option allows the parameterization of the texture for arbitrary geometry types. Blending mode is the option where the pixels from different images will be combined in the final texture, and mosaic allows a better quality to the orthoimage.

Figure 10 shows the result after the step of applying the texture of the façade of the Artiaga Museum, in perspective. The photogrammetric model had 947,710 faces, resulting in a model with satisfactory quality.

In Figure 11, a more enlarged image of the façade is shown in perspective, in which the ornaments can be seen in detail, as well as some of the pathological manifestations: paint peeling, chromatic alteration and efflorescence.

Figure 12 shows the Artiaga Museum façade orthoimage generated after the absolute external orientation and the export step in PhotoScan. It should be noted that no element of the façade concealed another part of the building, since the UAV allowed recording all parts by in-flight range.

Enlarging the orthoimage, it is possible to observe the ornament details and the efflorescence stains, paint peeling and even the cracks present in the façade with precision (Figure 13).

This level of detail perception in the orthoimage is possible since, after processing, it has a relevant resolution of 13,738 × 6,974 pixels, while an image has 5,472 × 3,648 pixels. This image size allows for magnification to view details without significant loss of resolution.

4.2. Damages map presentation

A damages map was constructed from orthoimage analyzes and visual inspections performed at the site. In Figure 14, the damages map, generated by computational vectorization, is presented, in which the pathological manifestations visually detected were vectored by coloring and hatching in their respective areas on the façade.

The main pathological manifestations found are presented in Table 3, where the Damage Factor is indicated, which was determined by the ratio between the affected area and the total area of the façade. Next,

Figure 10: Photogrammetric model of the main façade of the Zoroastro Artiaga.

Figure 11: Photogrammetric model of the main façade of the Zoroastro Artiaga Museum: platform area.

Figure 12: Orthoimage of the main façade of the Zoroastro Artiaga Museum.

some diagnoses of pathological manifestations are presented, through the identification of the cause and its effect.

It is observed that the pathological manifestation with the highest incidence on the façade area is the chromatic alteration of the paint, with DF equals to 21.3%. This pathological manifestation was possibly caused by the position of the façade, and, consequently, the effect of the sun's rays and the direction of rain.

The pathological manifestation of peeling of the paint appeared predominantly in the upper region of the museum's façade, which may be susceptible to the action of water that infiltrates through the platband, and had a DF equals to 2.49%.

Figure 13: Detail of the main façade orthoimage of the Zoroastro Artiaga Museum.

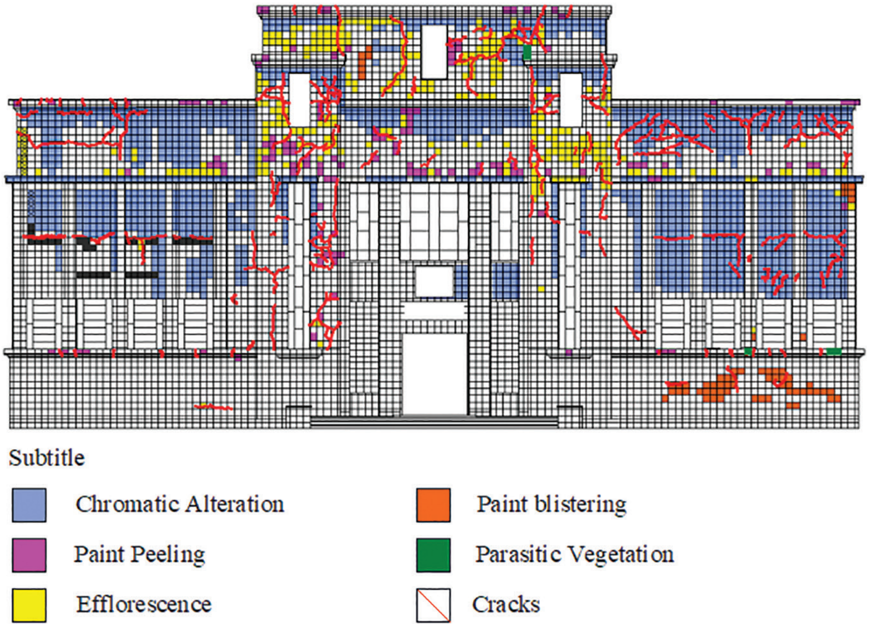

Figure 14: Damages map of the main façade of the Zoroastro Artiaga Museum.

Moisture in the building does not always act alone for the manifestation of stains on façades, but also together with other factors to trigger other types [58]. Efflorescence, paint blistering, and parasitic vegetation are pathological manifestations that originate from the presence of moisture.

In Figure 13, it is observed that the efflorescence occurred predominantly in the region close to the platband and represented a DF equals to 4.59%. The paint blistering was verified only on the lower right part of the façade and presented a DF value of 0.95%. The appearance of parasitic vegetation occurred more in the upper part of the façade and presented the lowest DF (0.08%), possibly due to cleaning and building maintenance actions.

It was verified, in the upper part, that there is a greater concentration of cracks, and the determined DF was equal to 0.43%. The fissure is the pathological manifestation that requires more time in its detection and mapping, and the visualization will depend on some aspects, including camera resolution and proximity to the building in the photographic record stage.

4.3. Infrared Thermography inspection

In Figure 15(a), there is a cut-out of the orthoimage and the thermogram corresponding to region 1 of the inspection by Thermography. In the orthoimage, one can see the presence of efflorescence with greater concentration to the right side of the image, accompanied by peeling of the paint near the central area.

From the thermogram, the problems of peeling in the paint observed by the damages map were corroborated. In this case, higher temperatures were represented by red and white colors in the thermogram.

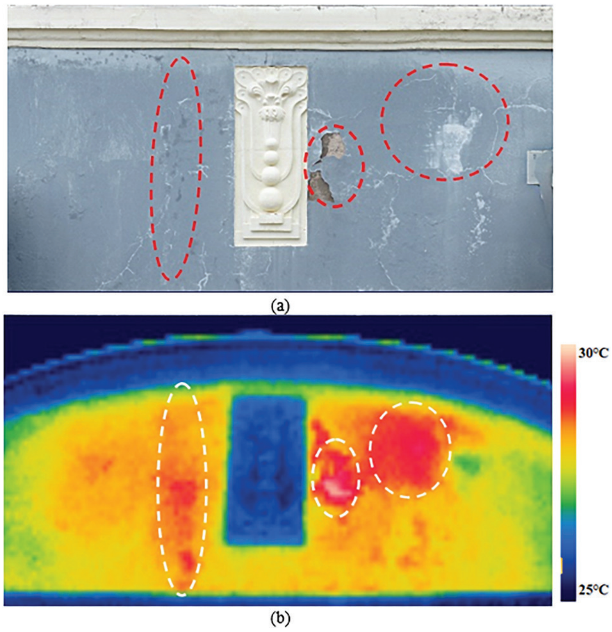

Figure 15: Pathological manifestations in region 1: (a) orthoimage; (b) thermogram.

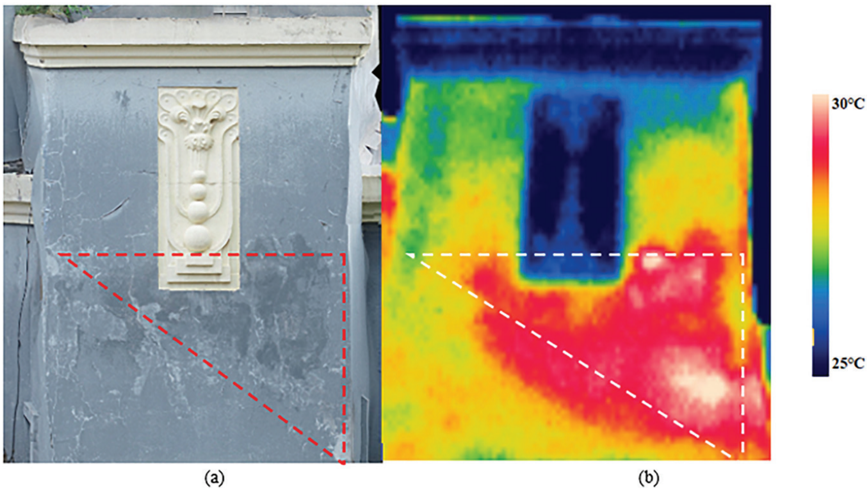

Figure 16: Pathological manifestations in region 2: (a) orthoimage; (b) thermogram.

Efflorescence problems, which originate from the presence of moisture, can also be confirmed in the thermogram. The predominantly red areas (warmer than the neighboring areas without defects) are an indication of moisture presence close to the surface, considering the greater specific heat of the water and the fact that the platband receives sun from the opposite side. Moisture problems in thick masonry walls were also detected by Kominsky *et al.* [42] as the hottest areas in the inspection carried out during the day.

Region 2, represented in Figure 16, was one of the regions where damages mapping showed the largest areas with efflorescence problems. The greater thickness of these elements can cause the upper part to accumulate excess moisture, resulting in infiltration and percolation through the platband, even causing the appearance of efflorescence.

Similar to the behavior of region 1, it was possible to observe in the thermographic image, in white and red, the presence of moisture in the lower right corner (Figure 16(b)). The greater thickness of the wall in the tower region and the lack of direct sunlight on the surface at the time of inspection facilitated the visibility of this phenomenon, considering that both factors reduce the process of water evaporation on the surface of the coating. Corroborating this, it can be seen that the extensions of moisture that propagate through the facade could be observed in the Thermography, however, they are not possible to be observed visually, so they were not represented in the damage map.

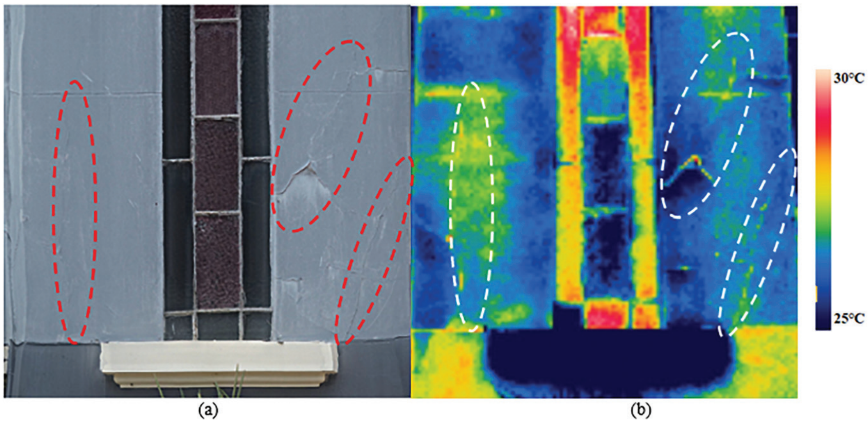

Figure 17: Pathological manifestations in region 3: (a) orthoimage; (b) thermogram.

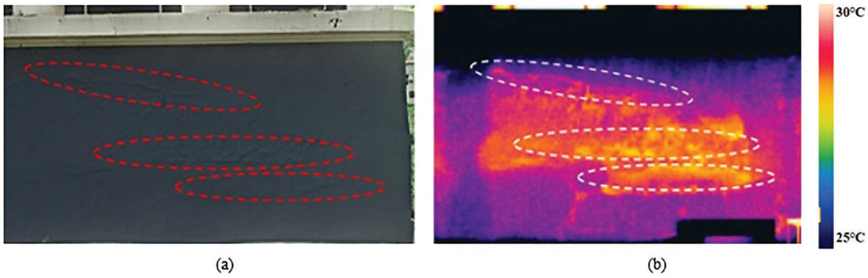

Figure 18: Pathological manifestations in region 4: (a) orthoimage; (b) thermogram.

The analysis of region 3 (Figure 17(b)) allowed us to verify the presence of cracks through thermographic inspection. In regions with dotted outlines in the orthoimage, the presence of white areas close to the cracks can be seen, which is an indication that part of the crack can contribute to the problems arising from the appearance of efflorescence. Thus, on the surface of the areas with fissures, there is a peeling effect of the paint that generates small voids along the path of the cracks, which allowed viewing them as warmer areas in the thermogram in relation to neighboring areas without defects. In the study developed by Bauer *et al.* [34], morning fissures were also detected as hottest areas in thermograms.

It can be seen in the orthoimage of region 4 (Figure 18(a)), areas with the presence of paint blistering in the painting. The voids behind the paint layer, with the increase in ambient temperature in the early morning, generate higher temperatures when compared to areas without paint blistering (no defects), behavior detected in the thermographic image resulting from the inspection (Figure 18(b)).

Note that the most visible areas in the orthoimage (dashed areas) appear in the thermogram as warmer areas, especially the central region. In addition, it is worth noting that the perpendicular distance between the thermographic camera and the façade was adequate, since the four areas analyzed resulted in coherent interpretations that correlated with the findings obtained by the aerial photogrammetry technique. The greatest distance between the thermographer and the target was in relation to Area 1. In this study region, considering the resolution of the infrared camera and the distance from the camera to the target, the pixel dimension (the largest) resulted in 3.5 cm, about. The pixel dimensions, in this order of magnitude, are still sufficient to detect problems related to the presence of moisture, given that this type of analysis is qualitative.

In general, the thermographic inspection results allowed us to validate the main pathological manifestations obtained by Aerophotogrammetry. It was verified the presence of moisture in the regions with the presence of efflorescence, fissure problems, and paint blistering.

5. FINAL REMARKS

In this article, two non-destructive methods were used for building inspection of the Zoroastro Artiaga Museum that can be applied to different types of buildings, but which fit perfectly to buildings belonging to the cultural heritage. These types of applied methods made it possible to guarantee the physical integrity of this museum, not disagreeing with the destructive techniques that are sometimes necessary for a thorough understanding of the damage that a building may be undergoing.

The generation of orthoimages using the Dense Stereo Matching technique requires some particularities when it comes to image capture. In terms of capturing images as close to perpendicular to the façade as possible, in this work the use of the UAV to obtain the images proved to be an efficient method for reaching the highest parts of the Zoroastro Artiaga Museum, avoiding occlusions and ensuring the observation of damages, like cracks.

As it represents the effective form of the façade, the orthoimage represented a practical and agile alternative for the creation of a damages map, using the methodology developed by Souza *et al.* [59] in the representation of the elevation of the façade and graphic overlays of pathological manifestations. In this way, it was possible to identify which damage has the greatest incidence, as well as to visualize in which part of the façade they are present. It appears that, from the damages map, it is possible to outline actions for monitoring, prevention and maintenance of buildings, using the Damage Factor.

Exporting orthoimages in PhotoScan provided an essential photographic model with excellent quality for the generation of damages map, due to its effective form, since photogrammetric models are built from photographs.

The use of the Thermography technique in a qualitative way confirmed the pathological manifestations identified on the damages map, thus highlighting the importance of employing more than one technique for evaluating façade damage. In addiction, the Thermography was important to identify non-visible damage to the façade, such as moisture extensions, since it was not possible to visually delimit the entire existing area of moisture through damages map generated by Aerophotogrammetry.

Finally, it is noteworthy that the use of non-destructive techniques used in this work - Aerophotogrammetry and Thermography - can be safely used for inspection and prior diagnosis, aimed at investigating the causes of pathological manifestations, with the purpose of tracing corrective measures and preservation of historic buildings.

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