

Photogrammetric Survey of the Historical Church of *Nossa Senhora do Rosário* and *São Benedito* in Brazil

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Abstract: In the history of cities and society, architecture plays an important role in the materialization of buildings, in the ways of life and in the constitution of an era. Documenting architectural heritage is an essential task for the conservation, management and collection of knowledge, however it is a time consuming and costly task. Presently, the application of digital aerial and terrestrial photogrammetry has made this process simpler, more agile and of relatively low cost. In this context, the objective of this study was to analyze the visual and geometric quality of the 3D model, of architectural heritage, generated by photogrammetric techniques. To this end, topographic mapping (reference) and aerial and terrestrial photogrammetric surveys of the *Church of Nossa Senhora do Rosário* and *São Benedito*, in Estrela do Sul/MG, Brazil, which is a historical and cultural heritage of the country, were carried out. Adopted as a reference, the 3D topographic model was generated by the points collected with a total station. To generate the photogrammetric 3D model, aerial photos were obtained using a UAV (Unmanned Aerial Vehicle) and terrestrial photos, acquired at strategic points. In both cases the *PowerShot SX260HS* camera was used. The two georeferenced 3D models were analyzed visually, considering texture and completeness, and compared geometrically through coordinates of homologous points. Comparatively, the photogrammetric 3D model presented results with a wealth of details far superior to the topographic ones and a geometry with centimetric discrepancies, showing that the method is suitable for generating 3D models relating to architectural heritage.

Key words: Photogrammetry, RPAs (Remotely-Piloted Aircrafts), architecture, historical patrimony, church.

1. Introduction

For an analysis and understanding of the history of cities and society, architecture plays an important role because it serves as an urban reference and materializes through buildings, ways of life of population and constructions of an era. In this sense, it is understood that real estate of historical and/or architectural relevance must be properly documented and catalogued. Inventory work on architectural heritage is the main documentation tool and creates a broad overview of the architectural assets of a location.

In today's society, there is a need to document archaeological and architectural heritage sites for the purpose of conservation, management, expertise and

scientific studies. In former times one had only registration methods by way of sketched archives produced by means of direct measurements determining angles and distances, frequently without topographic support or by way of photogrammetric restitution, to produce documentation for constructions, architectural complexes and historical regions. However, such processes, in their majority, are discarded due to their slow pace and high cost and because they do not offer a desired level of detail.

For this reason, new technologies are being used and adapted to meet these needs, such as digital photogrammetry and the laser scanner. Digital photogrammetry is an important part of the change that has occurred with regard to the agility and simplicity of the processes, as well as representing a reduction in costs in relation to conventional techniques [1].

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Heritage documentation can be carried out using such techniques as Topography, Geodesy, Photogrammetry and Cartography. Digital methods have enabled the development of a range of applications and new products, both in engineering and architecture, such as the generation of 3D models of buildings, enabling detailed representation and, thereby, the conducting of new studies and restoration projects or reconstruction of heritage.

For the construction of the mentioned models, UAVs (unmanned aerial vehicles) are being used increasingly as an option for traditional aerial surveys. UAVs were developed, a priori, to assist in activities of a military nature and have, today, conquered various other sectors of society, both for commercial purposes and for research, mainly due to the acquisition price, the facilities in the survey and the emergence of various processing software which are simplified and adapted for processing [2, 3].

For the same purpose, terrestrial photogrammetry has also gained prominence in these activities in surveying historical heritage. In fact, the two techniques (aerial and terrestrial) can be used in a complementary manner, so as to represent greater details, where the terrestrial survey is generally carried out by cameras attached to tripods, supported by control points surveyed by Topography or Laser techniques.

In the face of the deficiency in the registration and documentation of information about such heritage, this work has aimed to carry out the aerial and terrestrial photogrammetric mapping of an old church built by and for the use of slaves, considered to be one of the historical heritages of the city of *Estrela do Sul*, MG, as a way of giving support to the process of conservation and documentation of historical heritage.

It is a known fact that historical heritage directly represents the material and immaterial production of an era, being capable of expressing the way of life, thoughts, perspectives and social experiences of a society. This being said, it arouses interest and instills curiosity about the past and represents the

materialization of the culture of a locality.

In light of the above, it is important to preserve such heritage so that future generations can have access to the history of a particular place and make the past more palpable and closer to the present. To this end, it is necessary that new technologies and methodologies be tested so that the cataloging, collection and restoration processes become faster and more accessible, also enabling a variety of studies and perspectives on the place, based on the products generated through these technologies, as shown in Refs. [4, 5].

It should also be noted that the photogrammetric survey using UAVs has a lower cost when compared to the use of conventional photogrammetry, making the whole process more accessible and economically viable. In addition, for this type of survey, free remote sensing images do not meet the needs as they do not possess good spatial resolution. As for the tourist trade, well-preserved heritage and the development of a tourist structure are attractive for a locality, which generates resources both in the public and local community spheres.

With regard to flight, UAVs, or RPAs (Remotely-Piloted Aircraft), have the ability to fly semi-automatically or manually, being conducted by a pilot on the ground, using a remote control, offering no risk to the camera operator or the pilot [6, 7].

Presently, the use of unmanned aerial systems, such as survey devices, allows one to obtain images of very high spatial resolutions, of a centimeter order, enabling the detailed production of data, orthophoto and 3D models [8, 9]. Consequently, this technology has been stabilizing itself in the digital mapping market, bringing a gain in spatial and temporal resolution, meeting the demand for large-scale surveys [10]. However, in relation to regulations as to use, flight safety methodologies and authorizations for carrying out the survey, there is still a lack of information and of completely defined standards in the country [11].

2. Method and Materials

2.1 Study Area

The Church of *Nossa Senhora do Rosário* and *São Benedito* is located in the municipality of Estrela do Sul, situated in the Triângulo Mineiro region (Fig. 1), in the state of Minas Gerais, Brazil. The city was founded in 1722. Its first name was “*Bagagem*”, due to having been a resting place where several *bandeirantes* (flag carriers—officials claiming new territory for the King of Portugal) laid down their baggage. At that time, the city was basically formed by diamond prospectors, which was the driving force

for a change in the city’s name to *Bagagem Diamantina*. In the middle of 1854, a slave named Rosa, owned by Sir Casimiro de Moraes, found a huge diamond weighing 254.5 carats on a pile of gravel, which in Europe became known as the *South American Star Diamond*. This fact led to an increase in the population of the village, which later led to municipal autonomy, elevating the village to the status of a city, which was named as *Estrela do Sul*.

Presently the city has a relevant historical and architectural collection, with a considerable number of monuments such as mansions, *sobrados* (two story Portuguese colonial houses), churches, and listed

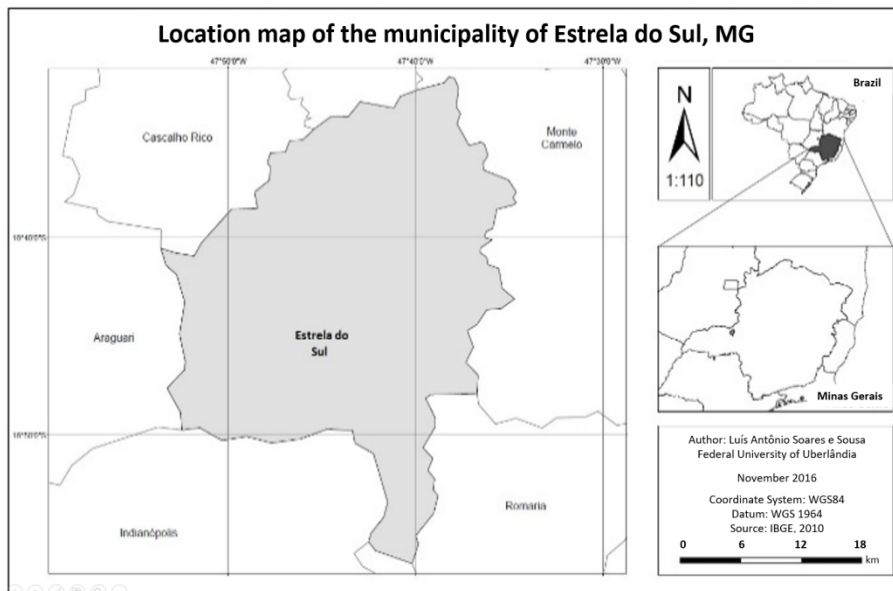


Fig. 1 Study area.

Source: Author.



Fig. 2 View of the frontal and right side elevations of *Nossa Senhora do Rosário* and *São Benedito* Church.

Source: Author.

items that make up the Historical, Artistic and Cultural Heritage, all listed by Municipal Law. Among the city's heritage, the Church of *Nossa Senhora do Rosário* and *São Benedito* stands out (Fig. 2), built by slaves in which to carry out their worship.

The only remnant of the four churches built during the second half of the 19th century, a period in which diamond mining brought a large influx of people to *Estrela do Sul*, the small chapel of *São Benedito* has great cultural importance at municipal and regional levels, although it does not have a grand or monumental character due to its small proportions and simplicity of decoration.

The construction system used employs a freestanding wooden structure with large adobe seals (20 × 20 × 40 cm), set in the direction of its largest measurement, forming protruding "cushions" within the walls delimited by the wooden pieces on the external facades. The wooden structure presents oil painting and whitewashed walls. It has a single nave, with a choir loft over the main door; an incomplete chancel arch connects the nave to the chancel and features a single sacristy that occupies the left hand side of the chancel.

The volumes and the different covers reflect the arrangement of the internal spaces, creating a delicate movement in its composition. The highest gable roofing corresponds to the complex formed by the nave and the choir. The chancel also has a gable roof, but lower than that of the nave. The cover of the sacristy, in gable form, is lower than that of the chancel. The roof structure is composed of high-end trusses, with cover and channel hand-made clay tiles, which is left exposed, without an internal ceiling; the eaves are finished off with ornate brackets. Access through the main door is made by way of a semi-circular stone stairway, which overcomes the unevenness of the terrain. In the church yard, at the front, a cross is raised.

The church's frontispiece presents the traditional organization, with the main door in the center,

surmounted by three windows completely hand made with cut-out wooden balusters, at the level of the choir loft. The central window of the choir loft supports the bell. The gable receives, in its center, an oculus formed by four volutes carved in a piece of wood.

The church nave is illuminated by two circular oculi arranged in each of the side walls, by the choir loft windows, the front oculus and the main door. The lighting and ventilation of the presbytery are also provided by the oculi arranged in the side walls.

2.2 Materials and Instruments

The materials and instruments used in this research are related to the collection and processing of data. To collect the photos, by aerial survey, an ×700 hexacopter was used, composed with GPS, Inertial System and two Canon PowerShot SX260 HS cameras (focal length: 4.5 mm, resolution: 4,000 × 3,000, pixel size: 1.5494 × 1.5494 μm).

Still in relation to data collection, a 30 m measuring tape and a booklet were used to record in the field the characteristics of the construction, annotation as to distances between points of easy identification, to help in the planning of the photogrammetric survey. According to Ref. [12], it is important to determine the distance between two easily identifiable points in the building to determine the scale.

In the topographic surveys, a FOIF 680 Total Station and auxiliary equipment (1 tripod, 1 prism, 1 rod and 1 measuring tape) were used to generate a closed polygonal and to collect control points on the church walls through the method of press free reading; and in the geodetic survey, a GNSS ProMark 500/200 was used to implement a base for polygonal georeferencing.

In the data processing phase, the following software was used:

- (1) Topograph: for data processing of closed polygonal and irradiations (UFU Heritage);
- (2) AutoCad 2015: for generation of the 3D model, coming from the topographic survey (UFU Heritage);

(3) GNSS Solutions: for processing data obtained by GNSS (UFU Heritage);

(4) ReMake and MeshLab: for processing the images obtained by the cameras on the ground and by the UAV and for generating the 3D model of the church (remake: trial version and MeshLab: free software).

2.3 Methods

So as to have a correct orientation as to the photographs it is necessary to know the parameters relating to the camera, such as the focal length, the image size and the distortion of the lenses, for an appropriate geometric relationship between the points in the image and the points in 3D space [13, 14]. For this, there are different methods we can use. In this study, the method proposed by the processing software was used.

Before beginning the surveys, a previous analysis of the area and the property itself was carried out. In this, some physical factors were considered, such as the presence of natural or artificial obstacles (trees and shrubs, buildings and antennas in the surroundings and the irregular topography), the degree of sunlight incidence on the facades and the geometry of the building.

The data surveys were carried out in 3 stages: (a) aerial survey, (b) topographic survey and (c) data processing. In the first stage, an aerial survey was carried out, using the UAV and small format cameras, to collect photos/images from the four sides and the upper part of the church. The flight plan was defined with the following configurations: height of 30 meters, three flight lines, 10 photos in each line, spatial resolution of one centimeter, lateral and longitudinal coverage of 80%.

The terrestrial photographs were obtained with the same camera used in the UAV. This set of photos was used as a complement to the set of photos obtained with the UAV, in order not to leave empty spaces in building the 3D model. The diagram below represents the positioning of the equipment during the

topographic survey and terrestrial photos, involving the creation of the polygonal, the irradiations and the process of taking terrestrial photos.

In the topographic survey, a closed polygonal was made, with 4 points, two of which have georeferenced coordinates, installed in front of the church. From these, vertices of the polygonal targets were made by irradiation, in the reading mode without prism, at strategic points on all sides, using the Total Station. Additionally, measurements were carried out with measuring tape between points in the church, such as the width and height of doors and windows. The georeferenced points were surveyed with a GNSS L1/L2 receiver, for georeferencing of polygonal and final 3D model. The basis of the GNSS survey was a landmark of the RBMC (Brazilian continuous monitoring network) located at an approximate distance of 22 km. These points were processed using the GNSS Solutions software.

After the surveys, the data were processed to obtain the 3D model. First, the polygonal was processed in the *Topograph* software, so as to verify the accuracy of the survey and obtain the coordinates of the radiation carried out. Then, the cloud of point was exported to the DWG format, compatible with *AutoCad* 2015, for the adequate creation of the 3D model, from the link/connection of these points.

The data originating from the aerial survey were processed in the modeling software called *ReMake*. This software makes it possible to convert the reality

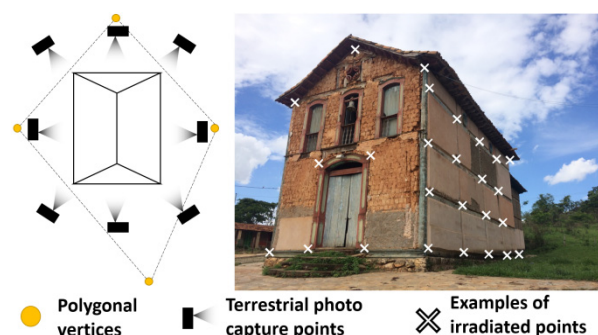


Fig. 3 Scheme for collecting topographic data and terrestrial photographs.

Source: Author.

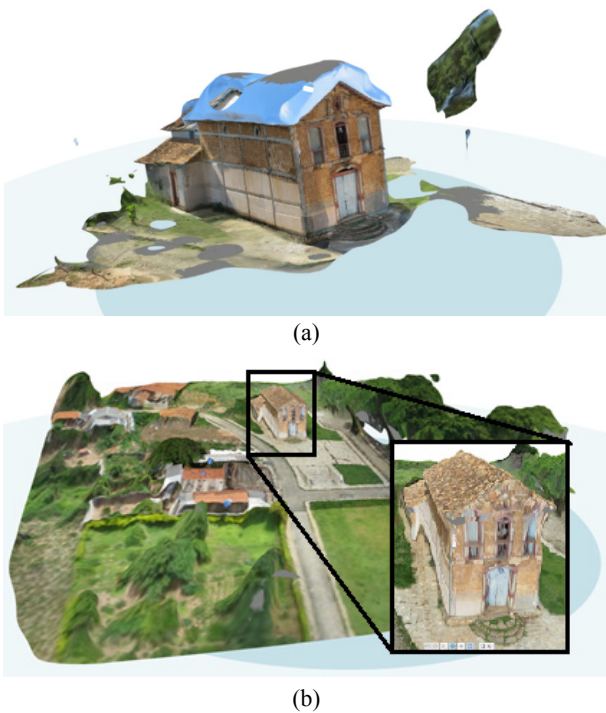


Fig. 4 Model of the (a) facades and (b) roof.
Source: Author.

captured with photos into a high definition 3D dot mesh, which can be edited, corrected, scaled, measured, compared and optimized, according to the user's needs. *ReMake* simplifies complex processes, as it was designed for accurate generation of digital models of real life objects.

Then, 164 photos were imported into the *ReMake*, 16 of which were aerial (the best photos from the UAV lift survey) and 148 were ground-based, to generate the definitive 3D model. The aerial images were processed separately from the ground photographs, thus obtaining a model of the roof (Fig. 4b) and another of the facades (Fig. 4a) of the Church, respectfully.

It is noticed that in the ground model (Fig. 4a), the coverage appeared completely distorted and, in the aerial model (Fig. 4b), a good result of the facades was not obtained. Therefore, the solution was to select the best quality for each model and group them into a

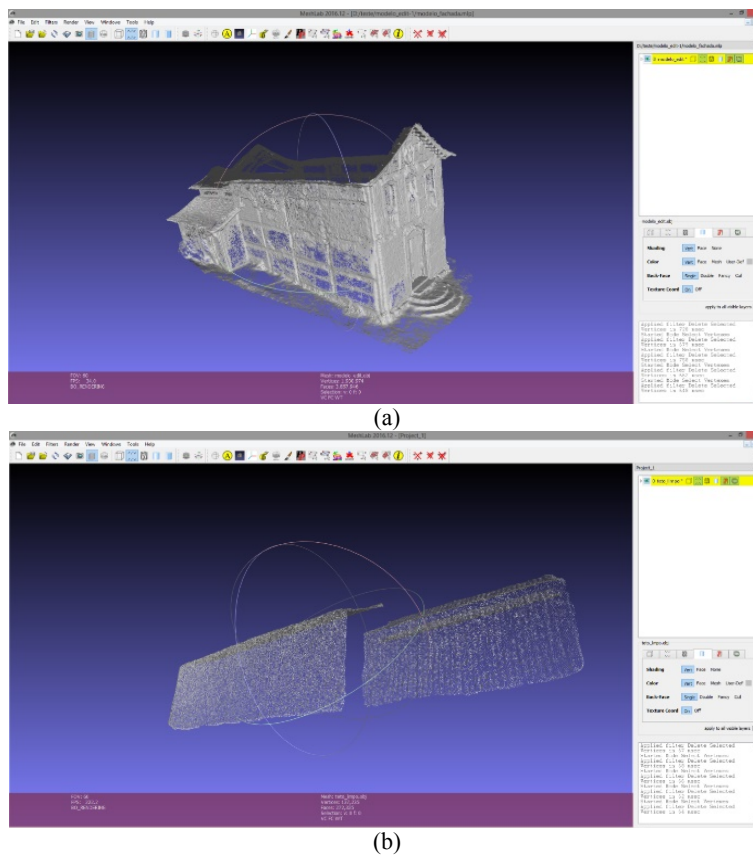


Fig. 5 Isolated/corrected models: (a) facades and (b) roofs.
Source: Author.

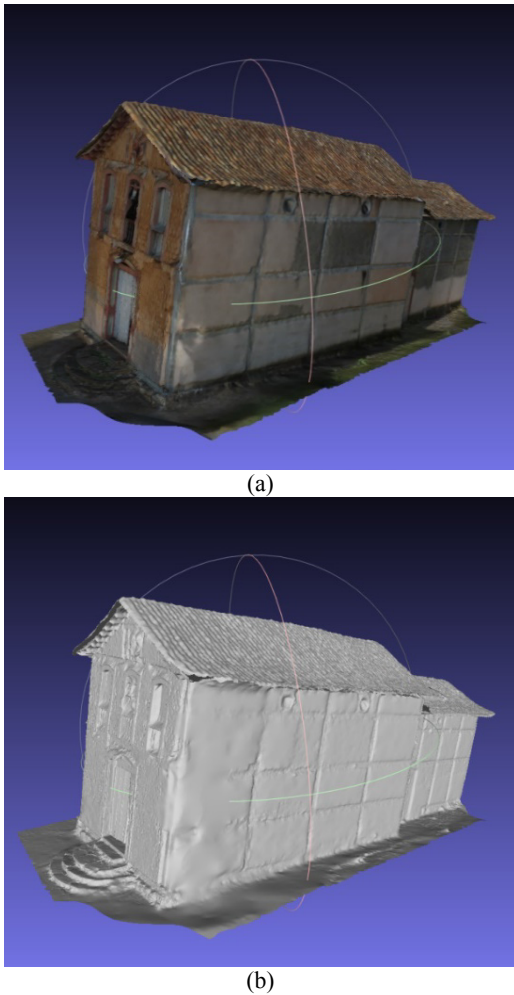


Fig. 6 (a) Final model with roofs and facades at different layers and (b) the final model at a single layer.
Source: Author.

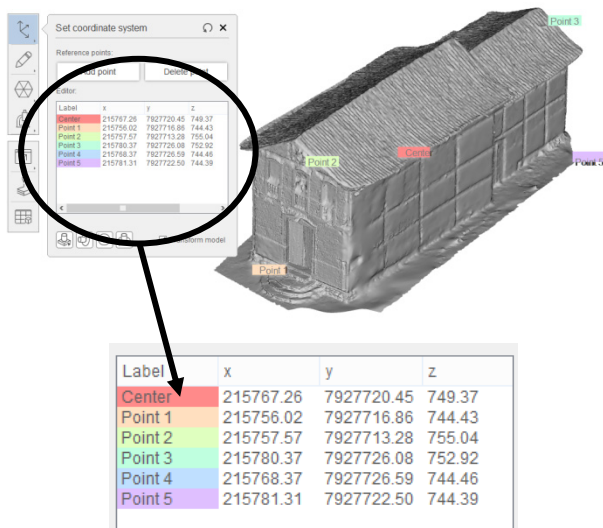


Fig. 7 Georeferencing of final model.
Source: Author.

single model. For this end, the models were exported in the “.obj” format to the *MeshLab* software and the process of adjusting the initial models began, manually removing the covers (Fig. 5b) of the model generated by the ground images and the facades (Fig. 5a) of the model of the aerial images.

With the isolated models (adjusted), one can join them using a sequence of steps on the *MeshLab*. The first step aligned the models using the alignment tool (Edit > Align), choosing the model on the sides as a reference and selecting the homologous points between the two models to reposition the roofs according to the facades. In this manner one has the model with the covers in their real positions (Fig. 6a). However, the models were still at different layers, which is not feasible for the study sequence. Then, the roof-facade models were joined and the creation of a single model resulted (Fig. 6b).

Then, the model was placed in scales, using the *Model Settings > Set Scale & Units* tool, inserting known distances, measured in the field with the measuring tape and identifying their equivalents in the model. In the case of this study, the dimensions of the doors were used as a reference for the scale.

Subsequently, the model was again exported in “.obj” and opened in *Remake* to begin the georeferencing process of the model. To this end, 5 control points were selected, among those raised with the total station/GNSS, spatially well distributed, to be used as a reference and locating their counterparts on the model, in *Remake*. When identifying each point, the reference coordinates of these points were inserted so as to guide the model using the *Model Settings > Set Coordinate System* tool (Fig. 7).

3. Results and Discussions

With the model finalized in both software (*AutoCad* 2015 and *Remake*), the process of analysis and comparison between both began. Two types of analysis were carried out: visual and geometric, the second being more relevant, as it presents a real

measure of accuracy. The visual analysis was done through the comparison of the models, observing the richness of details, the similarity with the real and the ease of recognition of the elements, as well as the importance of this product for application in actions such as local tourism. For the geometric analysis, some samples of points were collected in the *AutoCad* 2015 model and their coordinates were compared with those collected in the model generated by *ReMake*, so as to verify the difference between the model considered real (topography) and the model by photogrammetry.

3.1 Tourist Potential of Estrela do Sul: Present Scenario vs. Future Scenario

Presently, the city of *Estrela do Sul* encounters serious structural and environmental problems, like many small municipalities in the country. In general, the city has an estimated population of 7,978 inhabitants, 822,454 km² in area and a demographic density of 9.05 hab/km² [15]. The municipality's economy is based mainly on agriculture and livestock. In recent years there has been a rural exodus trend, where part of the population has been moving to the urban area. This can be confirmed when observing the historical series of the number of inhabitants of the urban and rural region made available in Ref. [15], which points to a reduction of about 75% in the population of the rural area.

Allied to the weak urban economy, the region's commerce and services establishments are essentially small, of a local and family nature. In general, the city does not have large investments in urban equipment, especially for culture, leisure and education. It has part of its architectural and urban collection abandoned or in a process of degradation.

Thinking about a future and optimistic perspective, we can see that the city has natural resources and cultural assets that can be leveraged through government incentives and the development of tourism, taking into account the ecological and

cultural aspects, being able to rescue or restore it to a relevant position, among the historical cities of the region. In this sense, tourism, when encouraged and well structured, can generate local income, through the flow of people in hotels, restaurants, supermarkets and the like, and public income through the collection of heritage visitation fees.

In this sense, it is proposed that all relevant goods in the city be digitally cataloged and made available on an online page, destined for tourism. It is interesting to create a sightseeing tour of the city, together with the internal mapping of the heritage, in 3D models, so that its details are archived and made available to society, so that a virtual tour can be carried out. These 3D models will be used for later restorations, as they will be stored in digital media.

3.2 3D Model Generated by Topography

As shown in the methodological flow, for the 3D generation of the model, based on the topographic survey, the coordinates of the points of the polygonal and of each irradiated point in the structure of the church were used. The coordinates of each point were imported into *Autocad* and by way of connection of the main points it was possible to generate the 3D model. Fig. 8 has the model generated by the data collected with the *Total Station*.

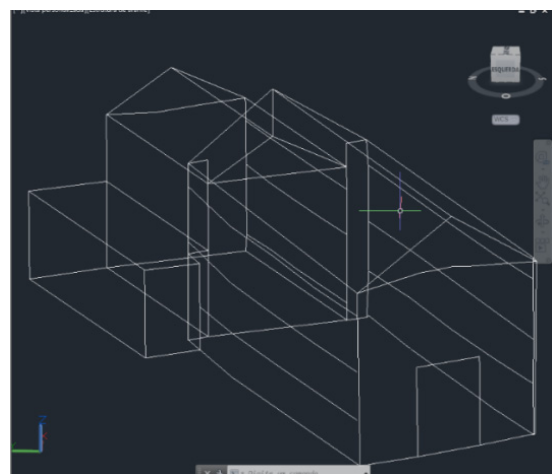


Fig. 8 Final model of building generated from topographic data.

Source: Author.

3.3 3D Model Generated by Photogrammetry

The generation of 3D models is extremely valuable when working with architectural assets. From them one can have, in greater detail, the form and conditions in which a building is found. In this study, the *Remake* software was used as a tool to support three-dimensional reconstruction and two models were obtained: one of the roofs and another of the facades. One can perceive the quality of the software when analyzing the richness of details and similarity with what is real.

In this process, it was evident that the importance of capturing the facades in the clearest and cleanest way possible, with photos that record the details, as done in this study, stands out. This is proven when analyzing the left side and the back of the church in the final model, in which there is deformation of the side and the back, due to the occlusion of parts by the presence of some small shrubs and undergrowth which is a little denser.

The richness of details can be seen in the model generated when compared to photographs of the building. Besides, it is clear that for viewing details in zoom mode, *Remake* offers better radiometric

resolution than *MeshLab*, but does not offer support for uniting the models. In Fig. 9, the similarity between the generated product (3D model) and its real 2D version (photo) can be seen.

When one thinks about reproducing an architectural project of this nature, the 3D model is much more informative than the 2D model, as it presents continuous details of height and location, with precision, as to internal and external details of the object. In this study, only the external model was presented, but the internal reconstruction would be carried out by an identical procedure, changing only the forms of image collection, since it was not possible, and did not make sense, to use the UAV inside the building. In this way, it is believed that this model will be useful for the managers of the city of *Estrela do Sul* to think about projects as to tourism promotion in the city, where they can show the historical heritage of the city from all angles, in an easy and quick manner, with great publicity, since the format is digital and allows for availability on the internet.

In this sense and by using the same methodology, it is to be encouraged that all other historical heritage of the city be mapped, in order to disseminate the cultural wealth of the municipality on digital



Fig. 9 Comparison of (a) the 3D model with (b) heritage photos.

Source: Author.

platforms and three-dimensional models with high resolution and level of detail. It is believed that these assets displayed in a detailed and realistic manner, combined with the ease of accessing and handling the model, will bring greater visibility and draw more attention of the population as a whole.

3.4 Analysis of the 3D Model Generated by Photogrammetry

As regards a qualitative analysis, it is clear that the model generated by photogrammetry presents a considerable difference in terms of details, becoming closer to the real than the model generated by topography, in addition to being faster and more practical to carry out.

To perform a geometric analysis (quantitative), some sample points were collected in the topographic model to compare their coordinates with the photogrammetric model. For this purpose, 16 points in the reference model obtained by topography were determined and then, the homologous points in the 3D model, generated by photogrammetry in *Remake*, were sought.

So as to make a comparison, the difference between the coordinates of the two models generated was performed. So, the accuracy of this model can be perceived by the average of the differences in the coordinates in X, of -0.1261 m, in Y, of 0.9926 m and in Z, of -0.0072 m. It can be verified that the model obtained less precise results on the Y axis, being displaced about 1 m, while on the X axis, centimeter accuracy was obtained and, in Z, an error of millimeter magnitude was observed.

The photogrammetric model presented moderate values of standard deviation, below 0.5 meters. It can be seen that for studies that require extreme precision, such data may not meet the need, however, for visualization, digital archiving of heritage, study of colors and textures, this methodology is very useful. It is believed that these errors can be reduced in cases of buildings in places that are freer of obstacles.

Additionally, the *t*-student trend test was performed,

with 95% significance, so as to assess the differences between the averages of the discrepancies of the two models. Therefore, the two hypotheses are tested: H0—the sample average is equal to the reference average and H1—the sample average is different from the reference average. In this analysis of the mean of the X and Z axis discrepancies, the H0 hypothesis was accepted, showing that the averages are statistically equal, which did not occur with the Y axis discrepancies.

A possible explanation for the error occurred in the direction of the Y axis is because it has the largest extension of the building to be reconstructed in the 3D model, which increases the number of observations and, consequently, there may be a greater insertion of errors. In addition, the lateral faces have planes at different elevation levels, which is a factor that can also cause errors.

4. Conclusions

The cataloging of historical heritage is extremely important so that future generations have access to the past in a realistic way. In this context, it was seen that the photogrammetric survey method is an excellent alternative and that it generates good results through quick and easy techniques in comparison with the conventional topographic survey. The 3D model generated by images had an excellent level of detail and proved the effectiveness of the method when a survey of restoration and conservation is required, having the visual aspect to the forefront.

The 3D modeling software, *Remake* and *MeshLab*, met the requirements of the study very well and for their performance and ease of handling. It is important to highlight that at the geometric level, the survey was considered satisfactory in the X and Z directions, and the accuracy on the Y axis could be improved, carrying out even more detailed surveys and more rigorous processing.

Finally, it is understood that the city of *Estrela do Sul* has relevant conditions and historical assets to become a tourist city, requiring government incentive

and preservationist actions, having in mind that many assets are in a state of deterioration and neglect, as is the case of the Church of *Nossa Senhora do Rosário* and *São Benedito*. For this, accurate 3D mapping is necessary, along the lines of that presented in this study, for future and permanent registration of the heritage therein.

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