Small Scale Unmanned Aircraft System and Photogrammetry Applied for 3D Modeling of Historical Buildings

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***Abstract*—Heritage preservation is the active conservation of cultural assets, historic structures and buildings of a specific cultural group. This paper presents a methodology for the 3D reconstruction of large-scale cultural assets, such as buildings using photogrammetry, which is a way to get measurements of objects from a set of photographs. The present study uses images from small scale unmanned aircraft systems (UAS) for the 3D reconstruction of the "Palacete da Babilônia". The study case presented here is a historical building from 1866, located in the Military School of Rio de Janeiro whose complex also includes a historical museum.The experimental setup used three mini drones in addition to flight mission planning and execution application evaluation.The final reconstruction used off-the-shelf software to generate the 3D model reconstruction, model adjustments finishing with the 3D printing of the model generated for the preservation of this historic construction.**

Keywords-Heritage Preservation; UAS; 3D Reconstruction; Photogrammetry.

I. INTRODUCTION

The conservation of historical buildings is crucial for the cultural preservation of a community, nation or social group. Therefore, access to a three-dimensional description of such assets is valuable and possibly crucial for the process of reconstruction and restoration. The three-dimensional (3D) representation of an object of interest can be achieved using 3D mapping techniques with photogrammetry [1]. In addition to the popularization of small-scale unmanned aircraft systems (UAS)[4], collecting and processing information can be automated using mission planning and off-the-shelf 3D surface applications[6]. The present paper focuses on evaluating the use of UAS for the large-scale model reconstruction of buildings in Rio de Janeiro, a 456-year-old city with hundreds of historical and cultural assets. Specifically, the present work focuses on the study case of 3D reconstruction of the "Palacete da Babilônia," a historic building part of the Military School complex in Rio de Janeiro.

Even though UASs have become popular, the present paper uses, and processes images generated by a UAS, which comprises the aircraft, control system guidance, and mission planning. Experiments used and compared three models of DJI rotary-wing drones of small size and low-price range, which allowed the generation of 3D models of the target building. Commercial aircraft usually have more straightforward flight control, reduced size and excellent portability and stability. Moreover, the efficiency of take-off and landing makes this kind of device optimized for solo control. The use of external applications and embedded technologies, such as inertial sensors, Global Positioning System (GPS) and good embedded cameras, with flight automation ability, makes this system perfect for a small-scale 3D reconstruction of historical buildings.

Weather, rain and wind, short battery life, reduced range, and small payload limit the use of small-scale drones. However, selected brands have compatible automated flight planning apps that enable easier mission planning in many devices such as smartphones. Furthermore, the evolution of the technology embedded in small-scale drones, along with the wide availability of software for the dense cloud of points, in addition to modern tools for model generation and correction, makes it the perfect tool to get a full-scale 3D model exported in a short time interval with a reduced staff.

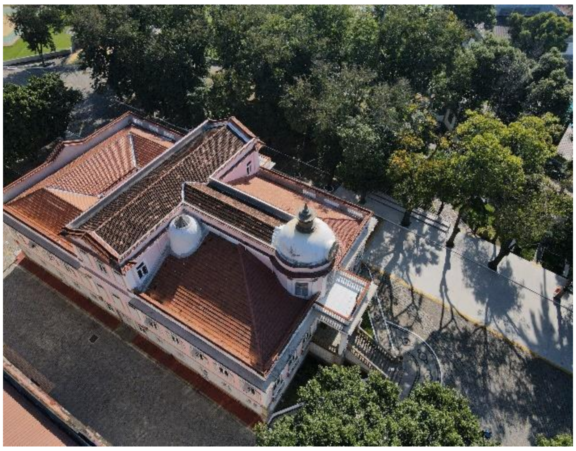

Figure 1. "Palacete da Babilônia" Mavic Air2 aerial photo

The application of easy-to-use, off-the-shelf components means that the flight mission would require less staff, usually a single person. Training the survey personnel, they could later perform post-processing for generating and adjusting the 3D models.

The following sections present the methodology, followed by the materials and methods used in this work. Sec-

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tion III presents the final model 3D printed in PLA, followed by a discussion in section IV with Conclusions in section V.

II. METHODOLOGY

The present work has a general objective to present how photogrammetry [2] with small-scale UAS can contribute to the 3D reconstruction of historical buildings. In addition, technological tools allow cultural preservation by archiving 3D models that could be used as a reference for future restorations. This section will present the methodology used for the study case in the 3D model reconstruction of the “Palacete Babilônia,” using drone photogrammetry.

The initial evaluation of drone images used three models, with the Mavic Air 2 performing more missions. In addition, a single external collaborator operator was able to perform several missions. Finally, some missions used a Spark and the Mavic Air 2 drones. Figure 2 shows a comparison of the camera's sensor size. An increased sensor size means better quality concerning the amount of noise in the image.

Figure 2. Sensor size comparison [7]

A. Mission Planning and Tools

First, the mission requires evaluation of weather conditions, a limiting aspect of small-scale drone use. Figure 3 shows a screenshot of UAVForecast.com that provides adequate information for the flight.

Sábado 2021-06-12: nascer do sol 06:30, por do sol 17:15										
Tempo	Vento em 60m	Raias em 60m	Temp	Prob Precip	Capa Nuvem	Visibilidade	Sats Visíveis	Kp	Sats Est. Bloq	Bom Para Voar?
07:00	6 km/h	17 km/h	19°C	1%	91%	16 km	13	1	13,0	não
08:00	6 km/h	19 km/h	19°C	5%	92%	16 km	13	1	12,9	não
09:00	7 km/h	21 km/h	20°C	-	90%	16 km	16	1	15,6	não
10:00	8 km/h	22 km/h	20°C	-	90%	16 km	13	1	12,7	não
11:00	9 km/h	23 km/h	21°C	-	89%	16 km	10	1	9,6	não
12:00	12 km/h	26 km/h	21°C	-	86%	16 km	9	1	8,9	não
13:00	14 km/h	28 km/h	21°C	-	74%	16 km	10	1	9,8	não
14:00	15 km/h	29 km/h	21°C	-	70%	16 km	11	1	11,0	não
15:00	14 km/h	27 km/h	21°C	-	52%	16 km	13	2	12,6	sim

Figure 3. UAVForecast.com information for the flight

The best time for this mission is around noon when shadows have a minor influence on the images. A cloudy day may also provide favorable image conditions if good flight conditions are also available. However, we must consider that the reduced light could affect the camera's shooting speed and image quality. It is essential to highlight that the choice of a micro-SD card is an essential factor. A low recording capacity card can interfere with the recording quality of the set of obtained images. Considering that the sequence of photos should have a good overlap, we use 80% in the front overlay and 75% in the lateral overlay.

Height is also a primary factor in the relationship of pixel size with the exact measure of the object. The number of pixels in a sensor is constant, and the Ground Sample Distance (GSD) is variable with height. The GSD is a sample of the terrain in the image. Figure 4 describes the camera parameter for the drone model we used. In the present paper, this issue is favorable because we fly at a low height very close to the historical construction.

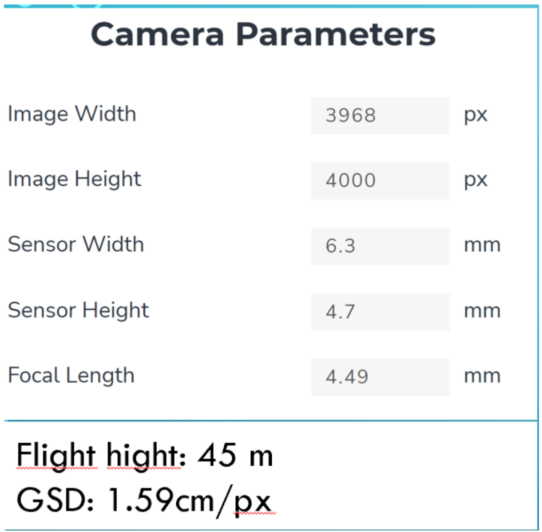

Figure 4. GSD Calculation Spark [8]

Flight automation applications are essential. Therefore, it is crucial to investigate the drone model’s compatibility with the application. The present paper used three drone flight apps: Copterus, Litchi and Dronelink. The Mavic Pro drone is compatible with most off-the-shelf applications, such as PIX4D and Dronedeploy. The Spark drone also works with pix4d but has restricted automated flight modes, which requires manual mode flights. The Mavic Air 2 drone works with Dronelink and Copterus, which runs on Apple smartphone models only.

The missions planned for this study case used three main types of flights: orbiting, waypoints and grid, Figures 5, 6 and 7 respectively. First, the operator builds the polygon, line or circle centered on the construction, adjusts the height predicting safety, and checks with the desired GSD to get as much detail as possible from the construction.

Second, there is the confirmation of mission time and the drone's battery time. The possibility of dividing the mission into parts was unnecessary, considering the dimensions of the target construction. Consequently, one battery was enough for a mission. Finally, the most battery autonomy drone is the Mavic Air 2, closely followed by the Mavic Pro.

The Litchi app allows plane flights in orbit and following waypoints such as shown in Figure 5. Mission planning works well, requiring more work for the path assembly.

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Unfortunately, it did not work with Mavic Air 2, considering the flight date of the drones in this work. The orbital flight requires angular velocity adjustments, radius measurement, circle height and image-taking interval.

Figure 5. Flight in orbit mode in the Litchi app.

Figure 5 shows the Litchi application. It is possible to create a point of interest (POI), referencing the gimbal to direct the drone's camera. Determining the height of this point will influence the angle of the gimbal. For example, Figure 5 shows the POI near the center of the rectangle with the building's top view, with a height of negative 6 meters. Figure 6 shows the waypoints mode, where it is possible to determine an action for each point in the chosen trajectory.

Figure 6. Flight planning waypoints in the Litchi app.

Dronelink presented a more significant number of automated flight patterns. The operator has the possibility of using a computer to plan the mission. Figure 7 shows the grid pattern, which is one of the quite comprehensive flight pattern alternatives.

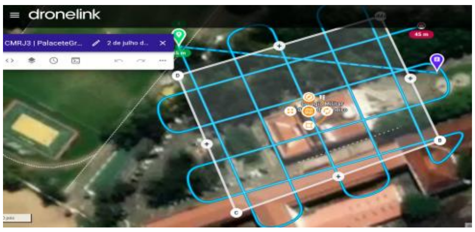

Figure 7. Grid Flight Planning in the Dronelink software.

The chosen application must automatically provide all the essential information for the model reconstruction with the drone's camera data. Manual flights were also required to circumvent another construction to the left side of the target building and near trees on the back and right side.

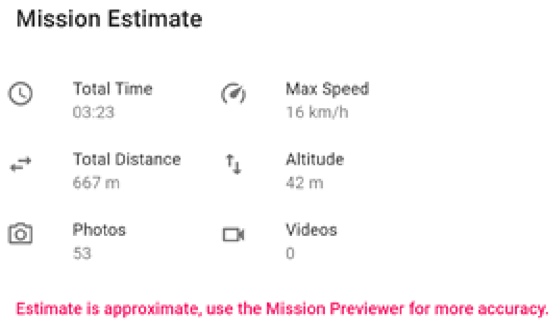

Figure 8. Mission measurements in the Dronelink app.

The solution used in this study case does not require previous camera calibration. Besides, the actual geographic coordinates of the terrain were support points taken from Google Earth images. In this way, misaligned sets of sparse dots could be fixed when they visibly did not align with the app's maps. In addition, this procedure fixed an issue while constructing points in the Agisoft Metashape software, allowing the operator to use it to perform automatic post-calibration of the cameras of the drones used. The spatial intersection was the main georeferencing used. We can align the position and orientation of two-by-two images, according to the principle of stereography. Dronelink works by allowing us to simulate missions in advance, helping to evaluate various data such as flight times, map trajectories, speeds, heights, photo shots and more. Facilitating flight execution.

Copterus was the last app tested, which works out of a smartphone. It also has several other similar functionalities to previous applications. The 4:3 photo setting was ideal because using 16:9, there is pixel loss, compromising images' overlay. Some Mavic Air 2's features, such as smart photo and the 48 Megapixel, which help reduce the noise of photos, are not available on the Mavic Pro drone. The digital negative photo (DNG) feature was also not available. Those features are also unavailable options on the Spark drone.

Briefly, the mathematics involved is in the relationship between drone translations and rotations on the three X, Y and Z axes that occur with drone movements and the fixed target building. The focal length, the number of camera sensor pixels, and the sensor dimensions are also fixed and associated with the fiducial system. Therefore, using the information above is possible to construct a projection of the camera perspective center (CP) to the points of the actual object.

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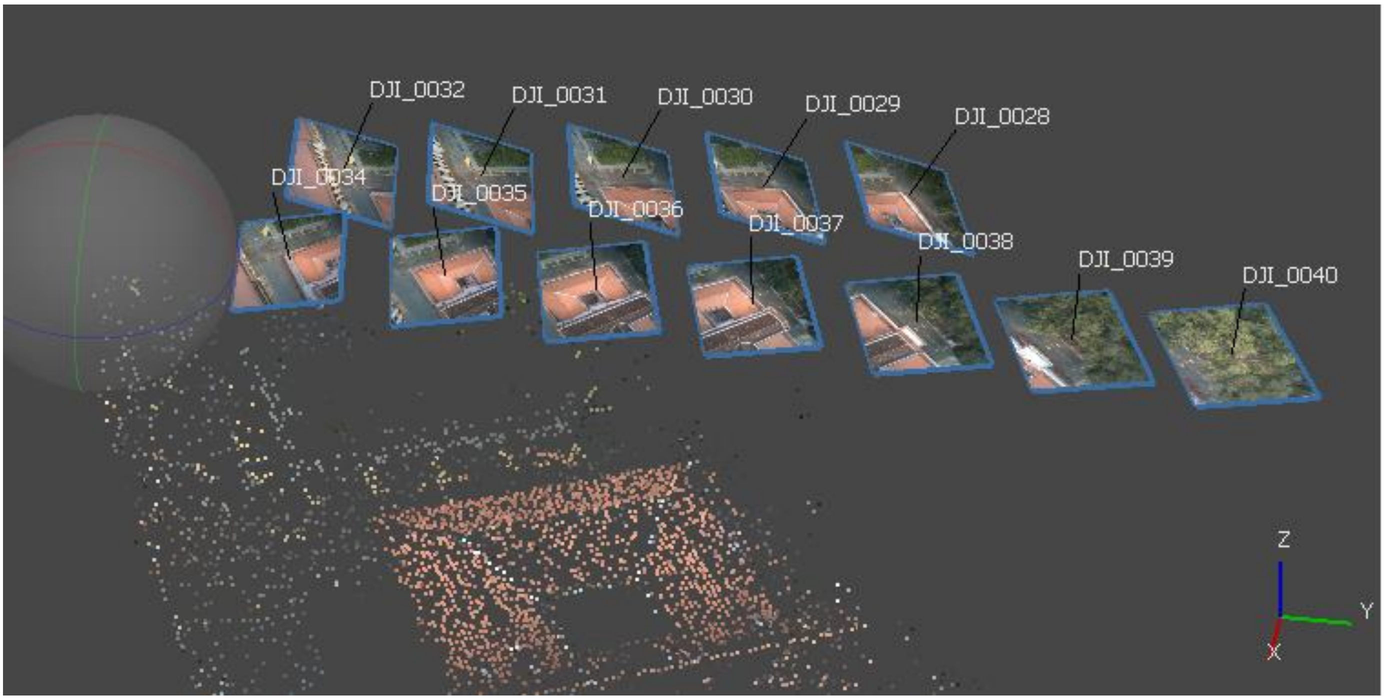

Figure 9. Drone's image shots position in relation to the object.

The drones used have an essential feature of storing the coordinates obtained by the GPS and the height in each image, facilitating the photos' alignment by the 3D reconstruction programs.

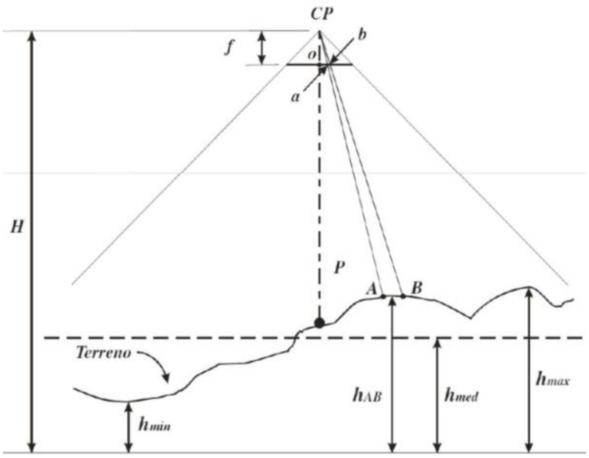

Figure 10. Geometric relationship between photo and scene when terrain is irregular [3]

The similarity of triangles can calculate the relationship for the irregularity of the heights found in the construction. Figure 10 shows this approach which can be arranged in the following equation [3]:

$$\frac{f}{H - h_{AB}} = \frac{ab}{AB}$$

Epipolar geometry [5] and stereo vision concepts of stereo vision are used here to reconstruct a 3D model such the one described in Figure 11. Then, taking the homologous points in 2D images, it is possible to describe the 3D view of the object by two cameras in different locations and the points projected in space.

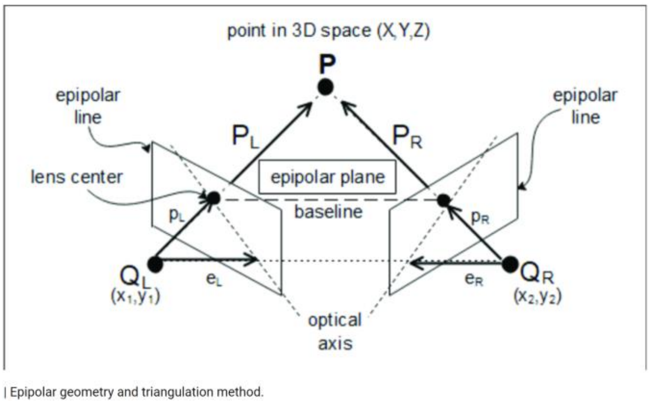

Figure11. Epipolar Geometry [9]

With the knowledge of the dimensions of the pixels, we can transform this system and the fiducial equation below:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} Sx & 0 \\ 0 & -Sy \end{bmatrix} \cdot \begin{bmatrix} x - \frac{W-1}{2} \\ y - \frac{(H-1)}{2} \end{bmatrix}$$

Where: x´ and y´ the coordinates of the fiducial system. Sx and Sy are pixel dimensions, and X and y are the coordinates in the screen system as described in Figure 15.

B. 3D Reconstruction Tools

This study case used three 3D reconstruction software named Meshroom, Open Drone Map and Agisoft Metashape, with the latter presenting satisfactory results.

texture. Finally, the Metashape algorithm does a very elaborate job analyzing homologous points, which leads to good results.

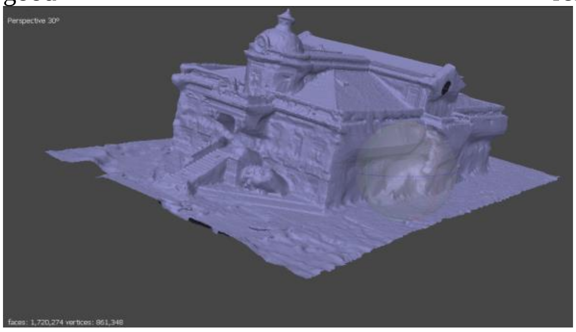

Figure 12. Mavic Pro 249 images in 16:9 format

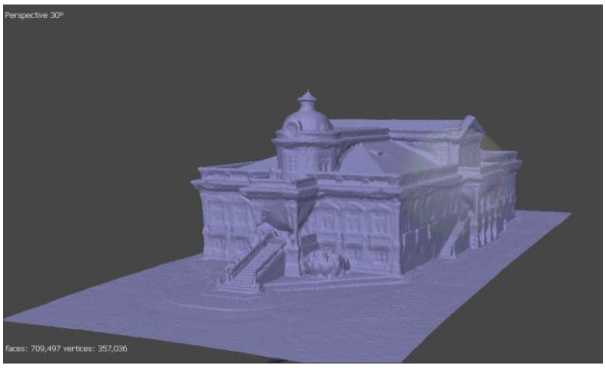

Figure 13. Mavic Air 2 697 images in 4:3 format

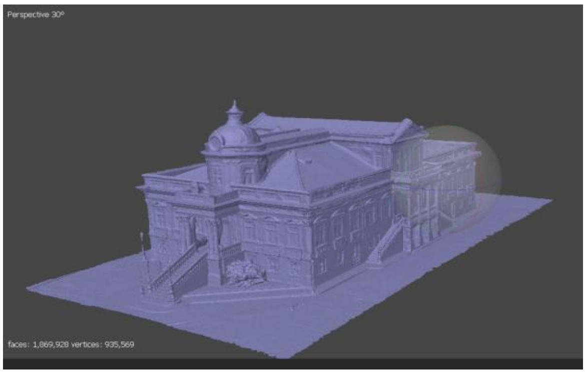

Figure 14. Mavic Air 2 with 526 images, separated by groups of object faces.

Metashape provides an easy workflow. The operator starts by adding the drone photos. After that, it is possible to use the software photo evaluation and select only images above 70% quality. Next, it is necessary to check the geographic coordinate system.

The software workflows proceed with alignment, where the sparse cloud is generated. After that, the workflow includes a dense cloud of dots, mesh construction and

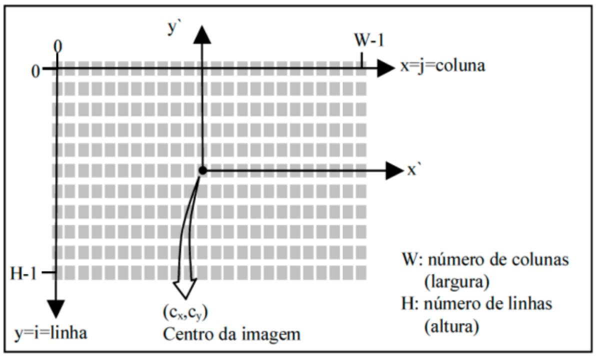

Figure15. Screen Coordinate System [1]

There was a problem using the images from the Spark drone obtained by the standard application. Even using the additional manual photos covering the lack of images on the side and background of the building, there was noticeable truncation. Marking common points concerning geographic coordinates and height obtained in Google Earth in the images manually could fix this problem, generating a considerable increase in manual work. The Spark drone also has an older sensor that only has jpeg images, generating more unsatisfactory results.

The Meshroom software presented the most automated operation. After adding the images, the operator follows a pipeline. However, this was the most time-consuming processing, making it difficult to perform many variations in the tests. Moreover, the result presented was not superior to that of the other tools. However, it is free software that, together with Meshlab, provides many possibilities for generating and correcting the 3D model. It was necessary to correct the model delivered in Metashape, which does not make corrections to the delivered part. Therefore, it is an alternative to use Meshlab in the sequence of generating the model for printing.

It is also noticeable comparing Figures 13 and 14 that using the 4:3 (dimension 4000 x 3000) instead of 16:9 uses more pixels, providing better results. Figure 15 also shows that tagging the images with the building faces groups outputs a more efficient model generation.

The Open Drone Map (ODM) software is a free software like Meshroom processing workflow. With few commands, the algorithm starts processing and delivers the finished 3D model. ODM and Metashape provide a lot of processing information, including detailed reports. Thus, they are potent tools that can be used to construct the orthophoto of the terrain. All programs worked in Windows with the main bottleneck in RAM. It takes a long time to process, even with a machine with 16 Gb.

III. RESULTS AND DISCUSSION

The result of the three-dimensional models generated from the historic construction had to adjust their mesh to be printed on a 3D Fused Deposition Modeling (FDM) printer.

Figure 16 shows the file on the Simplify 3D software was with the appropriate firmware settings for operation with the printer. Figure 17 shows the Sethi3D S3 software also tested for the printer model.

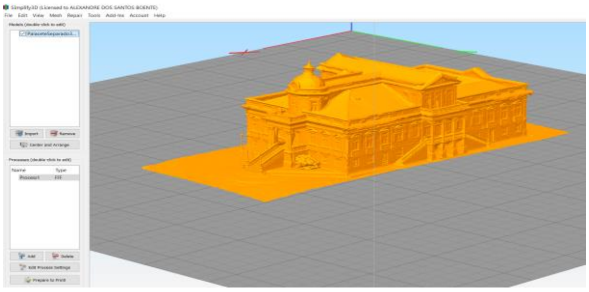

Figure 16. 3D model in Simplify 3D.

One application that worked well in automatic mode and running online was Netfabb from Autodesk. Microsoft 3D Printing works similarly but is more time-consuming and fails to process multiple STL file submissions. The Ultimaker Cura print program allows the installation of a Mesh Tools plugin that solves some problems of the generated part. The Slic3r program fixes some problems automatically. The Meshmixer program analyzes and fixes some parts automatically and allows for more advanced adjustments. MeshLab works similarly. Blender is also a free tool that allows more complex adjustments to the part.

We verified that the quality of the 3D reconstruction is directly proportional to the image quality. We must consider the quality of the camera, quality of light available at the time of taking the photos. It is important to adapt the speed of the UAS with its speed of taking images and their archiving processing.

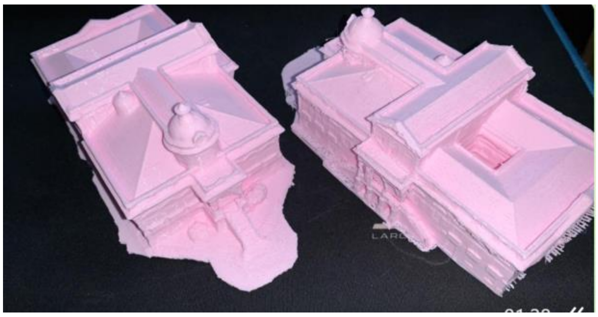

Figure 17. Full-scale printed model on Sethi3D S3.

IV. CONCLUSION

The study case of the 3D modelling of the "Palacete Babilônia" allowed an analysis based on the generation of 3D models of the historic building. The present paper presented a study on the benefits of using photogrammetry with small drones and the challenges encountered when working on the generation of the 3D model. The result includes 3D printing of the building for later preservation. In addition, the present work shows different applications and software that is constantly updated. Finally, it evaluates how each of them delivers the final model. The methods presented here make it possible to archive three-dimensional models to preserve cultural heritage with a small budget and a reduced crew.

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