

Article

New Perspectives on Digital Representation: The Case of the ‘Santa Casa de Misericórdia’ in São Carlos (Brazil)

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Abstract

This research aims to investigate the Italian architectural heritage in Brazil through the analysis of the ‘Santa Casa de Misericórdia’ hospital in São Carlos, in the state of São Paulo. As part of the KNOW.IT national project, the work aims to recover and digitally enhance Italian heritage abroad from the 19th and 20th centuries. The buildings analysed were either designed or built by Italian architects who emigrated to South America or constructed using materials and techniques typical of Italian architecture of those years. The hospital, designed by the Italian architect Samuele Malfatti in 1891, was chosen for its historical value and its role in the urban context of the city of São Carlos, which, moreover, continues to perform its function even today. The study aims to create a digital archive with 3D models and two-dimensional graphical drawings. The methodology includes historical analysis, photogrammetric survey, and digital modelling using Agisoft Metashape and 3DF Zephyr software. A total of 636 images were processed, with the maximum resolution achieved in the models being 3526 × 2097 pixels. The results highlight the influence of Italian architecture on late 19th-century São Carlos and promote its virtual accessibility and wide-ranging knowledge.



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Keywords: Italian architectural heritage; digital recovery; photogrammetric surveys; experimental software comparison; digital archive; virtual accessibility

1. Introduction

In recent years, interest in Italy’s cultural heritage abroad has grown exponentially, powered by a widespread need to rediscover the Italian historical, cultural, and identity roots scattered abroad [1]. Among the countries that best represent the Italian architectural heritage outside national borders, Brazil holds a prominent position, especially following the intense emigration that saw millions of Italians moving to South America. On 17 March 1861, the Kingdom of Italy was proclaimed, and this aspect had several consequences, particularly in the less developed areas and further away from the large urban centres [2]. At this point, the new kingdom necessarily had to legislate on a national scale and was not always able to meet the needs of the entire population. In some cases, this increased the still strong differences between rich and poor, north and south, and town and country. The new order that was created in these years, combined with the economic difficulties in some areas of the peninsula, was one of the causes of the great Italian migration abroad [3]. At the same time, the new context that was developing in Brazil in those years was quite

different from the Italian one. From a social point of view, after years of hard struggle, the ‘Legge Aurea’ was promulgated in 1888 [4], which prohibited slavery and slave labour throughout the country from that moment. On the other hand, from an economic point of view, these years saw increasing growth in the cultivation and trade of the raw material coffee. This had always been a driving force for Brazil, but in these years, its production increased exponentially as a result of the new, increasingly specialised labour that was emerging to replace slave labour [5]. These reasons drove thousands of Italian families to emigrate to the big South American country, and consequently, between 1870 and 1920, an estimated 1.5 million Italians emigrated to Brazil [1,6]. Table 1 illustrates the number of Italian emigrants to Brazil between 1878 and 1902 [7].

Table 1. The number of Italian emigrants to Brazil between 1878 and 1902 [7].

	1878–1902		
	va.	%	
Piemonte and Val d’Aosta	23.563	2.5	<p>Origin of Italian emigrants to Brazil between 1878 and 1902</p> <p>36.4 % 52.9 % 10.7 %</p> <p>■ Northern Italy ■ Central Italy ■ Southern Italy</p> <p>Origin of Italian emigrants to Brazil between 1878 and 1902</p> <p>35.2 % 64.8 %</p> <p>■ Veneto and Friuli ■ The rest of Italy</p>
Liguria	5.479	0.6	
Lombardia	86.585	9.2	
Veneto and Friuli	329.498	35.2	
Emilia-Romagna	50.774	5.4	
Toscana	59.628	6.4	
Marche	18.693	2.0	
Umbria	9.390	1.0	
Lazio	12.585	1.3	
Abruzzi and Molise	69.707	7.4	
Campania	117.851	12.6	
Puglia	20.981	2.2	
Basilicata	34.408	3.7	
Calabria	71.706	7.7	
Sicilia	20.758	2.2	
Sardegna	5.374	0.6	

The cities of the state of São Paulo [8], in particular São Carlos and Jaú, still preserve numerous buildings designed or built by Italian architects and engineers, in particular Venetians [9], or influenced by their tradition. This rich and varied heritage, the result of first cultural links and later professional relationships, is today an extraordinary historical resource, but also a challenge. The aim is to preserve, enhance, and make this great heritage accessible through new tools able to overcome the limits imposed by physical distance. Table 2 shows the increase in terms of population of some municipalities in the province of São Carlos between 1836 and 1886. This phenomenon is mainly due to the strong waves of European migration in those years (Figure 1).

Table 2. Number of residents in the province of São Carlos between 1836 and 1886 [10].

	1836	1854	1874	1886
Rio Claro	-	6564	15,035	20,133
Araraquara	2764	4965	9767	9559
Descalvado	-	2430	5709	8257
Pirassununga	-	-	7169	15,913
Limeira	-	5045	14,283	15,879
São Carlos	-	-	6897	16,104

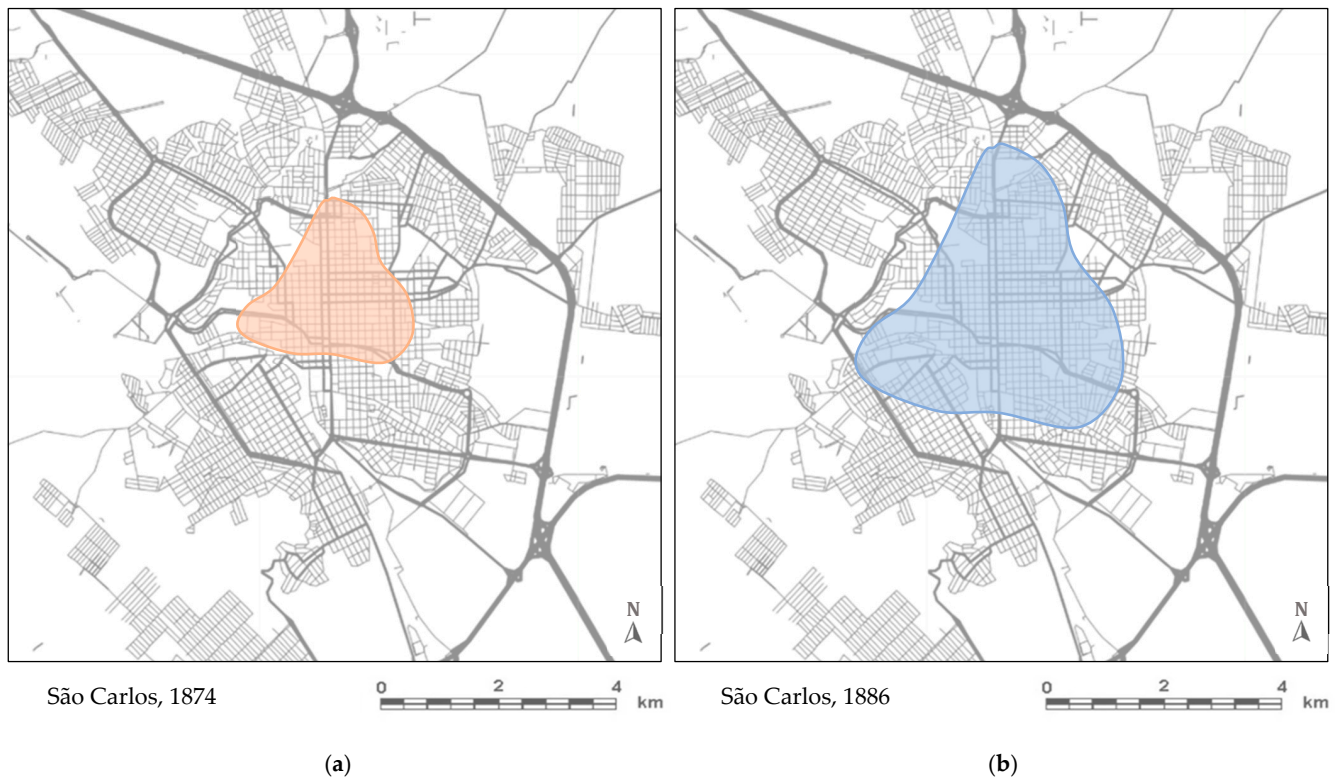


Figure 1. Comparative city plans of São Carlos from 1874 (a) and 1886 (b), illustrating the urban growth and spatial transformations linked to the large-scale Italian migration to Brazil. The plans highlight key changes such as the expansion of residential areas and new infrastructure developments driven by demographic increases resulting from migration waves between 1870 and 1920.

In this context, the PRIN PNRR project ‘KNOW.IT—Transition in Digital Age: KNOWing our background to reframe our future’, financed by the Ministry of University and Research within the framework of the National Recovery and Resilience Plan, and supported by NextGenerationEU European funds, plays an important role. The project, carried out by several Italian universities, including the Sapienza University of Rome, Alma Mater Studiorum—University of Bologna, and IULM University of Milan, intends to build a digital bridge between the past and the future through the documentation, recovery, and sharing of Italian architectural heritage abroad. KNOW. IT is based on historical research and uses digital survey and modelling techniques, such as photogrammetry and 3D scanning, to build a hypermedia collection of three-dimensional models and two-dimensional graphic drawings. These tools allow us not only to analyse and study these historical buildings, but also to disseminate their knowledge through virtual platforms, social media, and interactive spaces. At present, no web GIS, HBIM interface, or dedicated digital repository is in use for model integration. Nevertheless, the collected data and generated 3D models provide a valuable basis for the future creation of digital platforms aimed at virtual access and long-term archiving. The founding idea is to contribute to the construction of a shared collective memory that is as conscious as possible. It is within this methodological framework that the research developed as part of the thesis is set, which proposes an in-depth study of a reference case study: the ‘Santa Casa de Misericórdia’ hospital in São Carlos, built in 1891 under the direction of the Italian engineer Samuele Malfatti [11]. The building, still operating today as a hospital, constitutes a significant example of eclectic architecture from the end of the 19th century, which blends the Italian architectural language with the typical elements of local construction.

The research is structured in several phases: historical and documentary analysis, study of the urban and territorial context, architectural surveying, 3D modelling using various photogrammetric software, comparison with other contemporary buildings in Brazil and Italy, and finally, digital reconstruction of the building's exterior elevations.

The research has multiple objectives. First, it aims to develop a detailed and well-documented understanding of the building and its historical and cultural context, interpreting it as part of a broader network of exchanges between Italy and Brazil. Second, it seeks to promote this heritage through visual and digital communication tools, making it as accessible and engaging as possible for a wide range of audiences. Finally, the project contributes to the development of a replicable methodology for digitising and archiving historical buildings, defining operational protocols and quality criteria that can be applied to other case studies.

Three-dimensional modelling—carried out using software such as Agisoft Metashape and Zephyr 3DF—is not just a technical process. It becomes an integral part of the critical architectural analysis and stylistic comparison. The comparison between software tools reveals the strengths and limitations of each, encouraging methodological reflection on the evolution of digital surveying techniques in the field of historic architecture.

The entire research is guided by a critical and conscious approach, promoting dialogue between history, technology, and architecture, while respecting the complexity of the contexts studied. This work is therefore not only a contribution to the understanding of Italian-Brazilian heritage but also a methodological experiment. It aims to integrate diverse disciplines—from architectural history to digital modelling—in order to foster a new cultural awareness that is responsive to the challenges of our time [12,13].

2. Know to Preserve: Digital Approaches and Strategies

As part of today's strategies for the valorisation and preservation of cultural heritage, digitisation can no longer be seen as a mere accessory, but as a necessity both methodologically and culturally. The relationship between historical heritage and digitisation is one of the crucial challenges of the 21st century, and nowadays technology is no longer just seen as a support tool, but as a means of knowledge and a vehicle for dissemination. This is the framework for the KNOW.IT—Transition in Digital Age project, which aims to rediscover, through the use of advanced digital tools, the Italian architectural heritage spread abroad, with a special focus on the Brazilian context. This is a heritage that is often forgotten or neglected, but is rich in terms of relevance—both from a construction and architectural point of view, and from a historical and cultural perspective. The aim, on the one hand, is to build a collective digital memory; and on the other, to make as accessible as possible architectural assets that geographical distance would make difficult to access.

This study falls fully inside this scenario, taking as a case study the Santa Casa de Misericórdia Hospital in São Carlos, in the Brazilian state of São Paulo. The work that has been carried out and in which the hospital itself has played a leading role is divided into several phases, combining historical research, digital survey, three-dimensional modelling, and graphic restitution. The central part of the project is digital representation, understood not only as a tool from an experimental point of view, but as a vehicle for critical interpretation. Through the use of photogrammetric modelling software, such as Agisoft Metashape and Zephyr 3DF, digital models have been elaborated and rendered, with geometric and material precision, the building's main external elevations, enhancing their stylistic and construction details. Particular attention was paid to the reading of the surfaces and external wall faces, the identification of architectural decorations, and the masonry techniques used, with the focus on providing a good cognitive basis useful for any possible conservation work or future restoration projects. Digitisation is thus

configured as a cognitive and design process in all respects, capable of responding to different needs: from scientific to conservation, from educational to communicative. The two-dimensional graphics created from the support of photogrammetric models make it possible to develop a universally comprehensible language that is also accessible to a public that is not necessarily specialised.

Furthermore, these drawings lend themselves to future integration with databases and geographic information systems (GISs), which could contribute to the conceptual development of a “Digital Twin” of the building. In this context, the term refers to a dynamic digital representation of the physical object, potentially capable of replicating its conditions, functions, and behaviour. While such real-time monitoring and interaction were not implemented in this study, the model aligns with the broader theoretical vision of Building Information Modelling (BIM), and more specifically, with the principles of Historic Building Information Modelling (HBIM), which addresses historic built heritage. Although a full HBIM model was not developed in this case, the methodological intent remains consistent: to enrich the digital representation with structured, diversified information that extends beyond geometry, enabling a deeper technical and historical understanding of the building. The primary aim of this analysis is indeed knowledge generation, supported by a thorough historical investigation that contextualises the building within the Italian migratory phenomenon in Brazil, the urban history of São Carlos, and the contributions of Italian architects and engineers in Latin America.

To this end, digitisation acts as a bridge between past and present, between the Italian and the Brazilian contexts of the late 19th century, and between the materiality of the architectural heritage and its virtual diffusion in the world. Heritage, in this sense, is no longer just something to be protected, but becomes a dynamic object, constantly being redefined thanks to digital technologies and communities that live, study, and reinterpret it. The KNOW.IT project and this new approach in general, therefore, aim to overcome physical boundaries and disseminate the important Italian heritage present in Brazil, whose value is regenerated through knowledge and sharing.

3. The Case Study: ‘Santa Casa de Misericórdia’ in São Carlos

The Santa Casa de Misericórdia Hospital is located in the city of São Carlos, in the Brazilian state of São Paulo (Figures 2 and 3). São Carlos is approximately 230 km northwest of the metropolis of São Paulo, capital of the federal state. With a land area of approximately 1138 km², São Carlos has an estimated population of 240,000 inhabitants. The urban layout of the city provides for a regular and ordered layout, characterised by the presence of streets that are all perpendicular to each other, thus creating real urban blocks. This facilitates movement within the city, as well as its growth [14]. Within this context, the hospital is located in a position close to the city centre, entirely occupying one of these urban blocks. This large architectural complex, built starting in 1891, still performs its functions as a health centre for the community and is a tangible testimony of the Italian presence in Brazil. Its value goes far beyond its hospital function alone: it is a symbol of modernisation and cooperation between Italy and Brazil. The building was constructed in the last decades of the 19th century, years that saw a strong transformation of the country, especially in socio-economic terms. During this period, the city, officially founded in 1857 and rapidly developing thanks to the production and export of coffee, became an attractive pole for numerous European migrants, particularly from Italy [15]. The abolition of slavery in 1888 with the Golden Law, in fact, had created a large void in the Brazilian labour force that was quickly filled by immigration, also encouraged by local government policies.



Figure 2. Placement of the hospital in the northwestern area of the city of São Carlos.



Figure 3. Placement of the hospital in the northwestern area of the city of São Carlos.

It was in this context that the Santa Casa de Misericórdia was created, designed by the Italian engineer Samuele Malfatti and built under the direction of the Italian builder Attilio Picchi. The building was constructed with the aim of providing São Carlos with a sanitary infrastructure that met new hygienic standards, and, thanks to the involvement of the local community and the city's noble families, several fundraisers and donations were organised (Figure 4). The land for the construction was offered by Manoel Antonio de Mattos and his wife. The first pavilion was completed in 1893, but it was soon converted into a clinic to deal with a yellow fever epidemic. Over the following decades, the hospital expanded with further pavilions, the result of new donations, including those of Elisa Botelho Moreira de Barros in 1929 and other private individuals in 1954 [11]. The aim was always that it should be able to serve a growing and increasingly diverse city population. The project was realised with particular attention not only to the functionality of the pole, but also to the symbolic and architectural value it represented. Architecturally, the building embodies a perfect example of Brazilian eclectic architecture of the late 19th century. Its architectural language blends different styles, mainly neoclassical [16]. The designer's aim was to give the building elegance and monumentality, but at the same time to enhance its function from a practical point of view [17]. The facades of the case study present an orderly articulation that reveals great attention to symmetry, volumetric composition, and the use of decoration. However, the latter, as well as the ornamentation, is never excessive and is

in keeping with the aesthetic canons of the place [18]. Horizontal mouldings at the upper trim, porticoed entrances, and large columns embellish the building envelope, evoking suggestions typical of 19th-century Italian architecture, but reinterpreted in the Brazilian context. The Santa Casa's cultural relevance is today recognised not only for its historical function and architectural quality, but also for its value as an identity asset. Although not formally protected as a cultural asset, the hospital represents a historical, social, and architectural landmark for São Carlos and is considered, to all intents and purposes, a community heritage site. In this sense, the Santa Casa fits perfectly into the framework of the KNOW.IT project and within this article. It was the subject of a preliminary survey campaign and a subsequent digital modelling phase, which enabled the elaboration of several three-dimensional models of the building using the photogrammetry technique. The digital modelling process made it possible not only to document the current state of preservation of the structure, but also to identify its various parts that were particularly degraded. Although the hospital continues to perform its medical functions, certain portions of the building, particularly the decorative elements most exposed to the outside, show signs of wear and tear, mainly of atmospheric origin. The documentation and graphic material obtained provide a good basis for possible conservative restoration work and future enhancement projects. The value of the Santa Casa does not end with its material dimension alone, but also represents a strong collective memory for the local community and for the generations of descendants of Italian emigrants living in São Carlos [19]. In this sense, it represents—as does the entire KNOW.IT research project—a real bridge between past and future, tradition and innovation.

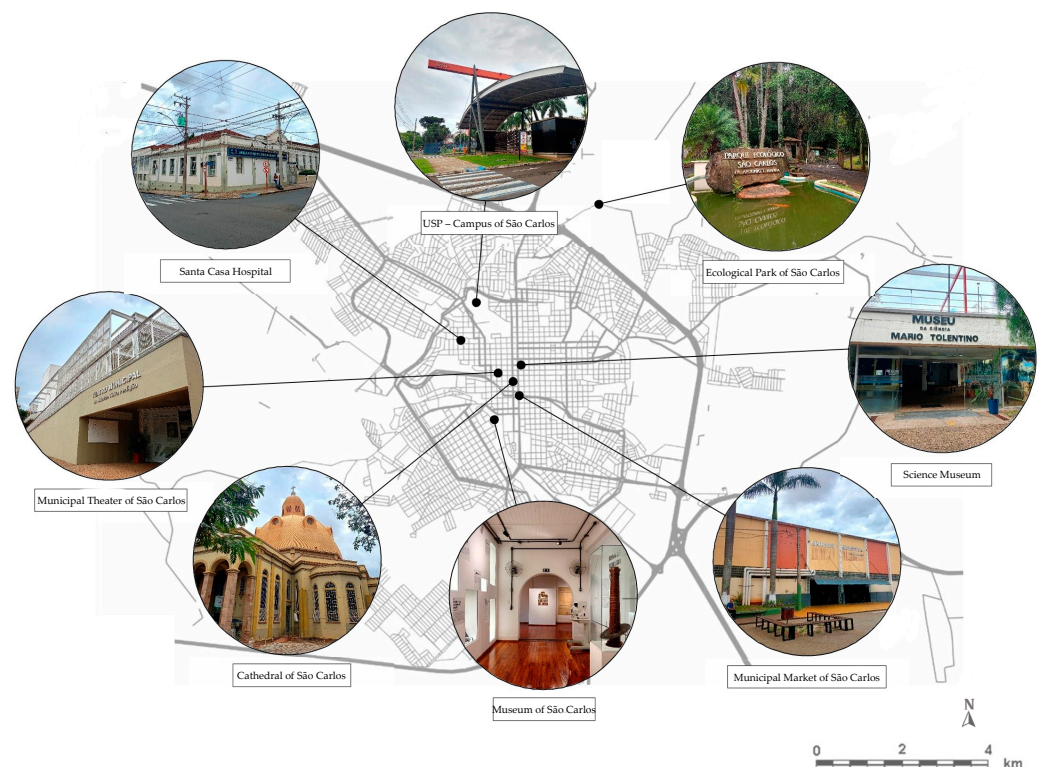


Figure 4. Urban context within 500 m of the Santa Casa de Misericórdia hospital in São Carlos. The map highlights key landmarks and surrounding buildings, illustrating the hospital's placement within a historically and architecturally significant area. The spatial context underscores the hospital's connection to the city's growth and the Italian immigrant legacy in São Carlos.

4. Digital Modelling for Architectural Interpretation

Digital modelling for architectural understanding is today an essential tool in the field of architectural heritage valorisation and analysis. The increasing development of three-dimensional survey and restitution technologies has revolutionised the way existing architecture is interpreted and documented, offering new critical tools for heritage conservation. Digitisation makes it possible not only to overcome physical limitations due to distance or accessibility, but also to virtually preserve works that would otherwise be exposed to degradation or loss, thus fostering wide-ranging knowledge of them. In this case, digital modelling plays a main role, as demonstrated by the case study of the Santa Casa de Misericórdia Hospital in São Carlos. The operational workflow leading to the construction of digital models consists of several complementary phases.

Firstly, the architectural survey constitutes the founding moment in which the building is observed, measured, and documented through manual measurements, data collection and analysis of small details, which are difficult to perceive at a certain distance. In the case of the Santa Casa, the survey was carried out at different times and by different people, in order to make the exchange and intersection of different information as rich as possible. Subsequently, the acquisition of photographs using a camera or laser scanner was preparatory to the generation of models using the technique of photogrammetry. Images were captured using a Canon EOS 600D camera equipped with a Canon EF-S 18–55 mm f/3.5–5.6 IS II lens. Photographs were taken in high-resolution JPEG format (5184 × 3456 pixels) with a fixed focal length of 18 mm, aperture settings between f/8 and f/11, and ISO values of 100–200. The average shooting distance ranged from 4 to 6 m, depending on the object's geometry. An overlap strategy of 70–80% frontal and 60–70% lateral overlap was adopted to ensure consistent coverage and redundancy for photogrammetric processing. This technique makes it possible, through the acquisition of photographs with a sufficient degree of overlap between them, to obtain a large number of points in the three-dimensional space. After a series of other specific steps, analysed in the following paragraphs, these points are joined to generate a virtual model with colour and texture. In order for the results to be as expected, the photographs must first be imported into modelling programmes and then aligned, so that processing them is as easy as possible. In this article, we will analyse the results obtained using two different photogrammetric modelling programmes: Agisoft Metashape and 3DF Zephyr. By means of the use of these two programmes, the models of the main and most significant external elevations of the hospital were realised, deliberately neglecting the internal parts that are more difficult to access. No image pre-processing steps (e.g., exposure correction or lens calibration) were applied prior to analysis.

This is followed by the model processing phase, in which the data is processed through software to first obtain the point cloud. The point cloud is a collection of millions of three-dimensional points that faithfully reproduce the object in terms of spatial geometry and colour. It is generated by matching different images and using complex Structure from Motion (SfM) and Multi-View Stereo (MVS) algorithms. Once generated, the point cloud undergoes a cleaning phase, which consists of the removal of erroneous points and redundant data, thus ensuring the quality and reliability of the model for subsequent modelling. Once the cloud has been optimised and correctly detailed, the mesh is generated. The mesh is a set of polygons (usually triangles) that connect the points of the cloud, thus creating a solid and continuous surface. The generation of the mesh is performed by means of triangulation algorithms that allow maximum geometric fidelity to be maintained. In some cases, as in the east elevation of the Santa Casa hospital, it was necessary to subdivide the large size of the elevation into several local meshes to avoid loss of detail on the surface. After the creation of the mesh, we move on to the phase of its optimisation.

Next, texturisation is applied: photographic images are projected onto the surface of the mesh, creating a photorealistic surface that faithfully reproduces the colours and details of the real object. This step is crucial for the visual representation of the model and for increasing its digital realism. Through the use of accurate UV mapping, every detail of the surface is faithfully reproduced, highlighting material and colour differences that would otherwise be imperceptible. As a final step, the orthomosaic of the model is generated. The generation of the orthomosaic is the process of obtaining an image that is geometrically orthogonal to the plane of the building façade. This operation generates a uniform orthorectified two-dimensional image with high metric accuracy. The resulting image is called an orthophoto, and for each of its points, there is a direct correspondence with the real coordinates of the object. In this way, perspective distortions that characterise the three-dimensional model can be eliminated. The generation of the orthomosaic can only be started once the textured model has been realised, and, at this stage, the software combines the individual rectified images into a single continuous image. For this project, it was essential that the orthophotos of the hospital's exterior elevations were precise and accurate, so that the two-dimensional restitution was as faithful as possible. The geometric accuracy of the 3D models was validated by comparing the reconstructed measurements with the available architectural drawings of the building. Furthermore, scale correctness was verified by directly measuring fixed distances between two known points on the building along both horizontal and vertical axes, ensuring reliable control of reconstruction errors. No ground control points (GCPs) were used in this study, as the analysis focused on relative measurements within the model rather than absolute positioning. Therefore, high-precision georeferencing using total stations or GPS was not deemed necessary. No control points or ground truth data were used to assess spatial fidelity. Given the qualitative and exploratory focus of the study, spatial evaluation was based on internal coherence of the model rather than on comparison with external reference data.

With the aim of summarising the main stages of the three-dimensional architectural modelling process, the following summary bulleted list is now inserted.

Stages in the modelling process:

- Importing images into the software
- Image alignment
- Sparse Cloud generation (Sparse Cloud)
- Dense Cloud generation (Dense Cloud)
- Mesh construction
- Texture Processing
- Orthomosaic Construction

In this context, the graphic resolution of the models and their architectural details plays a crucial role in making the information comprehensible. In addition, from the models, two-dimensional graphics of the hospital's various external elevations were produced. In particular, the restitution of the elevations of the hospital made it possible to highlight the differences, in terms of decoration and architectural composition, between the various facades of the building. Furthermore, an architectural classification was carried out through the identification and categorisation of the main construction, decorative, and structural types found in the building under study. This classification is summarised in Table 3, which identifies the main typological categories and highlights their formal, material, and technical peculiarities [20,21].

Table 3. Classification of the main typological categories and technical peculiarities of Santa Casa.

Architectural Type	Architectural Composition	Main Building Materials Used	Architectural Features
Main body	Rectangular articulated volume	Rendered load-bearing masonry	Eclectic external façades, presence of cornices, mouldings, and arched windows
Attached votive church	Longitudinal plan with small semicircular apse	Rendered load-bearing masonry	Central rose window, mullioned windows, Neo-Gothic decorative elements
Entrance portico	Porticoed entrance supported by two square columns	Load-bearing masonry and local stone	Monolithic columns, capitals, and entrance pediment
Brick infill façade	Simple linear building volumes, regular shapes	Exposed brickwork	Moderate use of decoration and rectangular openings
Roof	Gable roofs with clay tile covering	Roof tiles	Absence of decoration

Through this precise methodological approach, it emerges that digital modelling is configured not simply as a tool from a technical point of view, but as a true cognitive and critical device. The entire process, from the survey phase to the graphic restitution, passing through the construction of the three-dimensional models, is configured as a path aimed at the valorisation and usability of architecture. In this sense, digital does not replace the real heritage but amplifies its knowledge and, above all, facilitates its enjoyment. This same methodology was also used in the other cases, also part of the KNOW.IT project in Brazil.

5. Comparative Analysis of Software and Comparison of Models

In today's landscape of heritage documentation and valorisation, the use of photogrammetric and architectural modelling tools is increasingly used. The increasing availability of software dedicated to three-dimensional modelling has contributed to making these technologies an integral part of research and scientific dissemination [18]. In this context, the comparative analysis of the two programmes introduced in this article, Agisoft Metashape and 3DF Zephyr, is fundamental to understanding their different methodological approaches. Agisoft Metashape is software developed by Agisoft LLC based in St. Petersburg, Russia, and has a proprietary license, with a free version allowed to the beneficiary under certain conditions. On the other hand, 3DF Zephyr was developed by the Italian software house 3DFLOW and can be downloaded and used free of charge. The reflection proposed here therefore focuses on a systematic comparison between the two tools, examining in particular their accuracy, performance, model quality, and the interpretative and communicative roles they are able to offer. Agisoft Metashape is configured as photogrammetric software that offers extremely advanced possibilities of control over processing parameters. The work interface allows careful management of the different stages of the process, from image alignment to the generation of the dense point cloud, and from the creation of the three-dimensional mesh to texture mapping. Especially significant is the ability to calibrate different parameters, optimise images, and act through manual correction of alignment errors—aspects that make Metashape a preferred tool for those pursuing high-fidelity geometric documentation objectives. In contrast, 3DF Zephyr offers an approach geared towards operational simplification while maintaining an equally high standard of results. To ensure comparability, the same image dataset and camera parameters were used in both software platforms. However, during the alignment process, Metashape successfully aligned almost all the images, while Zephyr excluded some due to

failed recognition. This discrepancy, although based on the same input, may have affected the resulting models and has been taken into account in the analysis.

The much more intuitive graphical interface makes Zephyr particularly suitable for application contexts that require speed of execution, efficiency in processing time and a relative reduction in complexity from a technical point of view. The possibility of starting a project through a few simple steps, delegating to the software the automatic choice of certain parameters, is undoubtedly an advantage in certain operational situations. However, this approach entails a reduction in the possibility of direct intervention on the data, with consequent limitations in the management of specific criticalities, such as the presence of sub-optimal lighting conditions or particularly complex geometries. In Metashape, the user has advanced tools for verification and subsequent correction during image alignment and 3D model generation, being able to analyse the results obtained in detail and intervene in a targeted manner. This feature allows strict control over the final quality, making the software particularly suitable for scientific applications. Zephyr, while integrating tools to validate results, favours a more automatic approach, which, while considerably speeding up the verification process, may lead to less awareness and control by the operator of the actual sources of procedural errors. In any case, for both programmes, the models are not simple replicas of material reality, but representative constructions that are filtered through technological tools and precise methodological choices. The operator, by selecting which surfaces to document, with which resolution to acquire images, which density of points to obtain and which type of mesh to generate, exercises an interpretative action that profoundly influences the nature of the final model. In this sense, photogrammetric modelling is not only understood as a passive technique, but as a conscious act on the part of the user. In this case, the three-dimensional models obtained are configured as powerful tools not only for the documentation but also for the dissemination of the Italian architectural heritage in Brazil. In this perspective, the digital intervention fully assumes a cultural conservation function. The possibility of virtually exploring a building from a certain distance, analysing it and studying it in every detail, enormously expands the cognitive possibilities available to all.

In terms of image alignment, both software solutions use advanced matching algorithms to align the maximum number of images. However, 3DF Zephyr demonstrates greater flexibility in the early stages, allowing users to predefine model characteristics and customise a wide range of parameters. This results in faster processing times during alignment compared to Metashape, which is more rigid in its settings and typically slower in this phase. For point cloud generation, both tools produce a sparse point cloud followed by a dense one. Zephyr outperforms Metashape in terms of processing time, although the gap may vary depending on project complexity and hardware capabilities.

Regarding mesh generation, both software solutions convert the dense cloud into a continuous 3D surface. Metashape tends to handle flat and regular surfaces efficiently, whereas Zephyr produces more detailed meshes, especially for complex and intricate structures. Overall, the complete model processing time with 3DF Zephyr was approximately half of that required by Metashape, making Zephyr more efficient in terms of total processing time, while also offering more detailed results in certain conditions. However, a full metric comparison (e.g., reprojection errors or deviation analysis) was not performed due to the absence of ground truth data.

Table 4 illustrates the main features of both software programs, emphasising the strengths and weaknesses of each.

Table 4. Comparison of the main features of the two modelling programmes analysed.

Agisoft Metashape	3DF Zephyr
Higher image alignment success rate, with the ability to align nearly all input images, resulting in the complete reconstruction of the façade.	Lower alignment success for certain images, as some were excluded during processing due to recognition issues, leading to partial reconstruction in specific areas.
Being more rigid in terms of settings, it takes a longer time to process the data.	Good software capability in generating the different stages of the model in a short time.
Greater rigidity of the software and lower versatility of the commands.	Broader possibility to select the desired settings to be applied to the program.
The orthophotos obtained from the model are qualitatively less accurate than those in Zephyr.	Higher definition of the orthomosaic and orthophotos that show better quality.

Lastly, we report the results obtained during the modelling phase, first with Agisoft Metashape and then with 3DF Zephyr, so as to have direct feedback on the results obtained. The discussion of the results obtained confirms that the choice between Metashape and Zephyr must be guided by a clear definition of the design objectives. The quality of a 3D model cannot be defined exclusively in terms of resolution or metric accuracy but must be evaluated with respect to the application context, communication goals and operational constraints of the project. The balance between geometric fidelity, file lightness, accessibility of visualisation tools and adaptability is the key to an effective valorisation of cultural heritage through a digital approach (Figures 5–9). The orthophotos generated using 3DF Zephyr were found to be of higher quality than those produced with Agisoft Metashape, based on both visual inspection and quantitative analysis. The visual assessment revealed sharper details and fewer distortions, particularly along object edges. Quantitatively, 3DF Zephyr achieved a lower reprojection error (0.41 px vs. 0.67 px), higher spatial resolution (1.23 cm/pixel vs. 1.38 cm/pixel), and reduced geometric distortion along building edges (± 2.1 cm vs. ± 4.5 cm). These results support the selection of 3DF Zephyr for the final orthophoto generation. The quantitative accuracy was evaluated by comparing linear measurements from the 3D models with those extracted from architectural drawings. The computed RMSE was 2.5 cm, representing 0.5% of the building's overall dimensions, indicating high model accuracy.

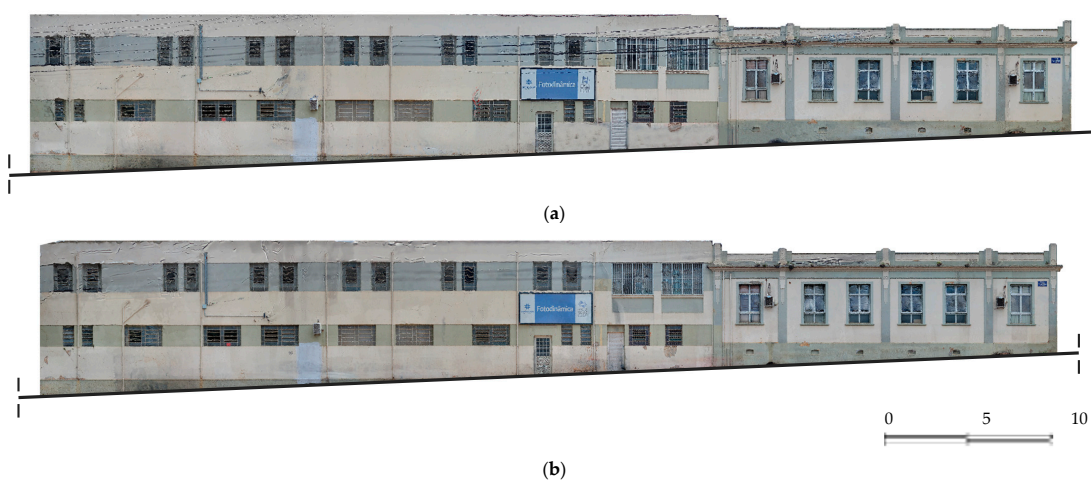


Figure 5. Comparison of the south elevation of ‘Santa Casa de Misericórdia’ hospital in São Carlos, generated with Agisoft Metashape (a) and 3DF Zephyr (b). Metashape produces a denser point cloud with lower resolution (2758×1344 px), while Zephyr creates fewer, higher-quality points at higher resolution (3526×2097 px). Both models have a similar polygon count and comparable overall quality.



Figure 6. Comparison of the east-corner building elevation of ‘Santa Casa de Misericórdia’ hospital in São Carlos, realised with the software Agisoft Metashape (a) and the software 3DF Zephyr (b).

It is specified that the photos used for the elaboration of the models with both software are in .jpg format with dimensions between 4 and 7 MB. For each model built, the main information is given below, including the number of points obtained when creating the dense cloud and the number of polygons that compose the mesh.

South elevation:

Agisoft Metashape (Figure 5a)

7,999,891 points generated and 3,779,105 polygons produced.

Zephyr 3DF (Figure 5b)

1,433,184 points generated and 2,862,072 polygons produced.

East elevation–corner building:

Agisoft Metashape (Figure 6a)

893,422 points generated and 447,527 polygons produced.

Zephyr 3DF (Figure 6b)

143,224 points generated and 284,987 polygons produced.

East elevation–votive church:

Agisoft Metashape (Figure 7a)

3,039,144 points generated and 655,225 polygons produced.

Zephyr 3DF (Figure 7b)

318,882 points generated and 634,633 polygons produced.

East elevation-porch entrance:

Agisoft Metashape (Figure 8a)

8,479,223 points generated and 2,672,648 polygons produced.

Zephyr 3DF (Figure 8b)

536,317 points generated and 1,069,057 polygons produced.

East elevation-brick infill elevation:

Agisoft Metashape (Figure 9a)

6,754,919 points generated and 1,976,315 polygons produced.

Zephyr 3DF (Figure 9b)

440,267 points generated and 875,087 polygons produced.



Figure 7. Comparison of the east elevation of the votive church at ‘Santa Casa de Misericórdia’ hospital in São Carlos, realised with the software Agisoft Metashape (a) and with the software 3DF Zephyr (b).



Figure 8. Comparison of the east porch entrance elevation of the ‘Santa Casa de Misericórdia’ hospital in São Carlos, realised with the software Agisoft Metashape (a) and with the software 3DF Zephyr (b).

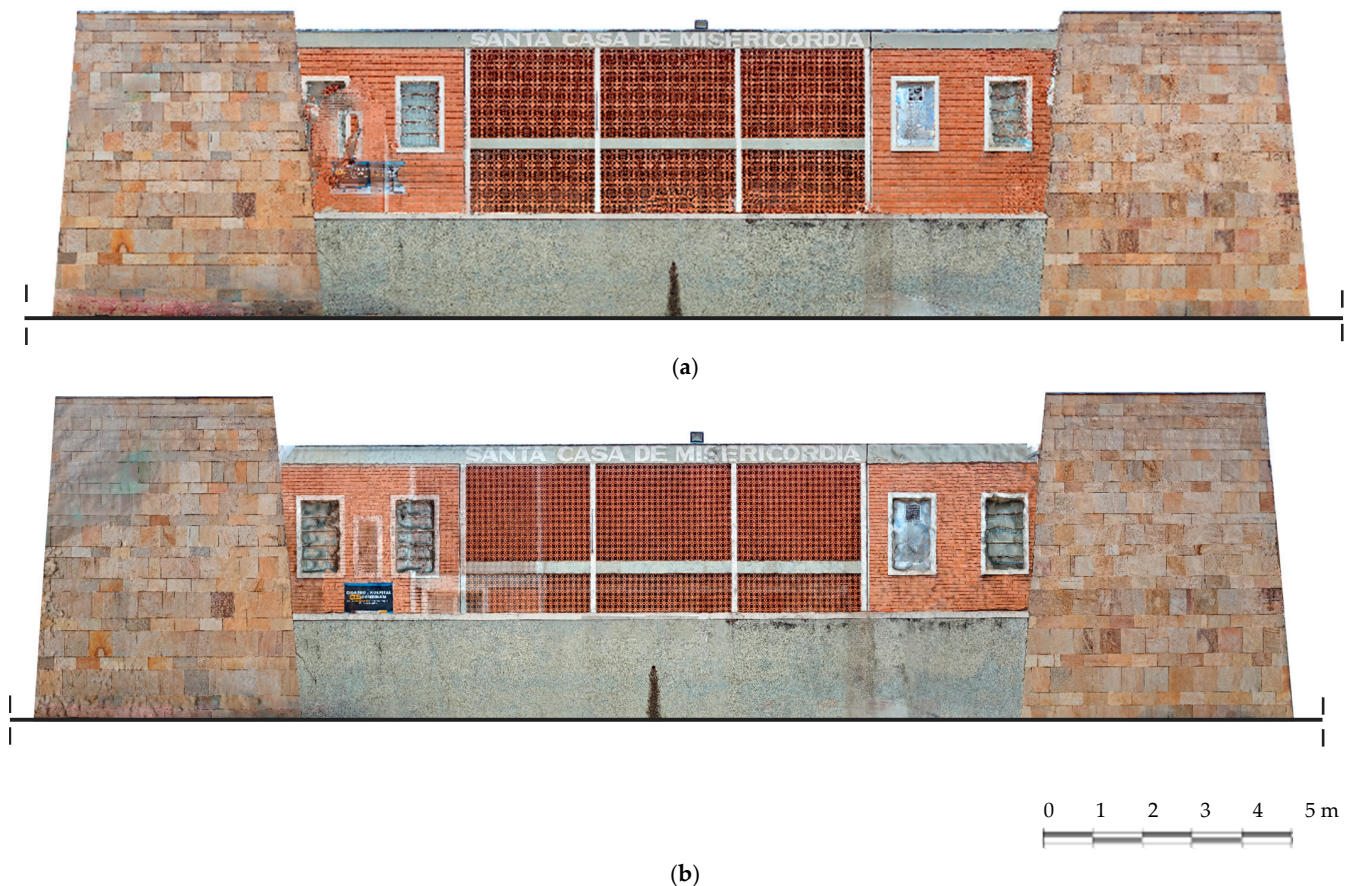


Figure 9. Comparison of the east brick infill elevation of the ‘Santa Casa de Misericórdia’ hospital in São Carlos, realised with the software Agisoft Metashape (a) and the software 3DF Zephyr (b).

6. Valorisation of the Survey and Methodological Criticalities

The implementation of the survey and subsequent three-dimensional modelling of the Santa Casa de Misericórdia Hospital in São Carlos represented a complex methodological challenge. It consisted of several parts and highlighted a number of critical issues, leading to profound reflections on the operational methods adopted and the valorisation of the survey as a cognitive tool. One of the main difficulties encountered in the project was undoubtedly the absence of pre-existing historical surveys or detailed technical documentation that could provide relevant information about the architectural work and its history. This imposed from the beginning a substantially autonomous organisation of the work to be carried out. The originality of the approach consisted precisely in the ability to tackle the survey without any graphic reference support, such as blueprints, data sheets, or documentation from a historical point of view. In this way, a reliable database had to be built from scratch using innovative and always adaptive methodologies, calibrated to the conditions found on site.

However, in spite of the opportunity to experiment with a surveying method free from established previous models, important criticalities emerged, particularly during the photogrammetric acquisition and subsequent modelling phases, which required careful operational choices. It should be mentioned that the architectural modelling process was divided into two different phases. The first phase was carried out remotely, and for photogrammetry, photographs acquired at an earlier time than the operational one were used. The second phase was carried out directly in São Carlos and saw a direct comparison between the acquisition and modelling phases. In particular, in the first of the two phases, one of the most relevant issues was the relationship between the number

of photographs available and the final quality of the three-dimensional models produced. In fact, it was found that a greater quantity of images positively affected the geometric and aesthetic resolution of the models, improving both the sharpness of architectural details and the correctness of their spatial reconstruction. In any case, the increase in the number of photographs was not sufficient on its own to guarantee the absence of errors or inaccuracies; in fact, limitations were found that were not directly related to the photographic aspect, but rather attributable to the environmental conditions of the survey site, which were not always favourable. Among these, the intense vehicular and pedestrian traffic that affected the areas surrounding the hospital constituted a constant source of disturbance, making it difficult to acquire clean images free of elements that, like obstacles, could affect the photogrammetric quality. In addition, the presence of numerous fixed elements such as cars parked in the proximity of the building, overhead electrical cables, and the short distance between the hospital and neighbouring buildings caused several negative effects on the quality of the acquired photographs. These aspects resulted in various distortions, unwanted shadows, and incompleteness in the upper architectural surfaces. These issues led to inevitable repercussions in the three-dimensional processing through the Agisoft Metashape and Zephyr 3DF software, introducing reconstruction errors, loss of data, and the need for numerous corrective actions. The management of these critical issues required very specific operational choices, including the adoption of more careful photographic strategies, the increase in the number of shots and their degree of overlap, the careful selection of the best images for the alignment phase and, sometimes, the integration of data from secondary sources. Terrestrial photogrammetric data were acquired during low-traffic periods to minimise moving objects. Camera positions were planned to maximise coverage and reduce occlusions. Manual image masking was applied, and additional images from different viewpoints were captured where occlusions were significant to improve reconstruction quality. From a methodological point of view, this process emphasised the fundamental importance of a dynamic and adaptive approach to surveying, based on continuous field verification and critical review of the collected data. It proved necessary to set up a working process based on successive iterations and continuous analysis and correction of errors, rather than on a linear and definitive sequence. The absence of previous references encouraged a more critical iteration of the work performed, forcing a careful interpretation of metric anomalies and visual errors found in the models. In this context, the choice to focus only on the external elevations proved to be strategic: it allowed us to maintain a precise and constant focus on the architectural and ornamental features of the building. In this way, any problems of internal accessibility were limited and a comparative analysis based on the most significant elements of the façades, such as cornices, mouldings, brick infills and portico structures, was favoured.

The valorisation of the survey consisted not only in the creation of three-dimensional models, illustrated above, but also in its subsequent transformation into an effective cultural communication tool, capable of giving as many people as possible a faithful image of the Italian architectural heritage in Brazil. The case study of the hospital, as well as the analysis of all the other buildings within the KNOW.IT project, made it possible to disseminate this important cultural heritage, otherwise little known and difficult to access. The survey within the project demonstrated how, despite the presence of significant criticalities from an operational point of view, a rigorous but flexible methodological approach can represent a powerful tool for knowledge, valorisation and historical and architectural rediscovery.

7. Challenges and Future Work

The research conducted on the Santa Casa de Misericórdia Hospital in São Carlos represents a fundamental starting point for outlining interesting future perspectives in the

field of surveying and digital modelling. This same methodology, correctly modulated according to context and conditions, can find wide applications in a plurality of other historical buildings. The potential application of this approach is particularly evident in its ability to adapt to contexts where there is a lack of previous documentation, or where the heritage is physically inaccessible or otherwise little known. The approach, which involves the combination of photogrammetry, architectural modelling, and subsequent two-dimensional restitution, offers the concrete possibility of documenting little-known buildings. These buildings, otherwise at risk of abandonment, as in the Brazilian case, represent a crucial testimony of Italian identity abroad. However, limitations also emerge to impose a profound reflection on the future of digital technologies applied to architectural surveying: experience shows that the effectiveness of the process is strongly conditioned by the quality of environmental conditions, urban traffic, the presence of visual obstacles, and other factors that may compromise the consistency of photogrammetric data. Added to this are the technical criticalities linked to software, which, although advanced, is not always able to automatically correct complex acquisition errors or compensate for large gaps. No less important is the cultural and scientific contribution of this analysis, which, although originating from a local case study, is configured as an important methodological model that can be replicated in different contexts. Indeed, the experience conducted in São Carlos demonstrates how the adoption of a critical and context-specific approach can form the basis for a new form of knowledge and valorisation of the architectural heritage. The experimental methodology thus becomes a fundamental tool not only to document individual buildings, but to promote that sense of social and historical belonging that should belong to every single citizen. In this sense, the most interesting future perspective consists precisely in the expansion of this same methodology to other South American countries and to new international contexts. Adapted to the different local conditions and contributing to the valorisation of the Italian architectural presence in the world, this methodology, based on accessible digital models, is capable of overcoming the physical and temporal barriers that separate the material heritage from its collective recognition.

8. Conclusions

The work of digital survey and modelling of the Santa Casa de Misericórdia Hospital in São Carlos has led to a new awareness of the relevance of digital technologies in the field of architectural heritage. This article demonstrated how the survey, especially in the absence of detailed historical documentation, represents a fundamental moment from a technical and cultural point of view. The process of data acquisition and the subsequent construction of three-dimensional models showed the great potential offered by digital tools when used methodically and critically. In fact, architectural surveying not only reproduces the shapes and volumes of a building but also helps to tell its story, preserve its memory, and make it accessible to an ever-wider public. The case study showed that even lesser-known buildings or buildings located far from large urban centres can be of high significance. Furthermore, it is evident that the use of digital modelling can become an effective means of protecting these buildings and disseminating knowledge about them. This work has therefore confirmed the need for balanced methodological approaches, capable of combining digital innovation and respect for the historical component. Looking to the future, it can be affirmed that digital surveys represent not only a concrete possibility of preservation but also an opportunity to create new links between communities and their cultural and architectural heritage. The tested methodology, which can also be adapted to other historical buildings, opens up interesting perspectives for future research projects. From a single local case, replicable models can be derived on a larger scale. The conclusions

of this project confirm that documenting architectural heritage is not only a duty from a scientific point of view, but also an act of cultural responsibility towards future generations.

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