



Digitization of historical heritage: Nossa Senhora do Rosário Church, Aracati-CE

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Abstract

The digitization of historical heritage has several advantages, such as the possibility of documenting and storing detailed information about the heritage in a digital format, allowing for better management of heritage assets. In addition, digitization can allow for the creation of accurate digital replicas of heritage assets that can be accessed by people around the world, thus promoting the dissemination and sharing of culture. The use of terrestrial laser scanning, or laser scanning, enables the digitization of these assets and the production of point clouds that can assist in various preservation and conservation activities of buildings. The objective of this work was to digitize the Nossa Senhora do Rosário Church, a federal historical heritage, using terrestrial laser scanning technology. A comparison between a 3D model generated from the point cloud and a 2D survey from 2010 showed differences in the values of room areas and wall thicknesses recorded in the models. Finally, it was observed that there is great potential to integrate laser scanning technologies with manual procedures in historic buildings. These scanning techniques and experimental tests have the power to provide much more precise and realistic geometric information.

Keywords Historical heritage · Digitization · Point cloud · 3D model · TLS

1 Introduction

Over the last few decades, the world has undergone profound technological and digital transformations, which have significantly affected several areas and institutions, including historical and cultural heritage. Historical heritage is an important part of a society's cultural and historical identity. However, these heritage assets are subject to damage and degradation over time, such as deformations caused by environmental degradation, wear and tear and landslides resulting from natural disasters, excessive human intervention during the preservation and conservation processes, in addition to the inadequate replacement of materials and shades during the restoration process [1, 2]. In recent years, significant technological advances in the area of cultural heritage have been due to society's greater interest in preserving and valuing its history. Currently, many researchers are exploring different ways to document, manage and sustain

historical heritage, making it an interdisciplinary approach to the development of culture [3]. Digitizing these heritage assets is an important way to preserve and share their cultural and historical value for future generations. [4].

Digitization allows the creation of accurate and detailed 3D models of historic buildings and objects, providing an immersive and interactive experience for the general public. The digitization of historical heritage is a relevant strategy for the preservation and dissemination of a country's cultural heritage, allowing democratic access to culture and promoting its appreciation. Digitization, in this sense, enables the creation of accurate, detailed and permanent records of historical heritage, as well as its wide dissemination and popularization through digital devices connected to the Internet, allowing quick and easy access by researchers from all over the world [5]. Digitization can also prevent the wear and tear and early disappearance of historical heritage, and reduce the risks of exposure to environmental factors or human actions [6–8]. However, it is important to point out that the digitization of historical heritage presents important challenges and limitations, such as the need for investments in technology and infrastructure, guaranteeing the security and

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privacy of digital data, as well as the management and storage of the digital data generated.

The process of digitizing historical assets begins with the choice of methodologies and technologies for acquiring quantitative and qualitative data [9]. 3D scanning technologies began in the mid-twentieth century with the first scanners using lights, cameras and projectors. However, these early scanners were limited and inaccurate, requiring a lot of time and effort to produce satisfactory results. Over the past three decades, scanners have improved using lasers, shadows and white light, making it possible to scan objects more accurately. With the development of scanners, it became feasible to better capture details and create complex models with texture and color. The main objective of this technique is to replace manual measurement, which is exhaustive and error-prone, with an automated approach, resulting in reconstructions of structures in more accurate 3D models. [10, 11].

The most used methodologies to carry out automated geometric surveys in historic buildings are photogrammetry and terrestrial laser scanning (TLS) [5]. Furthermore, manual or instrumental survey techniques are still routinely used. Photogrammetry is a technique developed to capture images at various scales. Unlike conventional scanners, photogrammetry is a much more affordable option, both financially and experimentally. It is a viable solution for anyone, as it can be performed with simple equipment, such as a camera and processing software available in mobile applications, such as a smartphone. Although the quality of the results depends on the equipment used, photogrammetry is capable of producing digital models from practically any image, thanks to processing programs for desktops with Macintosh and Windows operating systems [6, 8, 12]. The digital photogrammetry technique uses images to create 3D models based on the principle of triangulation. This process involves capturing two-dimensional photos from different angles, which are then transformed into a 3D model through specific software algorithms. These algorithms are able to identify common points in a set of superimposed photos, allowing to reconstruct the position, shape and size of the captured scene. Unmanned aerial vehicle (UAV) photogrammetry is widely used in architecture and archeology to create digital maps, 3D models, textures and document historic buildings. This technique is particularly attractive because of its affordability, as it is possible to use low-cost equipment. In addition, UAV photogrammetry is able to calculate volumes efficiently [5, 13].

Digitization via TLS is based on laser measurements (target sensor) using electromagnetic radiation and thus generates three-dimensional models of dense points of the geometry of the object under study (point cloud) with high speed, precision and reliability. There are several complementary information to the point clouds, such as color

data or individual intensity per point, as well as supporting images, which allow the user to achieve a clearer perception of the initial cloud. TLS is capable of measuring millions of points in a few minutes, while the technique's single-point accuracy is in the millimeter range. [14]. The scanning apparatus is operated through a line of sight, so it is necessary to perform multiple scans in different positions to capture all the essential details of a structure. Then each scan is associated with the sensor's coordinate system. All scans need to be aligned or registered with respect to their respective coordinate systems to be integrated into a single reference system [15, 16]. At the end of the process, 3D point cloud models are generated that allow the construction, through processing software, of Building Information Modeling (BIM), plans, sections, elevations and orthophotos of the structures [17].

Laser scanning equipment has undergone significant improvements in recent decades, both in terms of data collection speed and quality, as well as in the reduction of noise present in point clouds. In addition, methods have been developed that allow surveys to be carried out in more difficult to reach areas, using portable systems or attached to backpacks. Most laser scanners operate based on one of three different principles: triangulation, pulse (time of flight, ToF) or comparison (phase difference) [18]. Scanners that are based on the triangulation principle do not use lasers, but white light projected in a structured pattern of stripes or grids. Although these devices are not classified as laser scanners, they work in a similar way. The use of structured light offers benefits such as security and faster coverage of areas. However, it is important to emphasize that they require a controlled environment, since ambient light can affect the measurement quality, which is their main disadvantage. The accuracy of this technique is in the range of 0.03 mm to 30.00 mm, operating at a maximum distance of up to 20.00 m.

Pulse scanning equipment employs a technology that is considered simple: a beam of laser light is emitted and the time it takes for it to return is measured. The formula for calculating the measurement range is relatively simple and involves the speed of light. However, to carry out this measurement, the equipment requires a precise timing system, in addition to a sophisticated mirror and rotation mechanism that allows a general view (360°) around a vertical axis, and between 270° and 300° of view in around a horizontal axis. The "phase comparison" and pulse (time-of-flight) methods present significant differences in relation to the triangulation method. Its main advantage lies in its ability to provide virtually complete coverage around its own axis in a sweep, covering most or all of an environment, a room, for example. If, in the past, ToF measurement was slower compared to that of phase difference scanners, nowadays rates of more than 1 million points per second (1 MHz) can be achieved with technological improvements. The laser pulse emitted

Fig. 1 Nossa Senhora do Rosário Church, Aracati-CE



by the ToF method has a higher energy than the continuous wave of the phase difference, which enables the equipment to operate at longer distances, usually up to 1 km and, in some cases, even 6 km. A new trend in wrist scanners is lighter, lower spec devices like the Leica BLK360. Despite weighing just 1 kg, this scanner is capable of collecting data at a rate of 360,000 points per second and features a 150MP panoramic camera. This product is relatively affordable and is intended for both end users and professional research companies. Autodesk has followed this approach, offering a low-cost rendering software, ReCap Pro, which is compatible with this device. However, it must be borne in mind that reducing weight can compromise the stability of the scanner, as it is a device with moving parts. In equipment aimed at terrestrial scanning, the ToF method can achieve accuracy between 1 and 6 mm, at distances ranging from 0.1 m to 1 km [14, 18].

Phase difference scanners, also known as continuous wave scanners, use a different range calculation method than pulse systems, although their accuracy is similar. Rather than using time of flight, these scanners measure the phase differences between the emitted and returned signals. Therefore, they manage to achieve very high data capture rates, generally above one million points per second. However, wrist scanners are advancing in their specifications and some manufacturers are launching equipment with more competitive prices. These scanners can produce high-density point clouds, resulting in detailed scans that are useful in many applications, including asset management.

TLS makes it possible from the coordination and supervision of building projects to the preparation of records regarding projects that are in progress or completed [14]. Among

other possibilities, this technology guarantees the acquisition of three-dimensional data necessary for the construction of complex geometries of large historic buildings [5, 19, 20], studies on building facades [21], conservation of historical heritage [22–25], measurements of large-scale and highly complex structures [26], modeling of medium-sized objects present in museums [27], among other applications. Terrestrial laser scanners (TLS) are increasingly being used to identify cracks and deformations in building materials, but the quality of the scan data depends on several parameters such as material type and scan settings. The study of [28] investigated the accuracy of TLS measurements in the context of crack analysis in foam boards and common building materials such as concrete, wood and masonry, performing controlled experiments with different scan configurations to facilitate TLS planning and propose range limits for different scan configurations in relation to different building materials and crack widths. Still in the studies of measurements using TLS, [29] developed an automated method for dimensional quality assessment (DQA) of spatial structures (SFC) in the construction industry. The method uses the TLS technique to record precise data from the point clouds of the SFCs, allowing component recognition, estimation of geometric parameters and DQA. Algorithms for estimating geometric parameters for spherical joints and cylindrical tubes were proposed. The authors' method proved to be more efficient than manual measurement, which is subjective and inefficient, obtaining more accurate and complete results. The proposed method was verified by a validation experiment on 13 spherical joints and 33 cylindrical tubes. In terms of historical heritage, [30] chose the TLS system to carry out a complete architectural documentation process for Casa

Fig. 2 Image of the presbytery, high altar and altarpiece of the Church



Hazzazi in Jeddah. The main objective of the study was to provide architects and professionals with an accurate mapping of the architectural heritage of the ancient region of Jeddah, through a combination of ground laser scanning and traditional surveys. According to the authors, the methodology could be applied in other regions of the Middle East to establish conservation strategies for ancient historic buildings.

It is observed in the studies the need to include laser scanning technologies to support activities of documentation, representation, preservation and restoration of historical heritage, in view of the high precision in the measurements of complex elements and of difficult access, either due to the fragility of the structures, or by subjectivity in manual measurements. Carrying out these activities in historic buildings can be hampered by several problems, including neglect, abandonment, lack of maintenance, lack of architectural material to guide the technical staff and even wrong geometric studies. Overcoming these obstacles depends on fully identifying the problem and the steps needed to address the identified needs. Before the restoration phase, it is necessary to carry out architectural documentation and detailed studies [31–35]. And as seen, the use of TLS technologies can directly assist in obtaining qualified measurements of historical heritage, ensuring that surveys for renovation activities, for example, have a budget closer to the real, justifying their use.

The present work aimed to digitize the Nossa Senhora do Rosário Church, historical heritage located in the

municipality of Aracati-CE, using terrestrial laser scanning technology. With the help of the Revit Autodesk tool, the 3D model of the Church was generated using the point cloud data. Furthermore, a comparative analysis of the dimensions of the rooms and walls of the Church was carried out between the existing 3D and 2D models.



Fig. 3 Image of laser scanner Leica BLK 360

Fig. 4 Capture locations on the ground floor

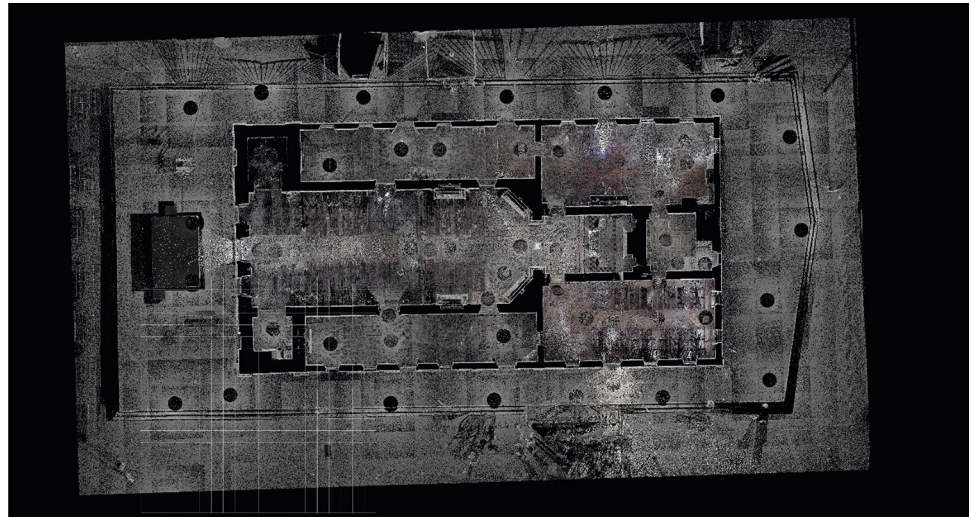


Fig. 5 Capture locations on the upper deck

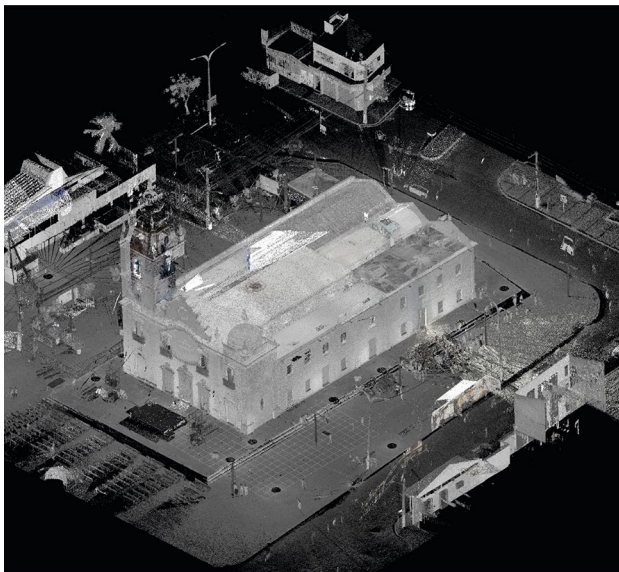
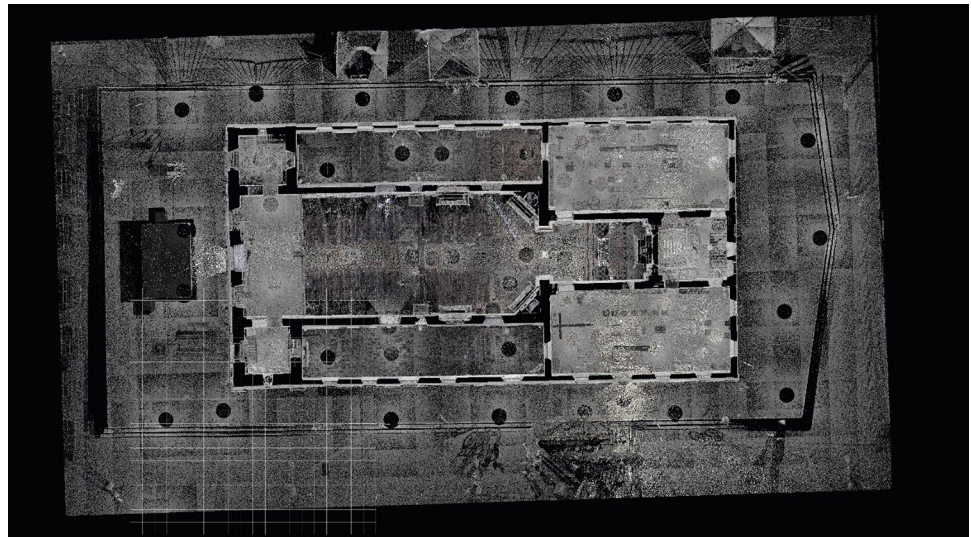


Fig. 6 Point cloud after recording and aligning all scenes

2 Case study–Nossa Senhora do Rosário Church

The Nossa Senhora do Rosário Church is a historic monument in the city of Aracati, located in the state of Ceará, in the Brazilian Northeast (Fig. 1). This Catholic church was built at the end of the eighteenth century and is one of the oldest in the city. With its baroque architecture, it represents an important historical and cultural landmark for the region. A chapel covered with straw and with brick and mud walls was built, where today the mother church is located, by charqueadores coming from Bahia and Pernambuco in 1714. In 1745, the chapel collapsed due to the floods of the Jaguaribe River, and in 1747, Father José Lopes de Lima started the construction of a new chapel with bricks and tiles produced locally. However, this building also collapsed due to harsh winters. [36, 37].



Fig. 7 Front facade of the church

In the church, there are some sculptures and a communion table made of rosewood. The flag that hangs on the door of the baptistery was carefully carved by hand. In addition, there is an entrance made of Bahian sandstone, with high-relief cushion doors decorated with details that have morphological characteristics similar to those of plants. Outside the church, a large cross was built in 1859, with symbols representing Christ's suffering during the Passion (dice, hand, rooster, mug of gall, spear, ladder and crown of thorns). In 1845, church bells were installed in Aracati. Later, in 1985, maintenance was carried out on the bells, as they had cracks. The largest bell has a mass of 550 kg, while the medium-sized bell weighs 250 kg and the smallest 80 kg. Inside the

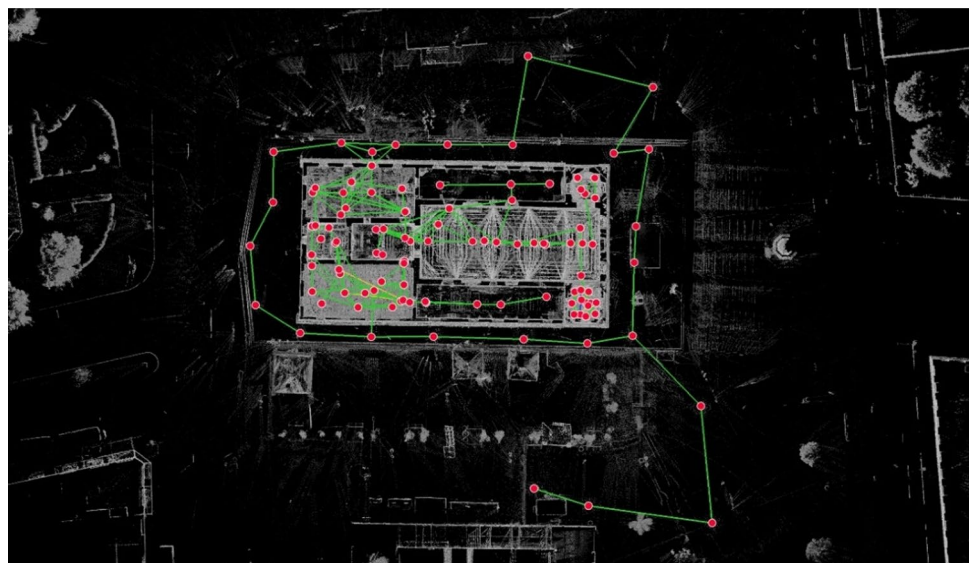


Fig. 9 Point cloud after processing step

church, you can contemplate the wooden altar with golden details in relief, where the baroque image of the patron saint, Our Lady of the Rosary, is located. The ceiling of the church is also made of wood, while part of the floor is made of burnt clay tiles [36, 37].

The Nossa Senhora do Rosário Church of Aracati follows the architectural tradition of Brazilian churches with Portuguese influence, featuring a rectangular shape that

Fig. 8 Connections between scene capture points



guarantees the unity of the structure (Fig. 2). The temple grew from a small chapel to its current form, with the chancel located in the center and the main nave surrounded by side aisles that provide access to the sacristy and the consistory. Unlike other churches in Ceará, this one does not have arches on the walls of the side aisles. The church has only one tower with pinnacles, finished in the shape of a bulb. The federal government classified the Mother Church of Nossa Senhora do Rosário of Aracati as a historic site in 1957. Today, the church is an important place of worship for the region's Catholic faithful and a popular tourist destination for those wishing to explore the rich history and culture of the city of Aracati [36, 37].

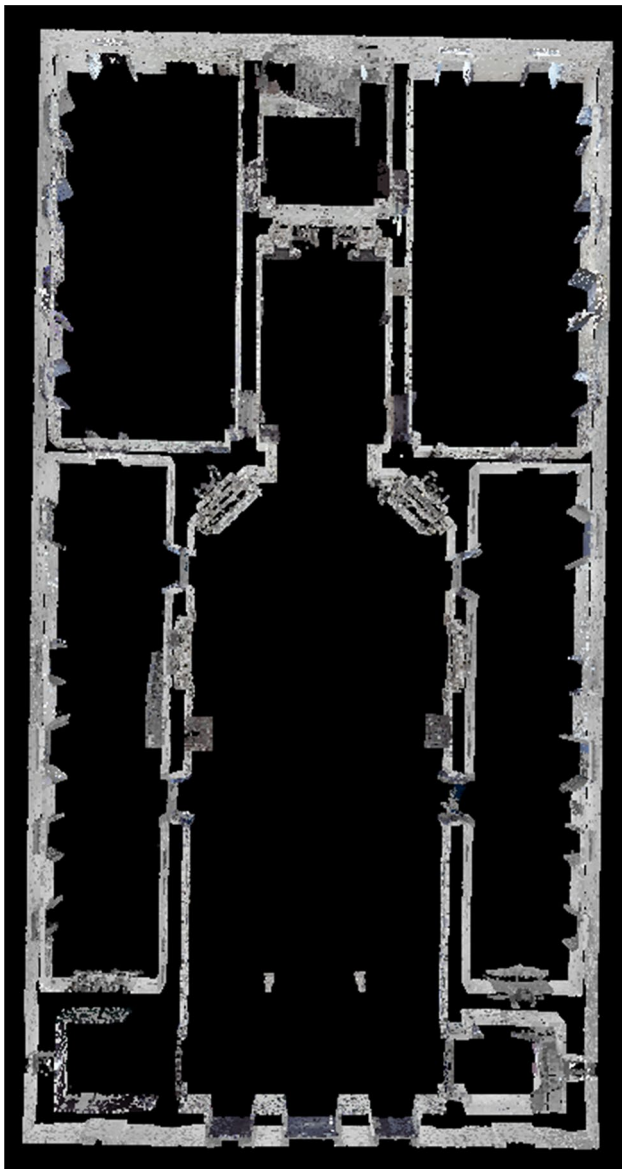


Fig. 10 Point cloud after cleaning the spaces to be measured

3 Materials and methods

In this section, the methods used for the scanning of Nossa Senhora do Rosário Church and the procedures performed during the scanning are described. The process of digitizing historical heritage is a delicate process that requires careful planning to ensure the accuracy and quality of the digital models. The methodology adopted for the digitization of Nossa Senhora do Rosário Church was divided into three stages: planning, acquisition and data processing.

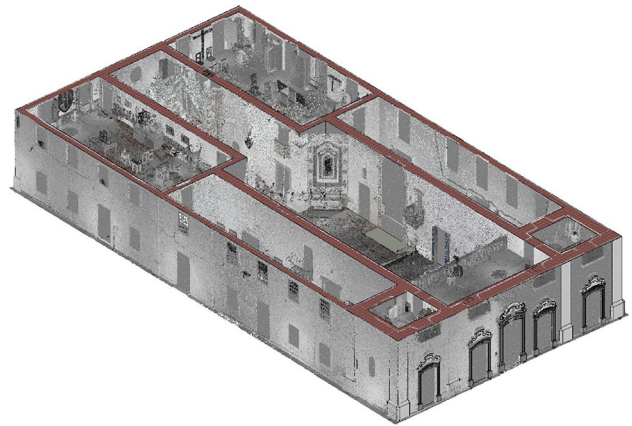


Fig. 11 3D modeling of the church from the point cloud



Fig. 12 3D modeling of the church from the point cloud

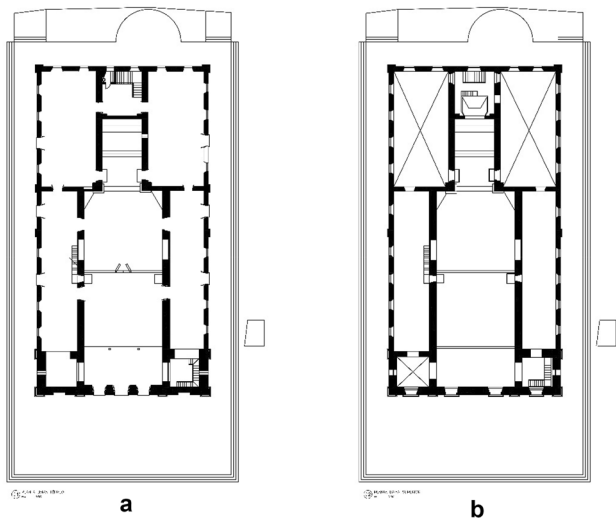
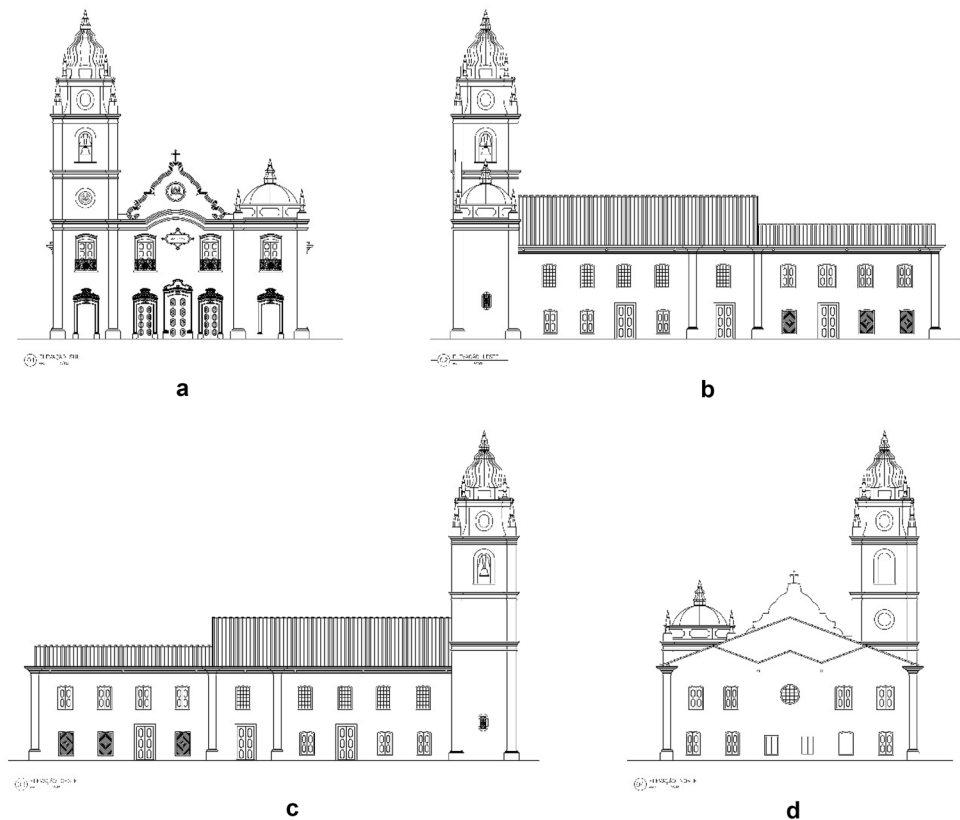


Fig. 13 Ground floor plan **a** and upper floor plan (**a**)

3.1 Planning

This stage was divided into three parts, namely: historical and archival survey, visual inspection and site recognition. The first part aims to obtain historical documents and information about the period of construction and evolution of the church, such as: construction method, materials used,

Fig. 14 Elevations: South **a**, East **b**, West **c** and North **d**

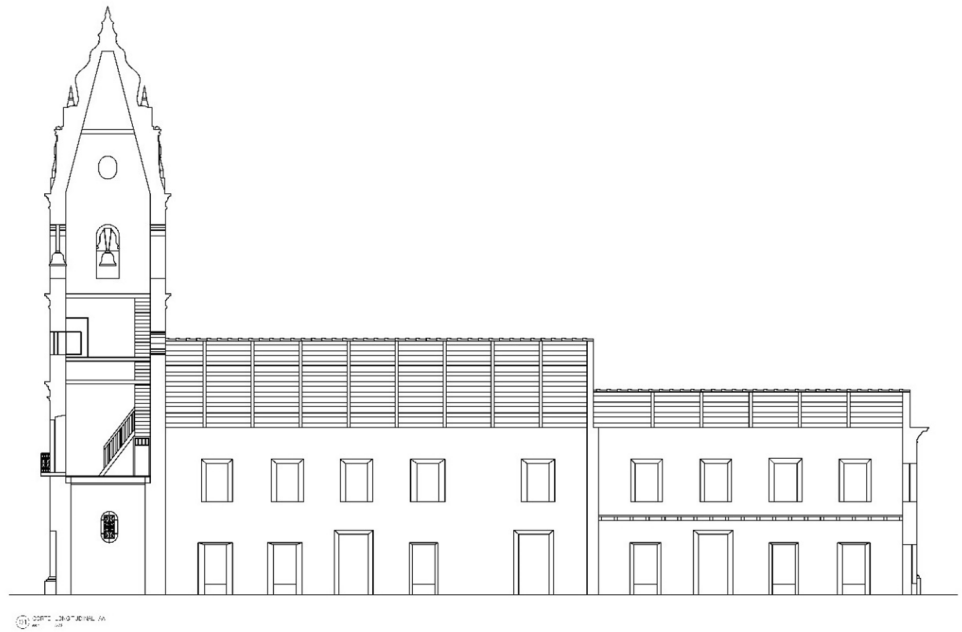


reforms, existence of hidden rooms and architectural influence. Also at this stage, architectural plans were requested: floor plan, elevations, facades and sections that would help in subsequent activities. The scanning team visited the church and performed a complete visual inspection of the structure. During this inspection, a survey was carried out of pathological manifestations and the state of conservation of the structural system of the building, as well as the identification of areas with a possible risk of collapse. The final planning activity consisted of knowing the lighting levels in the church, the possible interference of obstacles in the digitalization, such as columns, architectural elements, benches, among others, and the organization of internal and external areas, such as the removal of objects, materials and furniture not belonging to the architecture of the church.

After the analysis, a digitalization plan was defined, which included the objective of the digitalization, the choice of equipment for acquiring the scans, restricted areas and zones, plan of the scanning points, catalog of elements in need of special detailing, estimated time scanning, software for data processing, definition of the final product of scanning and the team responsible for the procedures.

3.2 Data acquisition and processing

The data acquisition and processing phase includes three main steps: data acquisition, pre-processing and point cloud

Fig. 15 Longitudinal section**Fig. 16** 3D modeling of the church from the point cloud

processing. Data acquisition is part of field work, which may involve creating sketches, direct measurements and surveying scan points. Initially, the details of the church were checked, such as the presence of doors, windows and unique structural and architectural elements that require special attention. Due to the architectural complexity of the construction and the existence of special details identified,

the scanning process was planned so that all these elements were included in the scan, even though it was not the main objective of this work, the capture of decorative elements was carried out to produce complementary works.

The digitalization of the church was carried out using the Leica BLK360 Geosystems equipment (Fig. 3). This equipment allows the collection of up to 360,000 laser scanning

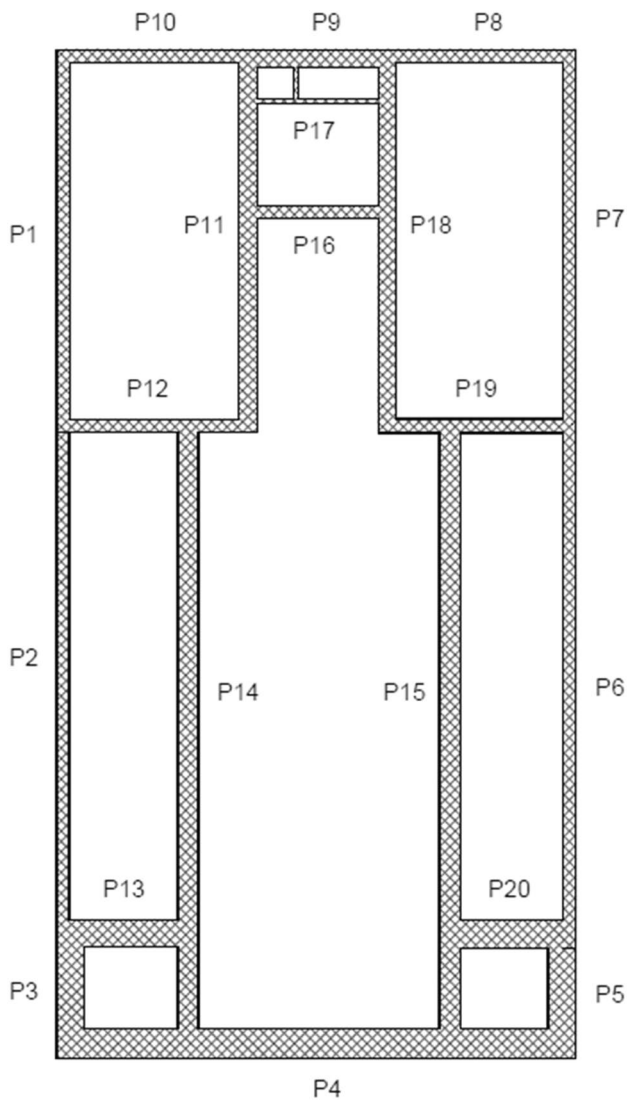


Fig. 17 Identification of church walls

Table 1 Area values of model rooms

Room	3D model (m ²)	2D model (m ²)	Difference of areas (m ²)
Yellow (Sacristy)	100.31	100.31	0.00
Blue (Aisle left)	88.34	90.90	2.56
Green (Side Chapel)	12.76	13.88	1.12
Pink (Nave)	283.80	287.67	3.87
Orange (Pantry)	20.69	20.20	0.49
Purple (Bathroom)	1.88	2.07	0.19
Red (Consistory)	98.93	101.94	3.01
Dark green (Aisle right)	83.35	85.79	2.44
Gray (Access to the choir)	11.85	13.18	1.33

points per second, with millimeter precision, in an average time interval of 3 min for each scene. To carry out the digitization, the team positioned the equipment in all the rooms and around the church, always checking the overlap between the scenes, with the locations chosen in advance in the planning. At each point, the equipment was positioned on a tripod and a 360-degree scan was performed, ensuring the scanner had a line of sight to capture all the necessary elements. During scanning, the team used the Leica Cyclone Field mobile app to receive real-time images and point cloud data from the scanner. The application enables the optimization, alignment and preview of the point cloud. The data capture steps were performed by two operators and took about 8 h to complete.

Figures 4, 5 show the positioning of all capture points (ground and upper floors).

The pre-processing phase comprises recording the digitized scenes, aligning the point cloud at planimetric and altimetric levels, and removing most of the unwanted points (raw treatment), according to the needs of the project. With

Fig. 18 3D model areas

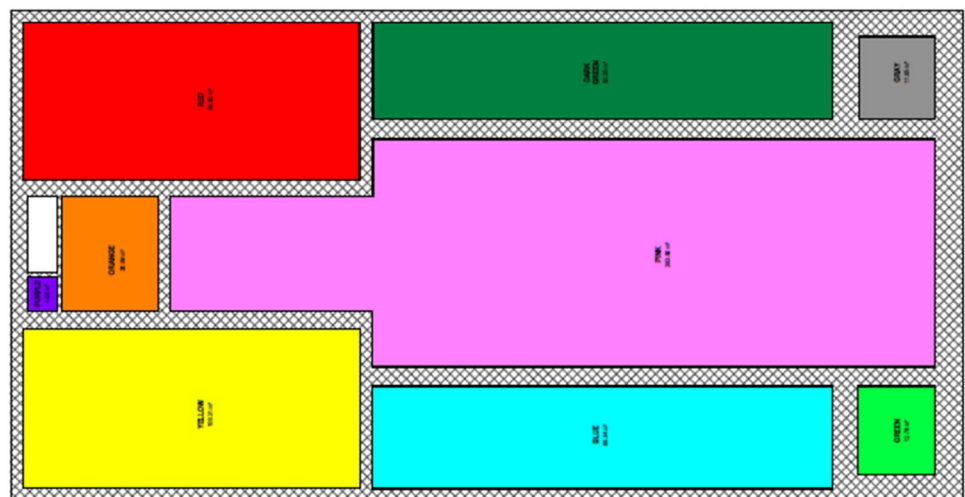


Table 2 Average values of the difference in thickness of the walls of the church

Wall	3D model (mm)	2D model (mm)	Thickness difference average (mm)
P1	570.00	550.00	20.00
P2	530.00	550.00	20.00
P3	1140.00	1100.00	40.00
P4	1230.00	1200.00	30.00
P5	1160.00	1200.00	40.00
P6	570.00	550.00	20.00
P7	570.00	600.00	30.00
P8	570.00	620.00	50.00
P9	770.00	620.00	150.00
P10	570.00	620.00	50.00
P11	750.00	800.00	50.00
P12	560.00	550.00	10.00
P13	1120.00	980.00	140.00
P14	850.00	850.00	0.00
P15	850.00	950.00	100.00
P16	500.00	350.00	150.00
P17	200.00	200.00	0.00
P18	750.00	800.00	50.00
P19	590.00	600.00	10.00
P20	1140.00	1200.00	60.00

the aid of the Cyclone REGISTER 360 software, the digitizations were registered (Fig. 6), adjusted in the planimetric and altimetric levels (Fig. 7). Through Fig. 8 it is possible to see the connection links of the digitization places, where the alignment and optimization processes make it possible to scenes are adjusted to ensure greater accuracy of the point cloud, procedures that favor the execution of modeling activities and measurement of rooms, walls and structural and architectural elements.

The final step to generate the 3D point cloud is the processing of the 3D model, which includes storing and exporting the files. In this project, it was decided to export the files in LGS format, which can be viewed in applications such as Leica TruView Digital Reality Viewer or JetStream Viewer, in addition to RCP/RCS formats, which allow the transfer of data to software such as AutoCAD and Autodesk BIM. Figure 9 shows the finished 3D model of the point cloud, after reviewing adjustments and rough cleaning the cloud.

The point cloud was exported to ReCap Autodesk software. In ReCap, which is also a point cloud treatment software, the finer cleaning of unwanted points in the church cloud was performed. At this stage, elements that were not interesting for the purpose of the project were removed, such as tables, chairs, speakers, benches, pictures, among others, leaving all rooms and spaces empty, without interference

for measurements and modeling (Fig. 10). Finally, the point cloud was exported from RCP format.

3.3 BIM modeling

The BIM modeling phase involves the tasks of the construction process of a 3D model of a building. The Nossa Senhora do Rosário Church was modeled using REVIT Autodesk software. Figure 11 shows the overlapping of the point cloud and the 3D model developed in the REVIT software.

The facades and details of the architectural elements of the 3D model can be seen in Fig. 12

3.4 2D survey

The architectural survey of the church dates from July 2010 and was provided by the Institute of Historical Heritage (IPHAN). The figures show the floor plans (Fig. 13), the elevations (facades) (Fig. 14) and the section (Fig. 15).

4 Results and discussions

4.1 3D modeling

Figure 16 shows the 3D model overlaying the point cloud of the church. The entire creation of the model was performed taking the points of the cloud as reference.

4.2 Comparison between 2 and 3D models

The comparison between the 2D and 3D models, IPHAN plans and the 3D REVIT model, respectively, made it possible to evaluate the divergences in the geometric characteristics of the church, mainly the values of dimensions (width, length and height) and areas of the rooms. Wall thicknesses were also analyzed (Fig. 17).

The areas found in the point cloud models (Fig. 18) and floor plan of the existing architectural project were also analyzed. Comparison between the models returned different values for areas ranging from 0.49 m² to 3.87 m², as shown in Table 1. The survey returned an average difference of 4.41% in the value of the measured areas.

Comparison between the models returned different values for wall thicknesses ranging from 0.00 mm to 150.00 mm, as shown in Table 2. The survey returned an average difference of 7.72% in the value of wall thicknesses.

Differences found in the dimensions of spaces and walls of the church may be the result of incorrect measurement practices, lack of attention in the use and positioning of equipment, access to masonry made difficult by the presence

of architectural elements, interfering with direct measurement, among others.

5 Conclusions

Through the study carried out at Nossa Senhora do Rosário Church, it was possible to verify that the use of terrestrial laser scanning technology proved to be promising in geometric survey activities of historic buildings. Thus, it can be concluded that:

- Laser scanning provided dimensional information and data needed to build a highly accurate 3D model of the church;
- With the use of REVIT, it was possible to identify dimensional differences between the observed models and accurately model complex architectural elements;
- The geometric survey of historic buildings using manual measuring equipment can return inaccurate metric information, which allows errors in the generation of budgets and quantities;
- The study shows good integration possibilities between laser scanning technologies and manual procedures in heritage buildings. Scanning technology and experimental tests can effectively provide geometric information closer to real ones.

Author contributions Tallis Rubens and Gilmário wrote the main manuscript text. All authors reviewed the manuscript.

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Data availability The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request. The article titled “Digitization of Historical Heritage: Nossa Senhora do Rosário Church, Aracati-CE” has Tallis Rubens as the corresponding author. Our aim is to promote transparency and collaboration in scientific research, and therefore, we are ready to share the underlying data of this study. We believe that the availability of this data can benefit the academic community and other stakeholders interested in the field of historical heritage and digitization.

Declarations

Conflicts of interest The authors declare that there are no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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