



Assessment of metric accuracy on data acquisition using point cloud: an application to the José de Alencar Theater

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Abstract

The data acquisition process is an important step in capturing information, especially in regard to historical heritage documentation. These buildings often have complex structures and little collection, which makes the geometric survey process in the traditional way even more difficult. Currently, studies have been conducted using a 3D terrestrial laser scanner (TLS) to capture geometric information to generate point clouds and serve as a basis for analysis, including using BIM and facilitating this documentation process. The paper was developed from a theoretical basis on the subject and application, performing a metric evaluation comparing existing point cloud and 2D surveys to generate a database and propose a method to improve dimensional inspections through point clouds in historic buildings, where it was possible to note some differences in shape and measurement between the two surveys. The study was validated on the metallic facade of the José de Alencar Theater.

Keywords Data acquisition · Documentation of cultural heritage buildings · Point cloud · Terrestrial laser scanner

1 Introduction

The process of documenting and diagnosing historic buildings is important for the conservation of cultural memory, as well as to support intervention measures, such as maintenance, retrofitting, and repair. The geometric registers of a building are essential for decision-making. The survey process in architectural heritage is performed in traditional ways, in general, as records of 1D and 2D metrics. In this scenario, there is a loss of information because the historical building elements usually present irregular shapes, which

can be a limitation of the information survey. In addition, structures can present various types of damage that need to be accurately documented [8]. Many research tools can be used to document historic buildings, such as terrestrial laser scanning (TLS), an emerging technology over the years that has improved the speed, quality, and accuracy of this process [9].

Terrestrial laser scanning (TLS) can circumvent these problems of survey and loss of information, mainly due to the increasing use of laser scanners. Along with this, there are new concepts within historic buildings such as building information modelling (BIM), which represents an evolution of the geometric model, having the potential to make architectural documentation complete and more consistent, making it easier to access and update data [8]. The use of digital documents provides the opportunity to update and extend data with long-term resource savings [2].

Digital documentation goes through some stages that can, according to [9], be summarized in two phases, starting with the acquisition of all the necessary data using a variety of capture tools and then the interpretation phase, in order to convert the data of a heritage building into useful information that can help build an understanding of the building. The data acquisition phase becomes important because all the other information needed for the analysis of the building is extracted from it, so special attention must be paid to the

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data survey. This phase aims to extract from the buildings the information relating to physical characteristics, historical, cultural, social aspects, among others; there are some survey methods for obtaining the physical characteristics, such as direct measurement, topographic methods, photogrammetry, and laser scanning [8].

In historic buildings, TLS has been used to collect spatial data on object geometries in the form of point clouds, rapidly providing large purely geometric datasets with a high level of detail [7]. TLS is the latest advancement in non-contact measurement of 3D object geometry, such as techniques to acquire point clouds and generate surface geometry [12]. Literature reports indicate that TLS has been used for different analyses, usually combined with BIM, such as in structural performance studies using finite elements such as the one performed by Ref. [15], as diagnostic support [6], for use in facilities management (FM) [16], and in energy retrofits in existing buildings [2], among other applications, all analyses highlighting the importance of the information capture process.

With that said, there are some works that analyze survey methods by taking different approaches, such as the work by Ref. [3], where a BIM model of a historical bridge is produced from different types of data acquisition. Nguyen and Choi [4] performed a comparative analysis between surveys using point clouds with as-built 3D CAD data, and Tucci et al. [14] described a study to evaluate the metric accuracy, using 3D scanning and photogrammetry, of a highly complex sculpture: the wooden statue “Maddalena” by Donatello, kept in the museum of the “Opera del Duomo” in Florence.

However, records of cultural heritage digitization strategies outside of the Europe zone are not easily reported in the literature. This paper’s novelty consists of comparatively evaluating two methods of data acquisition on a historical building, taking into account two existing surveys, 2D and point clouds by TLS, thus assisting in building a database

that can contain and correct different information, such as geometry, photo files, and structures, among others. Additionally, we propose an improved method for as-built dimensional inspections of historic buildings, which usually have no or little collection, using laser scanning. The study was carried out on one of the facades of José de Alencar Theater, a building of great historical and cultural value.

2 José de Alencar Theater

2.1 Brief history

In the late nineteenth century, Fortaleza, located in the state of Ceará, Brazil, was experiencing a cultural atmosphere. This process was one of the motivations for the creation of a new and large theater, which at the time was an important architectural remark [1]. José de Alencar Theater was built between 1908 and 1910 and opened on June 17, 1910. Due to its artistic and cultural relevance, it was classified as a national monument by the National Institute for Historical and Artistic Heritage (IPHAN) in 1964. The structure was made of steel and cast iron, designed and produced in Glasgow, Scotland, and imported from Paris, while the ceiling lining is made of wood [5].

Since the theater opening, the building suffered conservation problems and was subjected to several interventions in 1918, 1938, 1956, and 1974, the largest one being carried out from 1989 to 1991 [5]. According to Bezerra et al. [1], although the theater was listed in 1964, a survey of its architectural complex was only done in 1969, produced by students from the Architecture and Urbanism of the Federal University of Ceará (UFC), under the guidance of architect and professor José Liberal de Castro, who had requested the granting of the listing. This survey was essential for the beginning of the restoration in 1973 (Fig. 1), when landscape designer Roberto Burle Marx designed the first version of

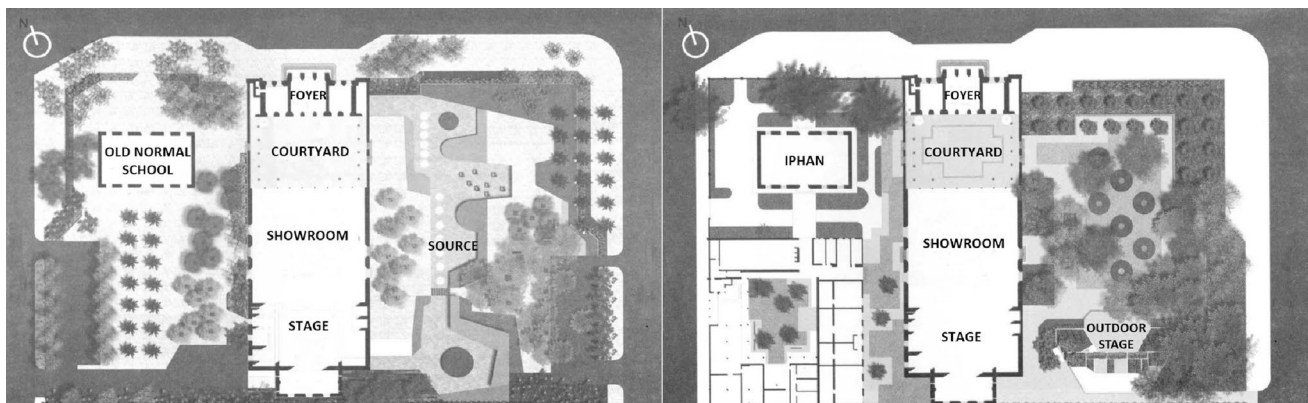


Fig. 1 1973 project and 1990 project, respectively. Adapted [1]

theater gardens, the spectacle garden, with a large water mirror and a luminous fountain. The project started in 1990, with the new, utilitarian garden, which diverges completely from the first one, without the fountain and with a simpler proposal (Fig. 1).

In 1989, the lack of maintenance brought the theater to a compromised and risky situation and urgently needed restoration. At the time, an inspection was carried out where serious conservation and operational problems were found [4]. There were ceilings with old decorative paintings threatening to collapse, the metallic facade was deteriorating, the presence of humidity in parts of the roof compromised the structure, and the electrical installations and the window frames needed repairs, among other problems. The solution chosen in 1989 was a deep intervention to recover the historical identity of the building, bringing it closer to what it was in 1910 [10]. Figure 2 show examples of deteriorated parts in 1989.

2.2 Case study: description

The José de Alencar Theater is located near the José de Alencar square in the center of Fortaleza, the capital of Ceará State (Fig. 3). The structure has an area of 3800 m² and consists of two blocks separated by an inner courtyard. The first is the foyer with a facade giving access to the square, with two floors. The second block, with a metallic facade with four floors, gives access to the showroom, and the building has 5 levels: basement, second floor, friezes, boxes, and tower [5].

It is a construction that reconciles the use of masonry on the walls with a cast iron structure and a wooden roof; on its right side is located the large garden designed by Roberto Burle Marx [5]. Figure 4 shows the architectural



Fig. 3 Localization of José de Alencar theater

layout with the rooms and the image of each location, taken and adapted from the 2018 conservation project provided by Iphan. The theater is rich in ornaments, and the iron structure contains various details and decorations (Fig. 5).

Both facades feature many decorative details and styles reminiscent of their period. The case study in question is the metallic facade, one of the major focuses of the 1989–1991 restoration, measuring approximately 16 m high and 25 m long, with elements in the Art Nouveau style, one of the most significant examples of iron architecture in Brazil [1], of great importance in preserving the memory of its time. It is also formed by a glass arch, with an elaborate decoration with the symbols of music and theater [5], as illustrated in Fig. 6.

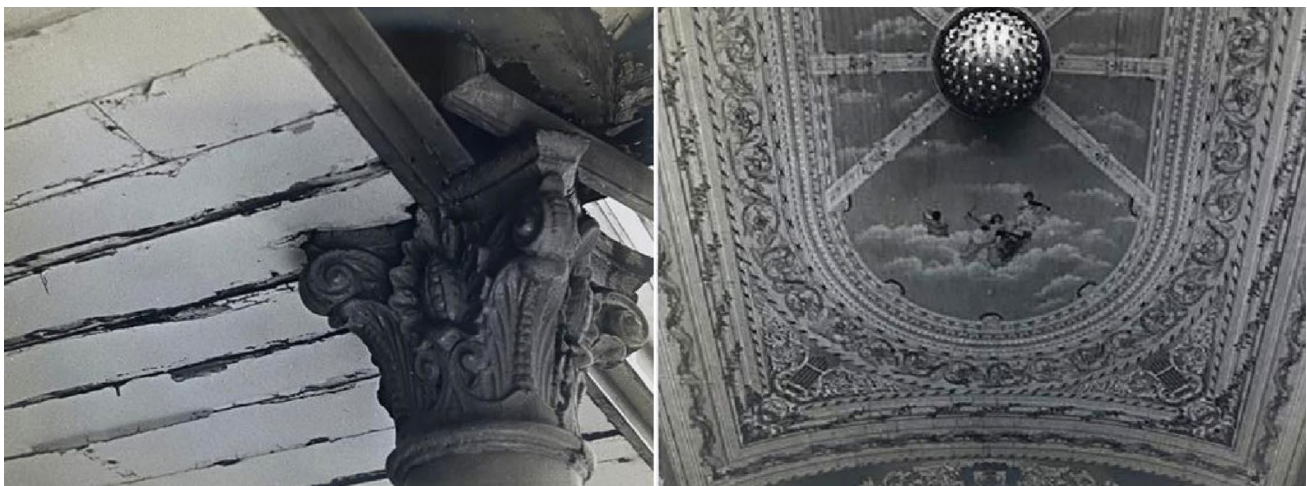


Fig. 2 Examples of deteriorated parts in 1989. In this order, damage in the wooden structure and wooden lining with compromised painting due to the presence of fungus caused by water infiltration [4]

Fig. 4 Architectural layout of José de Alencar theater

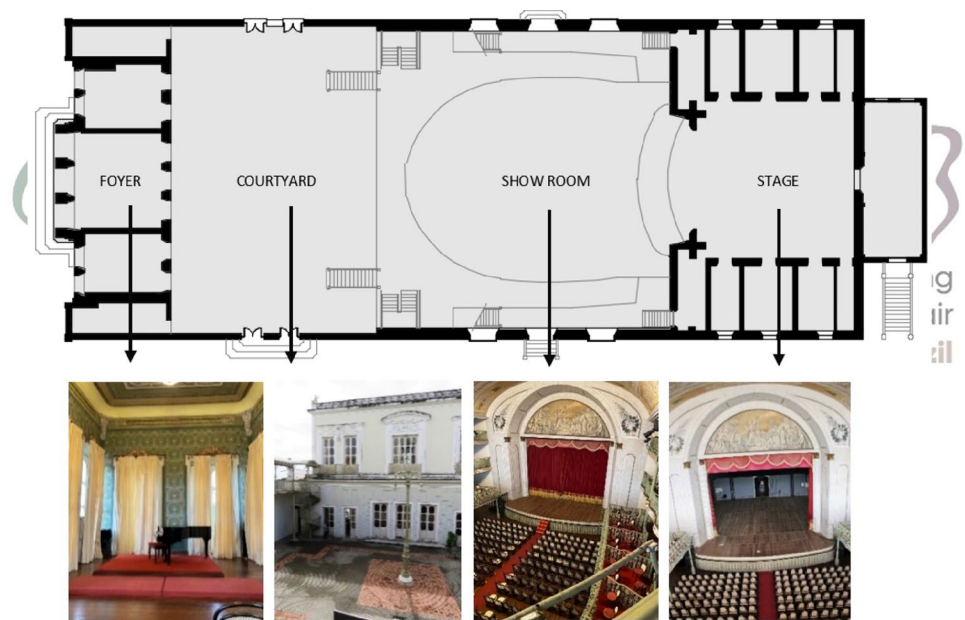


Fig. 5 Examples of adornments of foyer, show room, foyer façade and metallic facade of the showroom

3 Data acquisition

The phase of planning and data acquisition is essential for architectural documentation, especially for historic buildings and cultural values. According to [8], this phase aims to extract from buildings information about their physical

characteristics, their relationship with the surroundings, historical, cultural and social aspects, among others. The survey of physical characteristics, such as geometric properties, and the state of conservation requires some methods that, according to the same author, are the most used and appropriate: direct measurement, Global Navigation Satellite System (GNSS), digital photogrammetry and



Fig. 6 Metallic façade of the Jose de Alencar theatre

point clouds obtained by Dense Stereo Matching (DSM) or laser scanning, depending on the existing conditions for the survey.

3.1 Methodological procedure

For the analyses, the study uses data obtained through field visits and documentary research of architectural surveys, renovations or restorations already carried out in the theater provided by Iphan and the Carlos Câmara Library. Thus, the acquisitions under analysis will come from 2D surveys already carried out and digital surveys (terrestrial laser scanning) recently conducted by the Laboratory of Rehabilitation and Durability of Buildings—LAREB, from the Federal University of Ceará. The elements selected for analysis

include mainly ornamental elements and general measurements of the metallic facade, considering the importance of the compatibility of the measurements and the cultural and architectural value of the adornments. Figure 7 shows a diagram representing the workflow.

3.1.1 2D survey

According to the files provided by IPHAN, the last project identified was the one entitled Conservation Project 2018, where one can find .dwg research files made in 2015 and 2009 based on the 1989–1991 restoration with the aim of digitizing this collection (Fig. 8). With this, the metallic facade was selected in the file and prepared for future comparisons. Figure 9 shows the selection of the 2D facade.

Fig. 7 Diagram representing the workflow and related software used in the different analysis phases

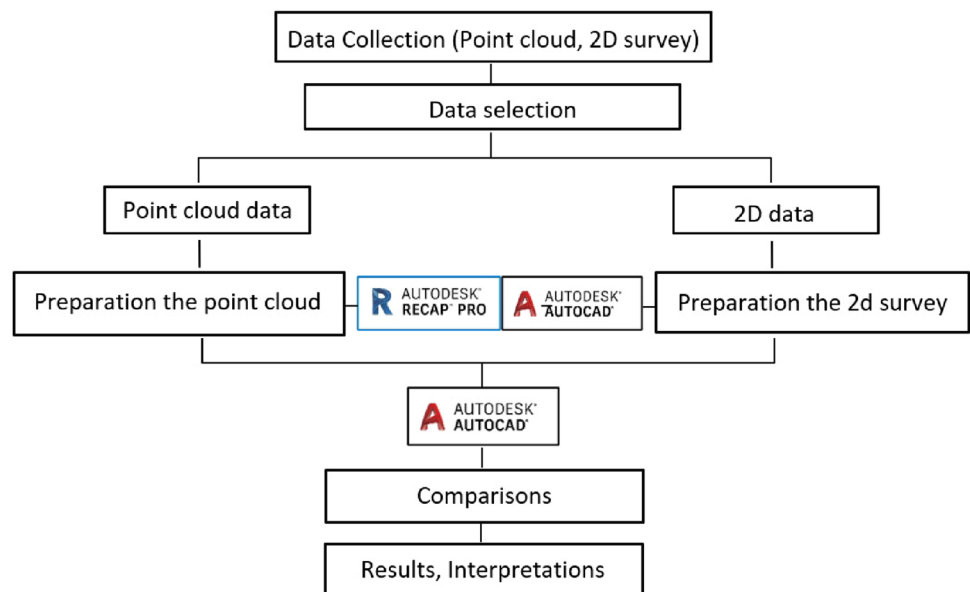




Fig. 8 Stamp with identification of the files extracted from the conservation project

3.1.2 Terrestrial laser scanner (TLS)

The equipment used was the BLK 3060 from Leica Geosystems, which allows scanning at high, standard and fast resolutions, captures take at least 3 min for scanning at standard resolution and generates 150 MP spherical images. At high resolution, up to 360,000 laser scan points per second are possible, and HDR and thermal images are possible. The data processing platform used was Cyclone Register software to record the captures made by the laser image scanner. For the survey, 239 setups were performed, divided into 4 main site visits, with 2 supplementary visits [11].

For the selection of the necessary data, the complete point cloud obtained by the scanner was taken to Recap Pro by Autodesk, a 3D scanning and reality capture software capable of preparing point clouds to be exported to another software, such as AutoCad in this case, cleaning

the cloud, which consists of removing unnecessary points, noise and cutting out specific sections. In this case, the part of the cloud referring to the metallic facade was cut out, and unnecessary points were cleaned, such as tree sections and objects that do not belong to the facade (Fig. 10), and then exported with an extension (.rcp) to the reference folder for later insertion in AutoCad to obtain a 2D view of the facade. The point cloud in 2D view obtained from this process is shown in Fig. 11.

The cloud export by Recap Pro was performed in two small grid adjustments, one exported with 2 mm spacing and the other with 15 mm spacing, the former for better identification of ornaments and the latter for better identification of measurements. Aiming at better visualization and data extraction, in the AutoCad software, the



Fig. 10 View of the point cloud after processing in the Recap pro software

Fig. 9 Viewing 2D survey

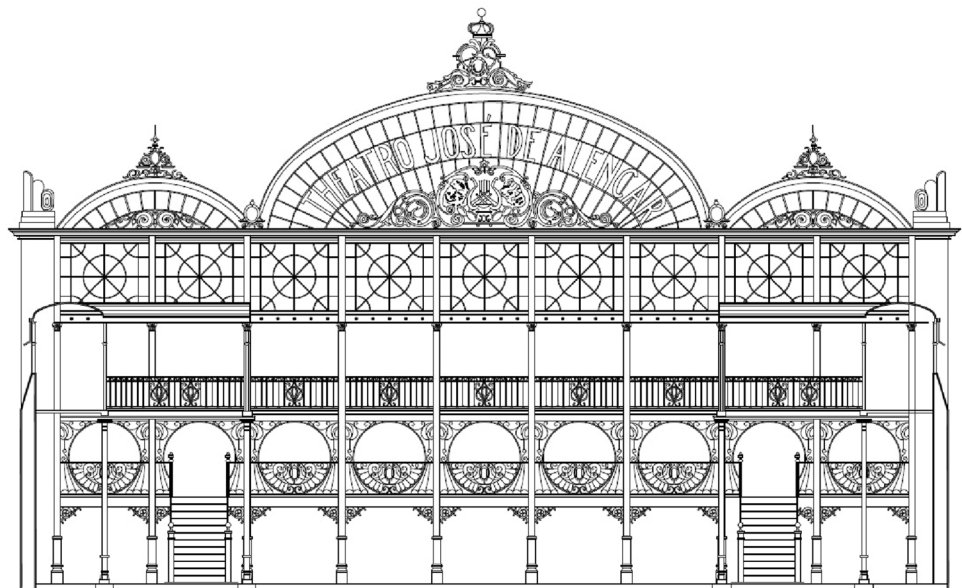
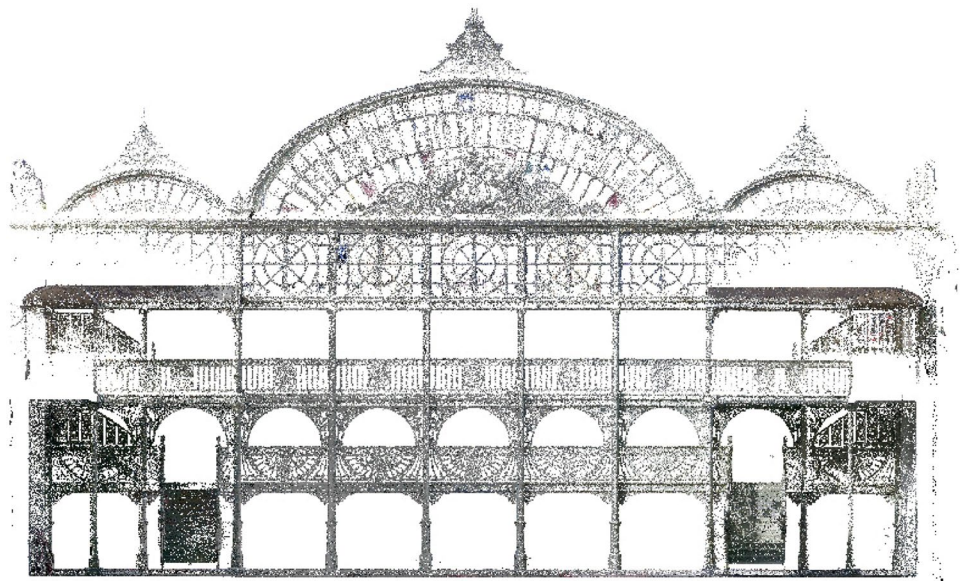


Fig. 11 Viewing the point cloud in software Autocad with visualization in scan colors



visualization mode was changed from scan colors to object color (Fig. 12).

4 Results

4.1 Point cloud data

It can be seen in Fig. 13 that the point cloud with 2 mm grid adjustment helps better in identifying and visualizing the contours of the adornments, as highlighted, and was used for the comparison of these features with the 2D CAD survey. The point cloud with 15 mm grid adjustment (Fig. 13) was better for comparing the internal structure and overall measurements due to better contouring of the shape.

In the highlighted examples in Fig. 13, it is noticed that the ornaments with 2 mm configuration, the phrase with

the name of the theater and the decorative details are better highlighted, while in the highlighted examples with 15 mm configuration, the outline is better observed.

4.2 Point cloud and 2D survey adornment evaluation

First, the point cloud with 2 mm adjustment (in black) and the 2D survey (in red) were integrated. In this step, the cloud and the survey were placed in the correct position of the considered elements. For this, the AutoCad coordinate system was used as a reference. With the overlay, it was possible to notice that the ornaments are relatively similar, but it is also possible to identify some differences in size and shape, in some with a more significant difference than in others, as highlighted in Fig. 14.

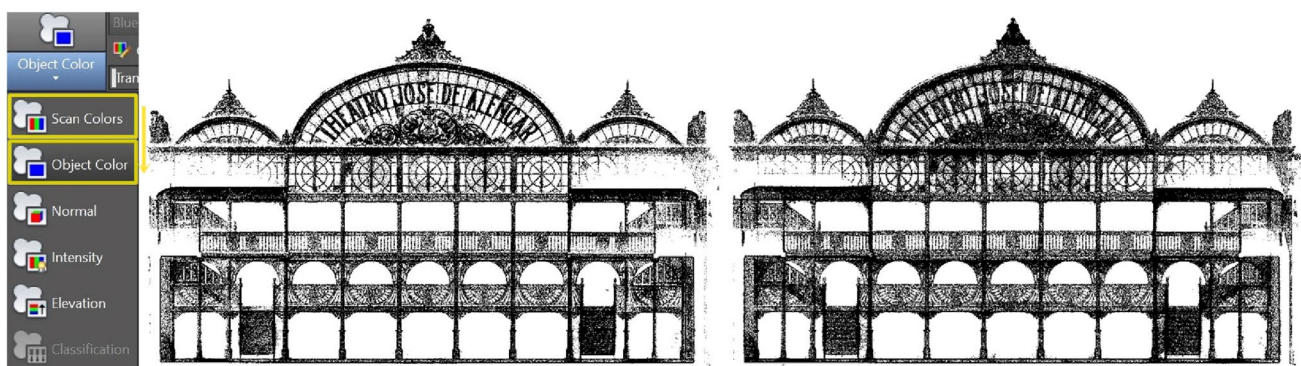


Fig. 12 Point cloud with object color view spacing 2 mm and Spacing 15 mm, respectively

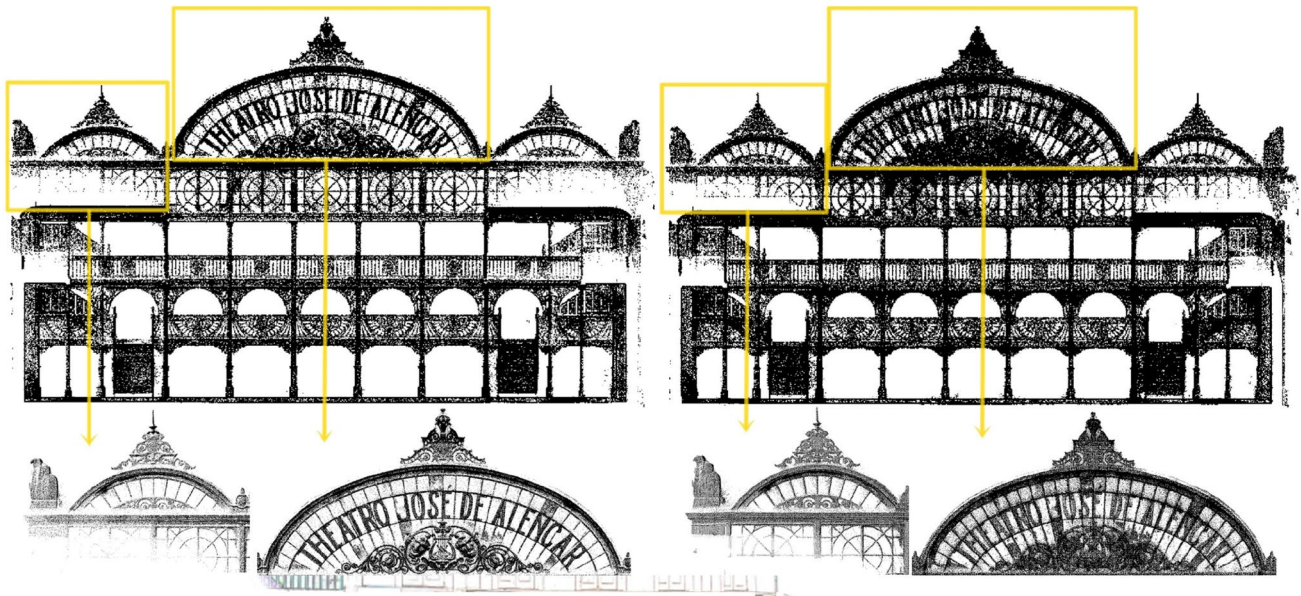


Fig. 13 Point cloud in different large settings, 2 and 15 mm, respectively

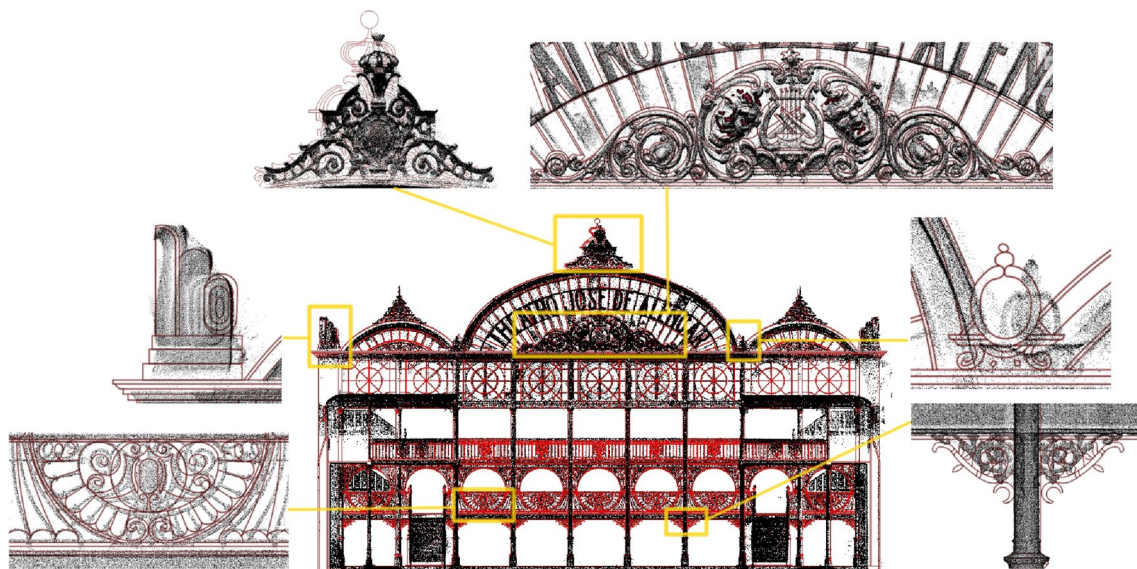


Fig. 14 TLS e 2D survey fusion (2 mm)

4.3 Point cloud and 2D survey measurements evaluation

First, the point cloud with 15 mm adjustment (highlighted in black) and the 2D survey (highlighted in red) were integrated. In this step, the point cloud and the 2D survey were placed in the correct position of the considered elements. For this, the AutoCad coordinate system was used as a reference. With the overlay, it was possible to see that the facade contours are generally very close, differing in some points,

axis by axis, as highlighted in Fig. 15. There are some differences in the facade elements, as the guardrail, the axis of the ornaments at the top and the steel structures move slightly away from the axis of the point cloud, which is considered a more accurate survey, given the ability to represent the actual shape of the building [8]. Considering the differences found from axis to axis of each survey, in the upper ornaments and arches were approximately 10–15 cm, while in the internal structure of the facade, the differences were approximately 5–6 cm. In relation to the general measure of

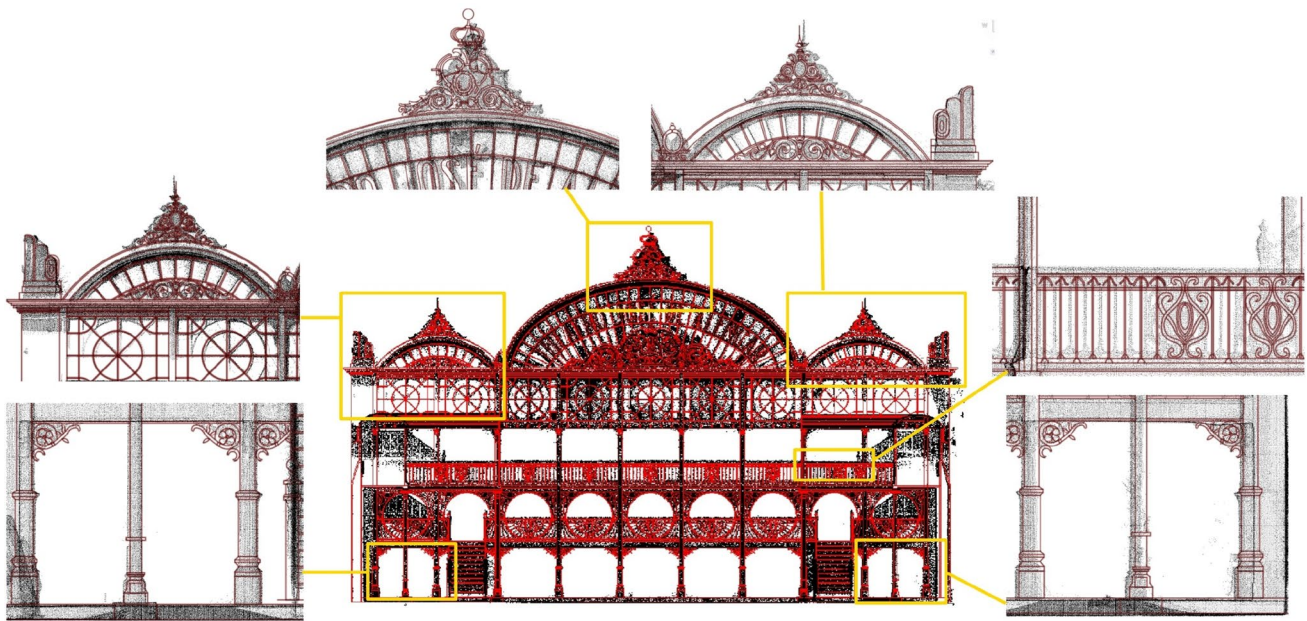


Fig. 15 TLS e 2D survey fusion (15 mm)

the facade contour, the difference between the lengths was minimal, approximately 1 cm, but the height was the greatest difference ever observed, approximately 27 cm.

Ten points were selected to measure the distances, five of which were related to the ornaments and five related to the facade structure measurements. The points were selected mainly prioritizing those with the greatest visual difference. All distances measured using two data points are shown in Fig. 16; Table 1. It is noted that the greatest differences occur in the measurements of heights (D2, D6 and D7), both in ornaments and overall height of the facade, as identified in Table 1. Despite some differences found, the similarity

of the two surveys and the accuracy of the techniques used are confirmed.

In this paper, an evaluation of the measurements between two databases, with a 2D CAD survey and point cloud, was performed. The high accuracy achievable with 3D scanning and the speed with which the survey is carried out with the scanner are remarkable, and this seems to be enough to maintain an overall accuracy; however, the surfaces are complex, with difficulty in the acquisition of some points. It becomes essential to combine several survey methods to make the most faithful to reality, especially in regard to historic buildings.

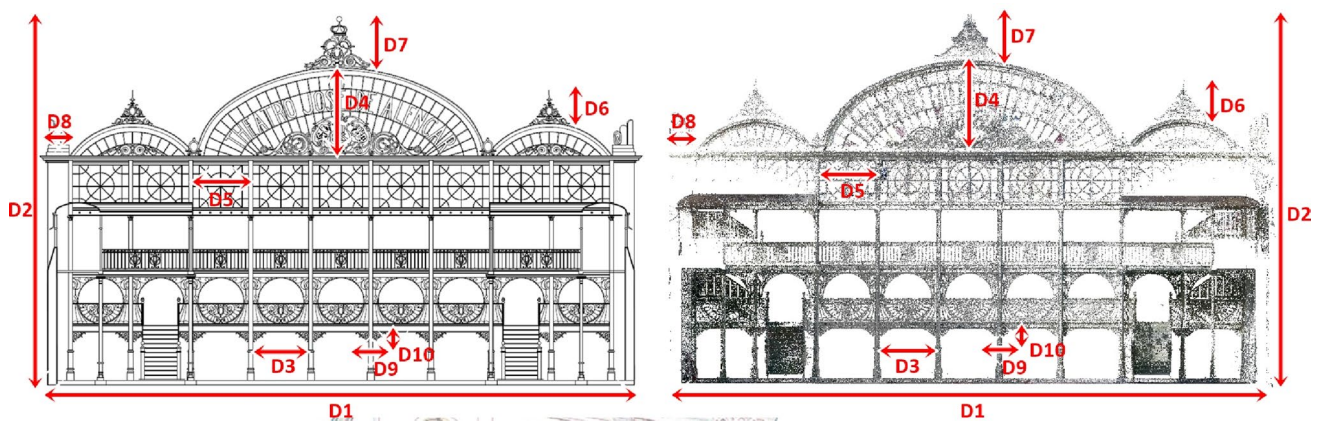


Fig. 16 Identifying the measured distance. CAD and point cloud, respectively

Table 1 Measurement on the point cloud e 2D

ID	Point cloud (mm)	2D survey (mm)	Difference (mm)
D1	25,620	25,630	10
D2	15,790	16,060	270
D3	2400	2410	10
D4	3920	3850	70
D5	2450	2470	20
D6	1710	1430	280
D7	1940	2210	270
D8	760	910	150
D9	1320	1310	10
D10	360	440	80

The difficulty of manipulating the cloud of points due to its size and level of detail, was mitigated with the use of Recap Pro, so it was essential to use this software in the process of preparing the cloud, because it facilitated its manipulation before inserting it in AutoCad. Moreover, with the different grid adjustments, 2 and 15 mm in Recap, it was possible to make a better comparison related to the ornaments and the structural measures, due to the density differences in the points.

The two surveys were relatively equal, but with some larger differences in measurements, as in the case of D2, D6, D7 and D8, which negatively influences the total geometric survey of historic buildings, thus affirming the importance of TLS for surveying these buildings, mainly due to the level of detail and geometric accuracy in these cases.

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Data availability The data will be available on request to the corresponding author.

Declarations

Conflict of interest The authors declare no competing interests.

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