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**Evaluation of Three-Dimensional Photogrammetric Model from
Low-Cost Digital Camera Applied in the Cultural Heritage Registry**
Avaliação de Registro Arquitetônico por Meio de Modelo
Tridimensional Fotogramétrico Gerado a Partir de Câmaras Convencionais

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Resumo

As tecnologias como o Laser Scanner se destacam no âmbito de registros arquitetônicos. Laser Scanner representa um equipamento extremamente preciso, que possibilita a criação de modelos tridimensionais por meio da coleta de milhares de pontos. Por outro lado, as técnicas fotogramétricas também são utilizadas para tais fins, onde imagens são utilizadas na geração de estereomodelos fotogramétricos tridimensionais. Ambas as metodologias buscam obter representações fiéis da realidade, porém, podem haver grandes discrepâncias quanto à precisão e os custos para geração destes. O objetivo deste trabalho foi realizar uma comparação entre os modelos gerados a partir de Fotogrametria terrestre e de Laser Scanner, visando avaliar a viabilidade e eficiência de câmaras convencionais aplicadas a modelos tridimensionais voltados a fins de restituição de fachadas. Para tanto, os levantamentos por Fotogrametria terrestre e Laser Scanner foram empregados sobre as fachadas de uma igreja centenária em Monte Carmelo, MG. A partir dos produtos, observou-se que a distância entre as superfícies geradas pelas nuvens de pontos provenientes do processo fotogramétrico e Laser foi inferior a 5 cm.

Keywords: Modelo fotogramétrico tridimensional; patrimônios históricos; restituição de fachadas; varredura a laser

Abstract

The technologies such as the Laser Scanner stand out within the area of architectural registry. Laser Scanner represents a precise technology, which enables the creation of three-dimensional models through the acquisition of millions of points. On the other hand, photogrammetric techniques are also used for similar purposes, making use of images in order to generate three-dimensional representation. Both methodologies aim to obtain reliable representations of reality. However, there are potential discrepancies regarding the accuracy and costs of generating these models. The objective of this letter is to compare the models generated by terrestrial Photogrammetry and Laser Scanner, in order to evaluate the feasibility and efficiency of conventional cameras applied to three-dimensional models for facade restoration purposes. For that, the surveys by terrestrial Photogrammetry and Laser Scanner were used on the facades of a century-old church in Monte Carmelo, MG. From the products, it was observed that the distance between the surfaces generated by the clouds of points from the photogrammetric process and Laser was less than 5 cm.

Keywords: Tridimensional photogrammetric model; historical heritage; facade restoration; laser scanning

1 Introduction

Brazilian colonization has brought a large number of buildings with historical and cultural representativeness. These buildings' construction was influenced by different cultures and times, which creates several architectural styles along the country. Chagas (2014) claims that a pure stylistic compositions are uncommon, reaffirming cultural diversity that is extremely important for a society understanding. Thus, these aspects gave rise to a broad architectural history to be preserved and registered.

The state of Minas Gerais stands out in abundance of remaining architectural structures, mainly due to the search for gold and diamonds at the end of the seventeenth century, as mentioned by (Miranda, 2000). The author also emphasizes the intense religiosity formed by this people, who built the churches and chapels, started what today is a Brazilian architectural collection of great importance worldwide, as highlighted in "Late Baroque and Religious Architecture in Minas Gerais" (Chagas, 2014).

The cultural heritage of a country is a materialization of its history, and has great influence in the ideas of identity and even patriotism of your people. The Brazilian historical heritage runs serious risks due to the extension of the territory and the low investment in the recognition/documentation, preservation and restoration of the buildings, being necessary the conjunct action between national governmental entities and international organizations.

An important aspect of the theme are the registration of monuments, which store the details of the structures, which helped to compose the process of building tipping, which establishes the cultural importance of the heritage and elevates it to a category of protected properties; (Law 25/1937) and modifications, as the Brazilian Law 3551/2000, which encompasses intangible assets (Tomaz, 2008).

Detailed survey of the structure can be done through the application of several survey methods. Laser scanning, for example, is a remote sensing technique that enables the creation of three-dimensional models through the collection of large numbers of points, and can be applied for architectural

records purposes, as presented in (Medina & Antunes., 2011). The Laser Scanner is a technology conceived to creation of two-dimensional or three-dimensional models, with applications in historical monuments, archaeological sites and items linked to historical and cultural heritage (Shuler *et al.*, 2010), or even products aimed at dissemination and incentive tourism, such as virtual tours. Photogrammetry is a science or technology that uses images for purposes of measurement and describing the nature of materials.

Other approach is the use of Photogrammetry that presents an extensive list of applications and with computational advances have been used for historical heritage survey purpose, mainly by the generation of three-dimensional stereomodels via terrestrial Photogrammetry. The works of Cortes *et al.* (2007), Wutke *et al.* (2005), Campos, (2015) are examples of the application of Photogrammetry to architectural surveys.

The main contribution of this letter is show the use of two methods to validate the possibility of using Photogrammetry techniques allied to non-metric cameras for the purpose of historical monuments surveying and the use of laser scanning technique as a validation parameter of the proposal. The following sections are divided in: Section II presenting the methodology, some results and discussions; Section III bringing the conclusions.

2 Methodology, Results and Discussion

A high quality reconstruction of a three-dimensional model using Photogrammetry needs some attentions regarding the data acquisition and processing. This section presents the steps executed in this work. Considering this aspects, a series of tasks were performed: camera calibration; data acquisition, point cloud generation, data comparison; generation of final photogrammetric products, the restitution of church faces and texturing.

2.1 Experimental Area and Equipment

The object of study is the "Nossa Senhora do Rosario Church" (Figure 1 A), located in Monte

Carmelo, State of Minas Gerais, Brazil. This church was chosen due to its historical, cultural and social importance to the city. The data acquisition for the 3D reconstruction was carried out by using a Canon 600D low-cost digital camera. The reference point cloud for the evaluation of the reconstruction was obtained by a total station Leica MS-50, which is assembled with a laser scanning module.



Figure 1 A Nossa Senhora do Rosario Church B Camera Canon 600D C Total Station Leica MS-50 with Laser Scanning

2.2 Data Acquisition

For the adjustment of the internal orientation parameters (IOP) of the camera, an auto calibration was performed, being used for this purpose a calibration field according to Figure 2. The coordinates of the field targets were measured using a total station Leica MS-50, considering a local coordinate system.



Figure 2 Calibration field adapted on a wall. In total, 45 targets of 0.26 m with a center of 0.02 m²

The necessity of a camera calibration is explained by the fact that the movement of the camera and the lack of geometric stability change the alignment between the lenses and the camera body, modifying the IOP. For the church data acquisition and camera calibration the focal length was set in 18mm.

Three photographs in convergent arrangement were taken, considering all images registering all targets and varying their rotations in relation to local coordinate system (2 in landscape and 1 in portrait orientation). This configuration was used to avoid parameters correlation during the bundle block adjustment process. After the data acquisition the calibration was performed in the CC software developed by (Galo, 1993).

2.3 Arrangement for the Camera Calibration

First of all a topographic survey was established to create a adjusted polygonal aiming to provide precise points for the church scanning and photogrammetric control points materialization.

The scanning of the church was performed using the Leica MS-50 robotic total station, based on the reference polygonal. The facades control points were surveyed also based on the polygonal and materialized by printed targets over the church structure (a total of 67 targets). The photogrammetric survey (images acquisition) encompassed a series of actions: taking photos, determination of camera positions (using the total station), determination of approximate camera rotation angles (ω , φ and κ), materialization and survey control points.

In total, 46 images were captured around the church. The camera positions were spaced between 2 and 3m to each other (seeking for a overlap around 60%), and always oriented to view as most as possible the church structure. In each camera position two photographs were taken (1 in landscape and 1 in portrait orientation) aiming to cover as much as possible the facades. The distance between the church structure and the cameras had a considerable variation, from 4.5 to 15.5 m, caused by the presence of obstacles such as trees, flowerbeds and other constructions. In total, 92 were acquired and, simulta-

neously, estimated the rotation angles of the camera (ω , φ and κ) related to the local coordinate system. The determination of the cameras position was done with the use of a total station, having as support the polygonal already described.

2.4 Data Processing

This step includes the following procedures: camera calibration (IOP estimation), photogrammetric cloud point's generation, a comparison between photogrammetric point cloud and the reference obtained by laser scanning, and the point cloud texturing and restitution.

2.4.1 Calibrated Interior Orientation Parameters

The first result obtained was the internal orientation parameters of the camera and their respective standard deviations, as shown in Table 1.

Parameters	Mm	Standart Desviation (mm)	Parameters	mm	Standart Desviation (mm)
Focal	19.4	0.25	K_3	0	0
x_0	0.06	0.21	P_1	0	0.0002
y_0	-0.79	0.35	P_2	0	0.0002
K_1	0	0	A	0.02	0.006
K_2	0	0	B	-0.19	0.0057

Table 1 Calibrated interior orientation parameters of the camera

Analyzing the table is possible to observe that the values for symmetric radial distortions (K_1 , K_2 e K_3) and decentralized (P_1 e P_2), affinity (A) and non-orthogonality (B), are very close to zero. Even thought, they were considered at the photogrammetric process. However, the significant values are x_0 and y_0 (values of the displacement of the camera principal point) and the focal length, which has the greatest influence, going from 18 mm to 19.4 mm.

2.4.2 Photogrammetric Cloud Points Generation

The cloud generation and texturing processes were executed with the Pix4D Software, which uses the SIFT algorithm for models. In this software, the

92 images and their related information, including the calibrated focal length and other IOP, coordinates and estimated Euler angles are used for input information during the generation of a photogrammetric point colud (Figure 3).

In order to guarantee a better quality of the cloud generated, the 67 control points were used. From these set, 14 were used as checkpoints and the other 53 were used in a point cloud adjustment performed by the software, by means of a relationship between the coordinates of the control points and the coordinates of their respective targets in the images. It is important to highlight that who defines the image coordinate of the target in the software is the user, being a supervised action.

The value of the GSD (Ground Sample Distance) for the photogrammetric survey is an important variable to obtain a visual and geometric quality of the model. This variable is inversely proportional to the level of detail obtained. In this case, the GSD value was 0.36 cm, or it is possible to clearly display only objects and features larger than 3.6 mm.

The capture point coordinates were determined using a total station. The camera position had the following standard deviations: 0.033 for ω , 0.024 for φ and 0.041 for κ , given in degrees. While the 53 control points presented an error projection around 0.5 pixel (0.002mm).

In addition, the 14 points used as check points showed an error ranging from 0.2 to 0.7 pixels, with an average of 0.5 pixel. The Pix4d software performed adjustments of all the coordinates initially inserted in the search of a precise model. The closer the initial value adjustments, the better and faster the model is consolidated.

With the adjusted coordinates and the overlays of the images, the software generated a point cloud and its densification, as shown by Figure 3.

2.4.3 Point Cloud Evaluation

In order to validate the proposed methodology, a comparison was made between the point cloud generated by Photogrammetry and the point cloud



Figure 3 Densified point cloud of the facades of the Nossa Senhora do Rosario Church

generated by laser scanning. It is important to highlight that the data collected by laser scanning refer only to four sides samples of the church, and they were used as a basis for comparison, being restricted to this portion of the representation of the church. This comparison is valid since the results are reliable, although they are subject to intrinsic errors to the total station, such as: no verticality of the main axis, no horizontality of the secondary axis, collimation error, atmospheric refraction, among others.

The comparison was made using CloudCompare software that facilitates the comparison of two different point clouds by having specific tools that help identifying the differences between the models (photogrammetric and laser scanning). Basically, the software generates a product containing the distanc-

es between one point cloud and another. In order to perform a statistical analysis of the data, the point clouds were processed using the QGIS software by a tool for selection of minimum and maximum values of the distances.

The coordinates of each profile were manipulated to visualize the horizontal variation of the vertical points that align and represent the wall, as Z (height). In order to increase the homogeneity of the data and make it possible to obtain correspondence in the two models for all points, an interpolation using TIN (Triangulated Irregular Network) was performed into QGIS. Thus, with the two models of each facade aligned, 30 points were arbitrarily chosen on each facade through an identification tool. The two given values in Z for each X, Y coordinate

identical to the 30 points were stored, creating a sample of 30 points for each wall/facade.

Finally, these set were used in the statistical calculations of linear regression and RMSE (Root Mean Squared Error) performed separately and considering all values as a single group. These calculations were performed considering the formulation expressed by equation 1:

$$RMSE(\%) = \sqrt{\frac{\sum_{i=1}^n (x_{ref} + x_{med})^2}{n}} \quad (1)$$

Where, x_{ref} and x_{med} represent the laser scanning point cloud and photogrammetric point cloud estimated value, respectively, and n is the number of samples.

The distance comparison tool, applied with CloudCompare, allows an analysis of the distance between the points of the two clouds. This software provides a graph corresponding to the number of points in relation to the distances. Table 2 gives a more detailed description of this relationship between percentage of points referring to the distances between the cloud points.

This comparison showed that approximately 30% of points presented a difference less than or equal to 1 cm, while slightly more than 50% presented a difference smaller than 1.5 cm, 80% presented distance less than 0.3 m, the difference of other 90% corresponded to 0.5 m and less than 2% presented variations greater than 0.1 m.

From the distance data, we obtained an average of approximately 0.028 m, the value that most predominated in the difference between clouds was 0.006 m. These results show that the photogrammetric data have been able to approach considerably the laser scanning data.

The plot of points in relation to the difference in meters, also obtained from CloudCompare comparison tools, allowed the analysis of the distances in a color scale, therefore that colder colors correspond to a shorter distance and warmer colors at larger distances. This scheme of visualization (Figures 4 A, 4 B, 4 C e 4 D) facilitates the analysis of the distance between clouds belonging to each facade of the church.

Percentage (%)	Distance (m)	Percentage (%)	Distance (m)
9.8	<0.005	86.5	<0.045
30	<0.01	91	<0.05
50	<0.015	93.5	<0.055
63	<0.02	95	<0.06
72	<0.025	96.5	<0.065
77	<0.03	97	<0.07
82	<0.035	98	<0.075
85	<0.04	2	>0.02

Table 2 Percentage of points covered in relation to the distance from point clouds to the four faces of the church

The sample corresponding to the front of the church presented a predominance of distances below 0.5m (Figure 4 A). Nevertheless, there are some point's concentrations with bigger variation, reaching approximately 0.15 m. The right side facade (Figure 4 B) had a similar pattern to the front, however, containing higher number of points with high standard deviation. This pattern was repeated for the back and left side of the church, in Figure 4 C and Figure 4 D, respectively.

The back facade was the one that presented the highest distance values of the comparison, reaching more than 30 cm of difference. In addition, the left side had a variation limited to 0.12 m of difference.

Comparing the photogrammetric cloud and the distances, it is observed that the differences, approximately 0.15 m above the standard, correspond to regions of failures during generation the photogrammetric cloud, as shown in Figure 4 A, referring to the models of the front face of the church. This pattern was repeated for the other faces of the church (Figures 4 B, 4 C e 4 D), and the larger the void area presented in the cloud greater is the variation in distance observed in CloudCompare.

Differently from the cloud obtained by laser scanning, the photogrammetric cloud is less homogeneous and may present some imperfections. This problem may be related to the number of photographs of the region, the rate of overlap between them and especially the high homogeneity of features. An option to minimize the voids problem when working with clouds is to perform a point interpolation.

In this case, the interpolation of the two point clouds increases the homogeneity of the model, stan-

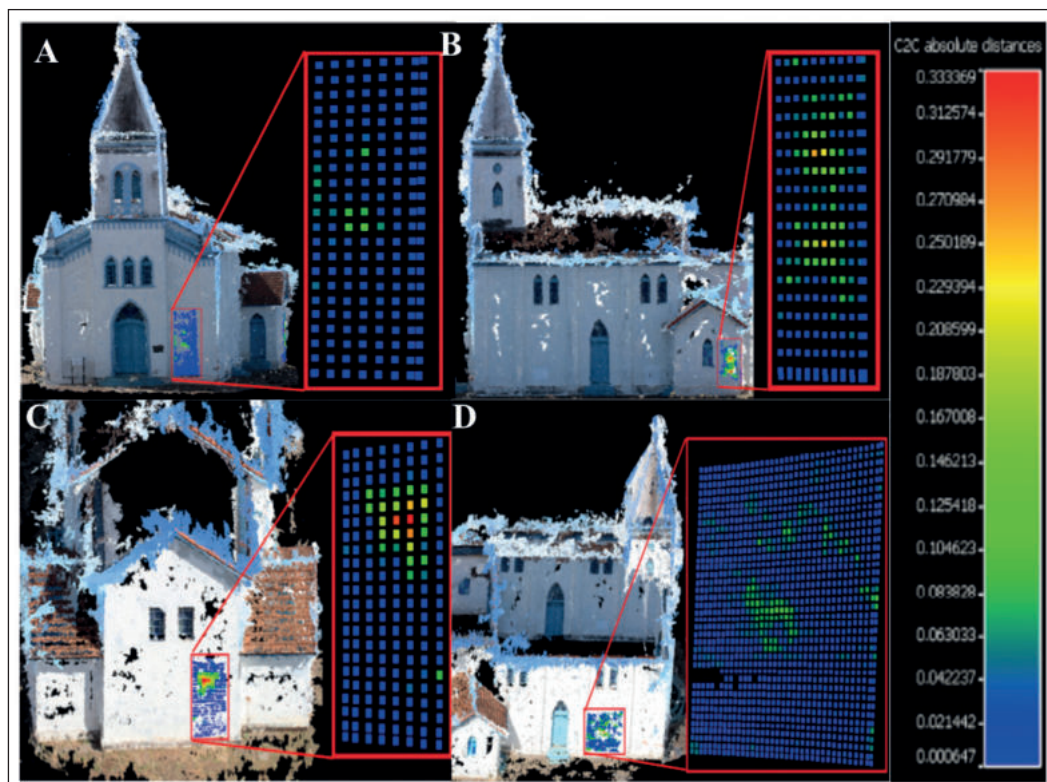


Figure 4 Comparison of the color scale distance of the Nossa Senhora do Rosario Church facades A Front B Back C Left side D Right side

standardizing the density of values, which made it possible to obtain values of the variation of the wall relative to a common position for both clouds, without problem with voids.

From this logic, thirty variation values were collected in the interpolation of the photogrammetric cloud and the third values of corresponding positions of the scanning interpolation, which were used in a statistical analysis. The Figure 5 (Graphs A, B, C and D) refer to the dispersion and the sampled data and present linear regression and coefficient of determination

The coefficient of determination (r^2) of the linear regression describes the relationship laser and photogrammetric scanning models, for each facade. The front of the church presented a r^2 of 92%, for the back one is 97.5%, the right side with 62.9% and the left side a value of 95.3%. A r^2 above 95% can be considered ideal (back and side left), and above 90% can be considered good (front case), but values less than shows that the correlation between the models is weak (right side).

This low correlation between the laser scanning and the photogrammetric data from the right side can be attributed to the low density of points in the sampled region. As already mentioned, this is related to the low homogeneity of features. The portion of the walls where the laser scanning was performed is white without the presence of marked details that help in the identification of points of similarity, making phototriangulation difficult and thus generating these void areas.

Analyzing the values for the RMSE, the proposed method had 0.029m for the front facade, 0.018m for the back facade, right side with 0.078m and left with 0.049m. This result represents the errors embedded in the clouds in relation to the dispersion of the points. Thus, the front and back faces presented minor errors, in agreement with the coefficient of determination greater than 95% and concentration of the data in the adjustment of the line, as the graphs A and B.

On the other hand, the result of the right side shows a high dispersion of the data (Graph C), with

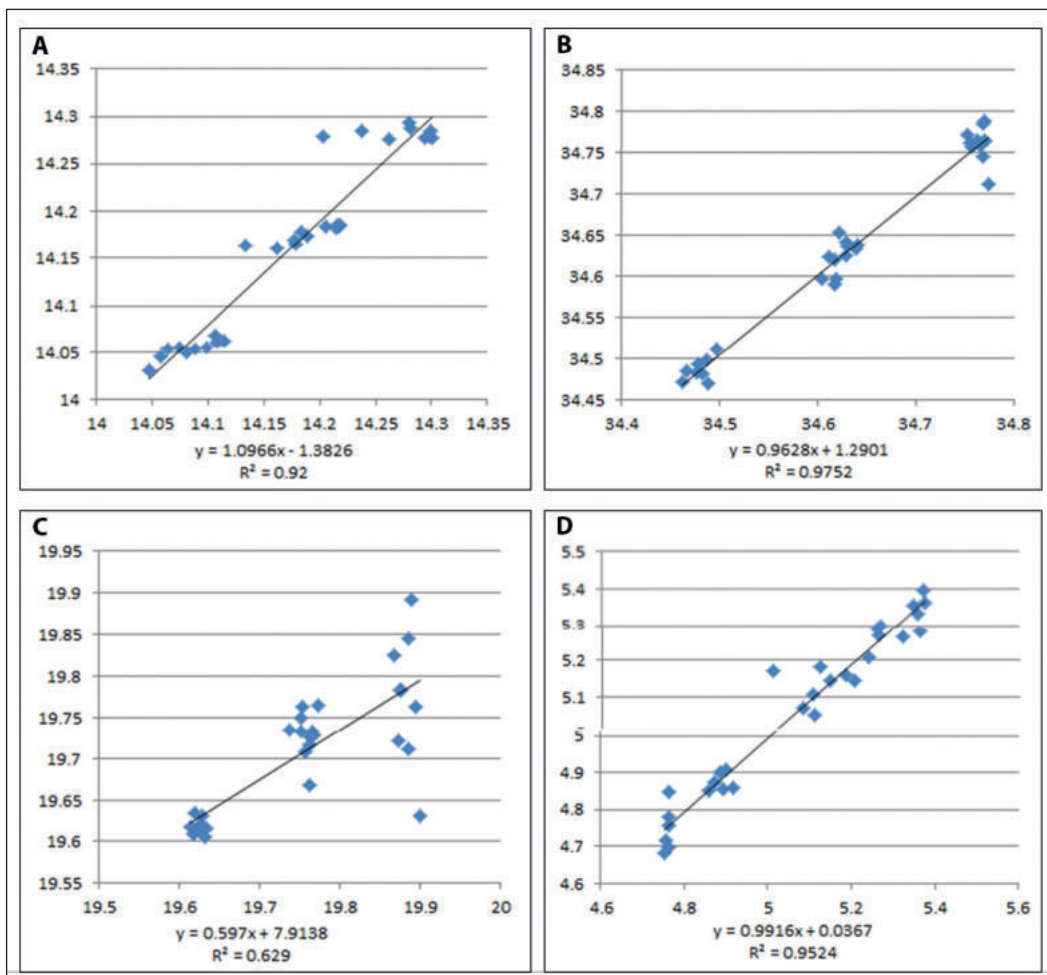


Figure 5
 Scatter plot between laser and photogrammetric scanning models of the Church facades
 A Front B Back
 C Left side D Right side

a low correlation coefficient and high RMSE. While the left side, despite presenting considerable coefficient of determination, had a high RMSE, which can be explained by the low precision in the dispersion of data (Graph D).

Even with a lower quality presented in samples of the sides of the church, when these are analyzed as a single group, there is a high correlation between the data with r^2 of 99%. This characteristic, together with the comparison of distance between clouds and visual quality, allows the validation of this methodology, which can be applied to surveys aimed at the preservation and registry of the architectural patrimony.

2.4.4 Point Cloud Texturing and Restitution

Another process carried out with this software was the texturing that brings the 3D representation

even closer of reality, with the addition of colors and textures to the cloud. Some products can be generated from the photogrammetric cloud, among these, we highlight the realistic representations as the textured surfaces (Figure 6).

The visual presentation obtained by texturing is very close to visual reality of the building. Analyzing the visible details in the structure, it is noted the divisions between the window panes (± 2.5 cm), the identification of the position of the targets used as control points (4 cm), and even the brick division of the foundation of the structure (± 1 cm). Still small imperfections are visible, such as stains on the building's paint and the detail pattern architectural can be easily extracted on the restitution.

All these details make this form of representation easily understood and accepted by society by acquiring applications for the preservation of local



Figure 6 Texturizing 3D model of Nossa Senhora do Rosario Church

history, in encouraging the conservation of architectural heritage and cultural tourism. Usually has a great impact, bringing economic and social changes to the environment.

In this letter, the three-dimensional model was not intended to represent the roof of the church, thus being presented in vain or empty. This is caused by the fact that the methodology used did not use tools to capture aerial images, such as an UAV (Unmanned Aerial Vehicle). However, the same procedure can be applied for a dataset acquired by this type of platform.

Should be emphasized that the result obtained clearly shows the main lines and vertices of the face outside the roof. With the help of CAD tools features can be evidenced, bringing the project closer to visual reality. As already observed by other authors, such as Centeno *et al.* (2006) and Wutke *et al.* (2005), the

time of capturing the images is quite relevant. The shadows provoke a discontinuity of the structure and can be difficult to identify homologous points. Images taken at times of sunshine can lead the image to have high levels of brightness or the so-called white burst, which can interfere with the quality of the photos and thus the point cloud generation.

The product generated presented a very high luminosity difference, due to the church position in relation to the sun and the difficulty of using artificial lighting. The photos of the left side presented a high level of brightness, which apparently reflected in the texturing as a greater contrast. The reverse happens with the front and right side of the church, with a lower brightness in the images and lower contrast in the model.

Another product generated was the restitution of the four facades of the church (Figure 7),

performed in AutoCad software based on the photogrammetric point cloud. This restitution is an example of possible point cloud application as used in this work. This type of product is a form of historical record, which according to Wutike *et al.* (2005), contributes to visual restorations of the structure, such as the National Museum in Rio de Janeiro – Brazil, that was destroyed during a fire in September of 2018.

The results obtained with the methodology satisfied the initial expectations that was only to identify the most severe deformations of the structure (<10 cm) and well-defined irregularities. So that the study could aid in the schematic and exact surveys of the whole building, which are applied to feasibility studies, volume, management and maintenance of facilities, as well as planning of buildings that do not have serious deformations or do not compromise the load of the structure. Moreover, the work highlights the necessity for studies that evaluate non-metric sensors in the generation of models, and the potential of these equipment for the most di-

verse applications – highlighting the cost benefit and accessibility of these set of equipment.

3 Conclusions

The realization of the architectural record is evident for the preservation and heritage conservation. The use of non-metric cameras and low cost photogrammetric methodologies are a good way for this type of record, favoring tasks in this line of research and work. With the technological evolution of recent years, high resolution cameras have become increasingly common because of the relatively low cost (off-the-shelf products). This proposal aimed at the validation of a photogrammetric product created by using a non-metric camera for surveying a historical monument.

The results of the photogrammetric survey, in terms of metric variation, were quite satisfactory, in relation to those obtained from the laser scanning, since the difference of distance between clouds was more than 80% below 3.5 cm and around 90% below



Figure 7
Restitution of
the facade of the
Church of the
Rosary

5 cm. In addition, the statistical analysis of the coefficient of determination for the whole set of samples shows that there is a great correlation between the data sampled. The visual quality of the texturing and restitution products of the church also proved to have a good quality, allowing the identification of the architectural details of the structure.

During the development of this work difficulties were encountered in the use of CC software. The software, in case of calibration error, it does not indicate what the error might be, which makes solving this problem difficult. These aspects make the calibration process a little slow. Other software used has an intuitive aspect, especially for the software Pix4D and CloudCompare. The planning process is a very important step in the execution of data collection, minimizing the time spent on field activities.

Finally, this study was important for the identification of feasible photogrammetric survey aiming architectural record. Another detail is the positive influence that this work creates in the preservation of architectural heritage of Monte Carmelo city, and the state of Minas Gerais, for the appreciation of local and national history.

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