Virtual Tours in Ouro Preto, Brazil: A Tool for Cultural Heritage Preservation

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Abstract

This paper presents a case study on how digital documentation, specifically a data-driven approach to heritage conservation, is preserving the history of Ouro Preto, Brazil, a UNESCO World Heritage Site. The methodology, which blends laser scanning, photogrammetry, and 360º virtual tours, is designed to support the documentation, education, management, maintenance, and restoration of cultural sites. Ouro Preto, with its numerous 18th-century art-filled churches spanning the city, justly gained UNESCO World Heritage status in 1980. However, the recent destruction of cherished heritage sites in Brazil and across the globe has underscored the urgent need for new approaches to conservation. Ouro Preto itself faces challenges such as material deterioration and the loss of historical features. To address these issues, the project "OURO PRETO FOREVER" was established. This collaborative effort between Brazilian universities and technology companies enabled the use of laser scanning, photogrammetry, and 360° image capture for the creation of virtual tours and point clouds of 24 Baroque churches and chapels. The resulting point clouds and immersive models were made freely accessible to the public and are currently utilized in professional training for conservation and restoration. This initiative demonstrates that digital documentation is essential not only to enable the community to access this cultural heritage in the present but also to safeguard it for future generations.

1. Introduction

1.1 Ouro Preto - Brazilian UNESCO World Heritage Site

The preservation of cultural heritage transcends the mere conservation of old buildings, as it represents the necessity of maintaining a locality's identity and communal memory by telling silent stories.

Ouro Preto is a repository of numerous histories, an embodied and overt testament to its existence, culture, and politics, with its architecture sustaining the aftermath of colonialism and the intense gold exploration in 18th-century Brazil. On the irregular terrain of the Serra do Espinhaço, the city of Ouro Preto was formed, attracting countless inhabitants due to the gold rush of the era. These newcomers required social control from the Portuguese Crown, the solution for which was found through religious influences, a fact that led to the emergence of 24 temples in the city (Figure 1).

The presence of a noble social elite in the region influenced the practice of substantial investments in the city, notably in the richness of local architecture and art. From simple to opulent Baroque, from Rococo influences to the artistic contributions of Mestre Ataíde, Aleijadinho and other officials, Ouro Preto became the first Brazilian cultural property to be inscribed on UNESCO's World Heritage List in 1980 (Fitzgibbon, 2024).

Through every construction and slope, the city narrates the trajectory of a people who, between exploitation, cultural background and faith, erected an invaluable heritage amidst the opulence of gold.

Figure 1. Partial image of Ouro Preto heritage site by IPHAN.

The city of Ouro Preto is located in the state of Minas Gerais, Brazil, is a UNESCO designated World Heritage Site. It encompasses the largest urban ensemble listed by the National Institute of Historic and Artistic Heritage (IPHAN) in Brazil, spanning approximately 1,245 km², with 81% of its urban area subject to heritage preservation (Verardo, 2024).

Ouro Preto holds significant importance in Brazilian history. The Baroque and Luso-Brazilian architecture were perceived as the first truly Brazilian cultural expression that carried the aura of the origin of the culture, of the nation itself (Fonseca, 2000). Despite its notable historical and cultural significance, the city faces major challenges and conflicts, such as the degradation and decharacterization of its heritage assets. Throughout history, the churches of Ouro Preto have been documented using several different techniques (Santos, 1951), as shown in Figure 2.

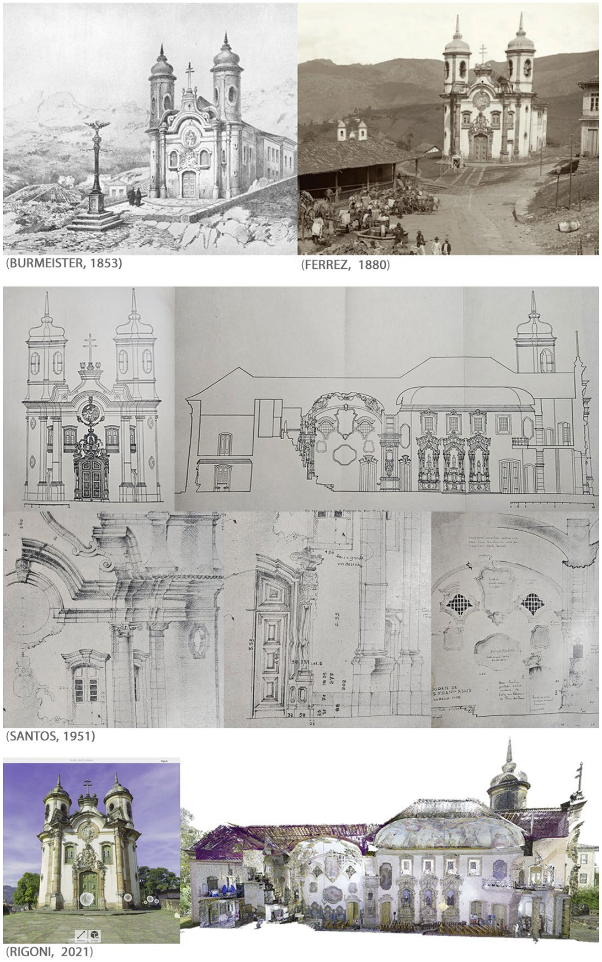

Figure 2. Documentation of Ouro Preto's architecture along history.

This paper presents a case study on the application of reality capture technologies for 3D digitization, employing laser scanning, photogrammetry, and 360-degree visualization in the form of virtual tours. The project named "OURO PRETO FOREVER" was developed in three phases: data capture by digital documentation, data processing and community data sharing (Figure 3). Laser scanning and drones were utilized to capture data from 24 churches and chapels in Ouro Preto, with the purpose of documenting cultural heritage. The processed data resulted in the creation of point clouds with millimetric precision and virtual tours, which have been made freely accessible. The findings demonstrated that virtual tours enable the creation and sharing of real-life imagery as if they were a book, where each heritage site narrates a part of the city's history. Therefore, documenting these testimonies is essential not only to enable the community to access this cultural heritage in the present but also to safeguard it for future generations.

Figure 3. Schematic representation of the project phases.

Cultural heritage preservation is currently undergoing a profound transformation due to emerging digital technologies and the refinement of long-existing, yet still underutilized, tools in professional practice. From photogrammetric documentation to Heritage Building Information Modeling (HBIM) and the application of Artificial Intelligence (AI) for diagnostics and monitoring, the field of conservation is entering the data-driven era, solidifying what many consider an irreversible global trend.

In the realm of professional training, substantial challenges persist, which are not exempt from the perceived contradiction between preservation and development. Education in cultural heritage preservation increasingly requires a balance between the maintenance of traditions and the integration of new technological tools. There is an urgent need to sharpen critical thinking to combine scientific, technological, and humanistic competencies, enabling the production, interpretation, and application of heritage data without anachronisms.

In recent decades, Ouro Preto has faced significant challenges in safeguarding its heritage, including: the encroachment of mining activities in surrounding areas, stagnant public policies on heritage preservation, discontinuities in heritage education and technical training programs, regarding: a) traditional construction techniques and, b) specialized disciplines aimed at the preservation of cultural heritage.

2. The urgency of heritage documentation and collaborative partnerships

In Ouro Preto, residents contend with frequent geological risk zones, severe limitations on urban expansion, a strong tourism presence, and pronounced social inequality. While the city presents considerable challenges, it also demonstrates immense potential for innovative preservation strategies.

This challenge motivated the project created as a collaboration effort between the "OURO PRETO FOREVER" project and the Conservation and Restoration Technology Program at Federal Institute of Education, Science and Technology of Minas Gerais (IFMG) – Ouro Preto *campus.* It has the pedagogical proposal aimed to bridge digitally collected data from virtual tours with on-site technical inspections, providing students with a comprehensive diagnostic experience (IFMG, 2018). Established in 2006, this program is one of Brazil's most well-regarded initiatives in professional training for cultural heritage preservation. Over nearly two decades, the program has graduated hundreds of conservation-restoration professionals skilled in understanding the socio-cultural dimensions of preservation, critically analyzing buildings, applying traditional techniques, and diagnosing pathologies.

Within this framework, the partnership sought to develop students' proficiency in digital technologies while fostering the critical and technical competencies required for built heritage conservation, focusing on the ceilings of religious buildings in Ouro Preto and Mariana (Minas Gerais - Brazil). The activity, conducted with fourth-semester students, exemplifies this integrative effort. Using virtual tours from the "OURO PRETO FOREVER" project, the students conducted preliminary virtual visits to the churches, even prior to any on-site analysis.

Combining on-site and virtual inspections allowed them to test hypotheses discussed in lectures with their professor. By the end, they produced technical reports identifying issues such as water infiltration, wood-boring insects, cracks, degradation of painted layers, and structural system concerns alongside critical reflections on the methodology itself.

While these architectural and artistic documentation systems improve the accuracy of surveys and diagnostics, which are essential for informed interventions, the volume and complexity of generated data demand specialized methods for interpretation and decision-making. This is evident in the students' initial surprise and unfamiliarity with "OURO PRETO FOREVER" outputs, though their keen interest highlights the need to address this gap through guided reflection on Virtual Tours' educational potential and targeted training.

3. Reality capture methodological workflow

The application of reality capture of Ouro Preto's 24 churches and chapels demanded a well-structured methodological workflow, employing laser scanning, photogrammetry, and 360-degree visualization registration technologies. The processed data resulted in the creation of point clouds with millimetric precision, textured mesh model and Virtual Tours, which have been made freely accessible to the community.

The reality capture by laser scanning and photogrammetry was conducted by terrestrial equipment and UAVs (Unmanned Aerial Vehicle) as shown in Figure 4.

Figure 4. Laser scanning and photogrammetry terrestrial equipment and UAV.

3.1 Reality capture: technical structured application

Each piece of equipment was employed for a specific reality capture task, as illustrated in Figure 5 and further detailed in the subsequent subheadings.

Figure 5. Application of equipment for reality capture according to their respective technology.

3.2 Reality capture: millimetric precision by laser scanning

Laser scanning was chosen as the most suitable technology for data gathering of the churches, remarkably due to its millimetric precision for point cloud registration.

The Leica RTC360 Terrestrial Laser Scanner was adopted, based on its range of 130m and a capture rate of two million points per second, with a measurement precision of 1.9mm at a distance of 10m from the object to be registered.

To capture the entirety of the building's details, the scanner was strategically placed at numerous points. For instance, the production of the point cloud illustrated in Figure 6 required 254 scans, encompassing the external facades and all internal environments of the building.

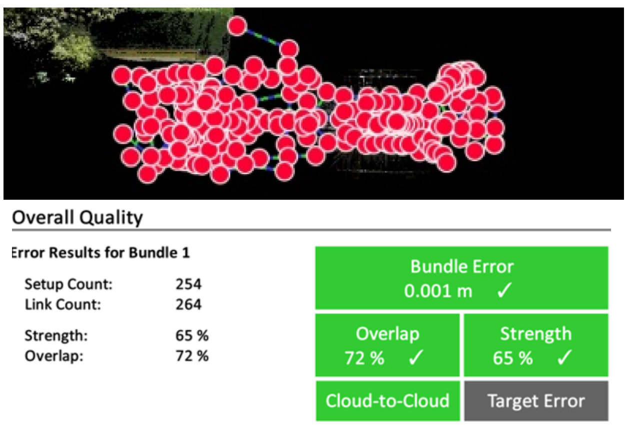

Figure 6. Sample of point cloud captured by laser scanning with millimetric precision.

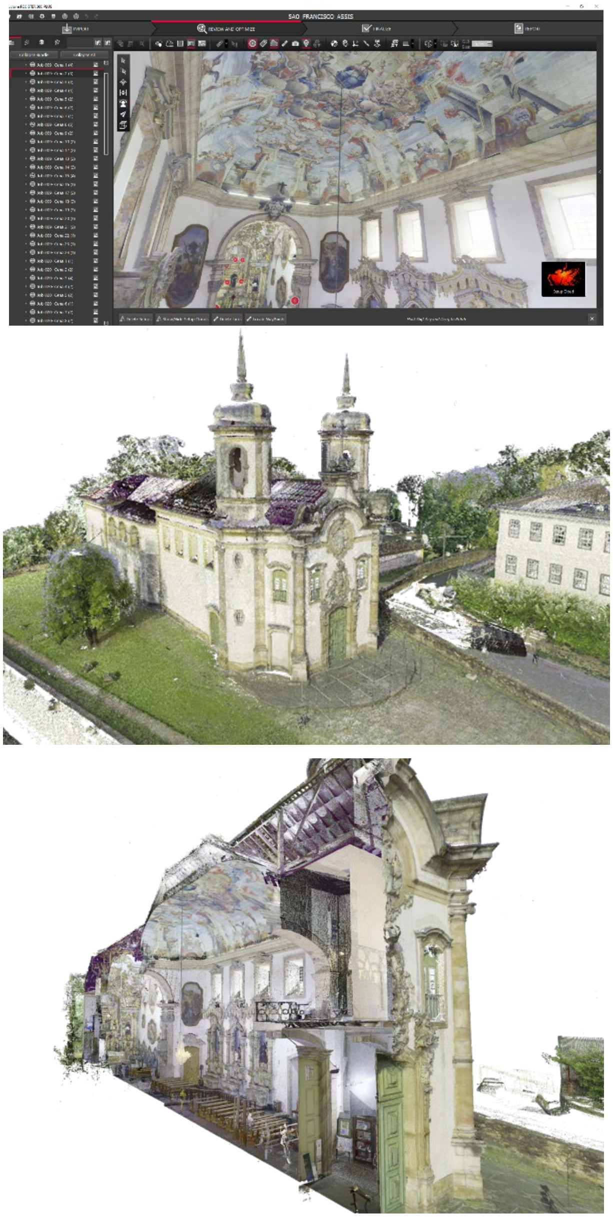

Figure 7. Sample of point cloud captured by laser scanning with millimetric precision.

3.3 Reality capture to virtual tours

To create an immersive virtual tour experience with high-resolution 360° images, the technology of the Matterport online platform was applied, using the Matterport Pro3 scanner. The Pro3 features a panoramic camera with resolution of 134.2 MP (megapixel) and LiDAR scanning technology.

The captured three-dimensional data are automatically registered by the Matterport software, generating a unified point cloud. The Pro3 can be operated via an application installed on a tablet or smartphone (Figure 8).

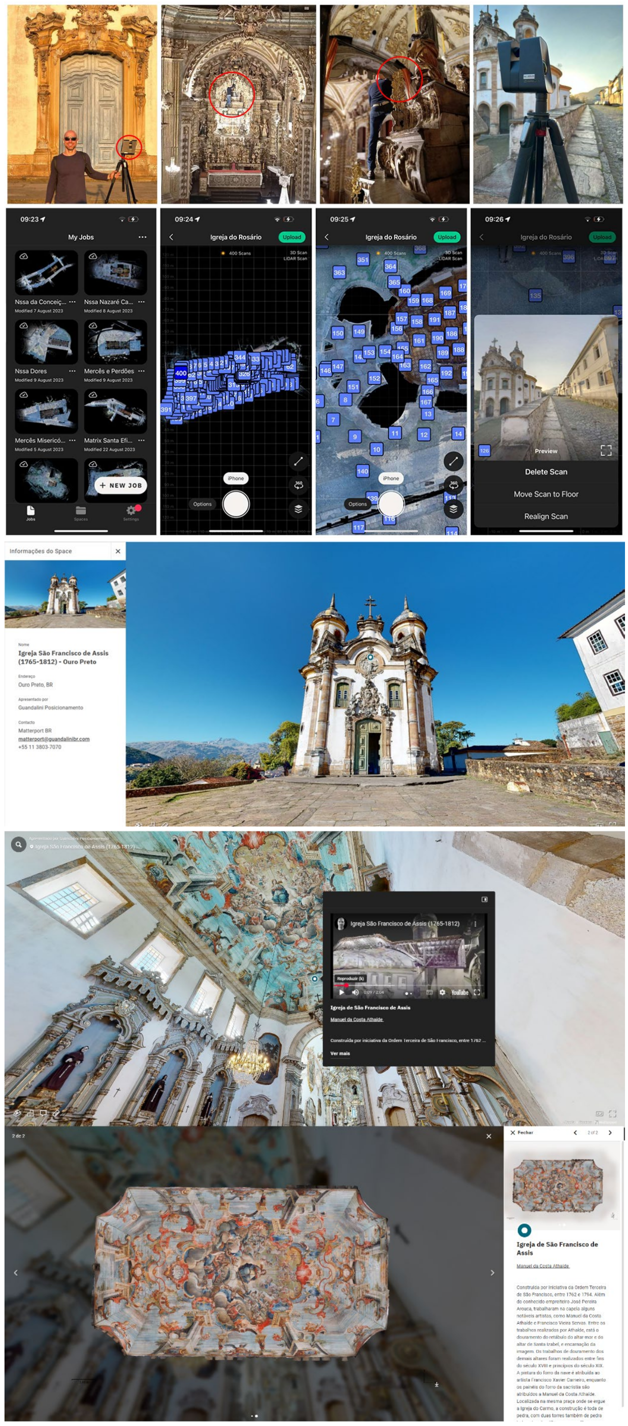

Figure 8. Mattepport’s virtual tours and app interface.

Figure 9 presents a summary of the churches and chapels registered from the scan captures available for virtual tours.

Figure 9. Summary of the churches and chapels registered by Matterport Pro3.

3.4 Reality capture: Ouro Preto's historic downtown

In order to guide and georeferencing the point cloud of the scanned churches, a LiDAR measurement of the topography, the external parts of the buildings and the streets of the historic center of Ouro Preto/MG was carried out using the CHCNAV AlphaAir 450 Lidar coupled to a DJI Matrice 300 RTK drone.

In a 20-minute flight at an altitude of 50 meters at an altitude of 50 meters above the ground level, it was possible to scan the urban layout and the main churches of Ouro Preto. As a result of the measurements, a point cloud with an absolute georeferenced accuracy of 10 cm horizontally and 5 cm vertically was generated. The point cloud can be visualized online using Potree. Potree is a free and open-source software for rendering large point clouds directly within web browsers (Figure 10).

3.5 Reality capture by photogrammetry

Photogrammetry has a dual role in heritage documentation, as discussed by Borges (2022). The creation of 3D assets not only enables the capture of geometrical features but also creates an immense database of highly detailed photogrammetry data that can be indexed through the 3D reconstruction method. In this sense, a discussion about photogrammetry must start establishing practices that optimize the acquisition of high-quality data. The most challenging aspect was the impact of the environment, especially the weather, on data quality.

Figure 10. Point cloud of Ouro Preto's historic downtown web visualization supported by Potree.

Specifically, harsh light produces shadows and highlights that cannot be removed further ahead in processing, thus staining the textured model. To expose the image correctly in such conditions can be challenging and may be aggravated if the used cameras have a limited dynamic range, such as compact drone sensors. Other conditions may cause undesired reflections and other surface effects. For these reasons, this work played a patience game, waiting for the best climate conditions to register the best images possible. The ideal environmental condition would be a cloudy and dry day at noon, in which one could expect soft lighting with decent intensity. In some instances, photographs were taken from the shadowed sides of buildings, opposite to the sun's position. This approach enabled image capture under non-ideal lighting conditions, although it extended the duration of the documentation process. In contrast, rooftop photography required optimal lighting conditions.

The equipment used consisted in a DJI Mini 3 Pro (48 MP) and Parrot Anafi Work (21MP) quadcopter drone and a Pentax K-70 camera. Both were used in complementary fashion, the camera yielding higher productivity in areas closer to ground and, by dividing the job, allowed the drone to be used for more time where it was needed. The camera was mostly handheld in outdoor sessions when lighting permitted sharp images. The lens was a Pentax-DAL 18-55mm f-1/3.5-5.6 at 18mm and f-1/11. In our tests, this configuration produced the best models. ISO was always kept below 400 and, if needed, a tripod was used. The drone, however, could be used even in relatively dark environments due to its stability. However, image quality quickly degraded when light became not ideal, and its use would be limited by the available lighting.

Processing was done employing an AMD Ryzen 5950x with 128gb of RAM and an Nvidia RTX 4090 graphics card using Metashape 1.8. The sparse cloud was generated in chunks that were merged to generate a single mesh. The model was then texturized utilizing all the RAM available, which resulted in highly-detailed textures.

Based on the digitalization of the Church of São Francisco de Assis’s facade, 2,091 images were captured from assorted positions and angles, with the aim of documenting all artistic and architectural details of the structure, as depicted in Figure 11. During image acquisition, the researcher meticulously ensured a 1/3 overlap for each image to facilitate the convergence and orientation of the photographs during the photogrammetric model creation in the processing phase.

Figure 11. Outdoor Reality capture of facade by Photogrammetry.

As a result, a 3D model rich in geometric details and material texture information was generated. Figure 12 presents the result of the external digitalization of the Church of São Francisco de Assis.

Figure 12. Photogrammetry facade model sample.

For the photogrammetric digitization of the ceiling paintings, the Parrot Anafi Work drone was utilized, which featured a gimbal capable of 90° vertical rotation for photography. Figure 13 presents the model of the painting by Mestre Ataíde (1812).

Figure 13. Indoor painting ceiling photogrammetry by Parrot Anafi drone with 90º vertical gimbal.

For the reality capture of sculptures, a Pentax camera was employed, as shown in Figure 14. Alternatively, high-resolution smartphone cameras (e.g., iPhone 14 Pro) can also be utilized, which similarly yield good results in the quality of the photogrammetric product.

Figure 14. Photogrammetry of sculpture by Pentax camera.

4. The pedagogical impact of virtual tours

The proposal to integrate virtual tours produced under the "OURO PRETO FOREVER" project into the pedagogical practices of IFMG's Conservation and Restoration Technology program tested the potential of these digital tools as teaching-learning devices for ceiling analysis. The methodology incorporated stages already familiar to students, such as technical analysis of construction elements, into the context of the digital environment. The comparison with in-person visits enabled the preparation of technical reports (Almeida Carmo et al., 2025) guided by applicable brazilian technical standards for heritage assessment (Figure 15). Some reports particularly illustrate the limitations and potentials of the activity.

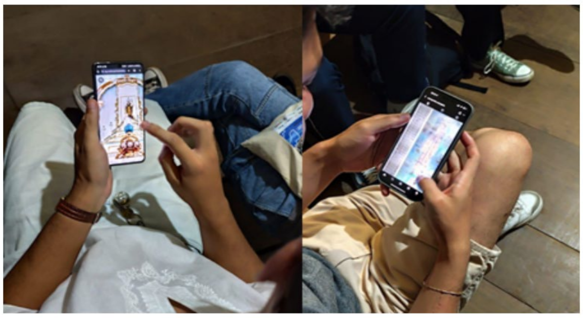

Figure 15. Virtual inspection using Matterport.

Student Vinícius Simedo, in his virtual analysis of the ceiling from Igreja de Nossa Senhora do Rosário dos Homens Pretos (1765), used digital measurements and on-site observation of pictorial damage to prepare a technical report. His diagnosis revealed vertical cracks, which he could measure, reinforcing the relevance of 3D scanning for analysing hard-to-access and detailed elements (Figure 16).

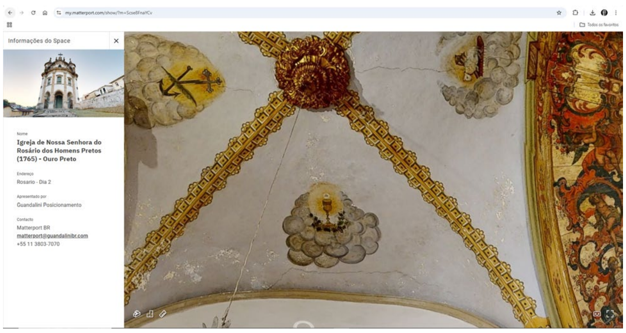

Figure 16. Virtual inspection at Igreja de Nossa Senhora do Rosário dos Homens Pretos (1765) - Ouro Preto.

Student Vanderlei Nonato analysed the ceilings of the Igreja São Francisco de Paula in Ouro Preto. The report, prepared based on an in-person visit and the virtual tour, concluded that the ceiling's overall condition was good, but noted deterioration of the paintings. For the student, combining on-site observation with the project's database was essential for cross-referencing data, highlighting the importance of hybrid methodologies in the diagnostic process. Student Gustavo Caldeira focused his study on analysing the nave ceiling of the Igreja de São Pedro dos Clérigos in Mariana. Using a combination of virtual inspection and previous on-site observations, the student noted the good conservation condition, observing only dirt accumulation as a factor requiring maintenance routine. The work demonstrated how even the technical analysis of simple elements requires mastery of digital tools, interpretation of historical data, and attention to less evident pathological processes. It is crucial to emphasize that serious degradation phenomena may be masked by the painting's apparently good condition, demanding more in-depth investigations and additional technological tools for thorough examination.

Despite the success demonstrated by the completion of these combined-method works, the process revealed significant challenges. The main challenge was considered to be the students' autonomous use of digital resources, as they conducted technical diagnostics based on virtual models for the first time, making it hard to fully explore the tool's potential. Difficulties typically noted in preparing technical reports and conservation assessments without virtual tours (such as the absence of scaffolding and drones as significant limitations) did not occur with the combination of both methods proposed in this activity. Another reported challenge was that the activity proposed not only damage description but also interpretation of causes and identification of deterioration agents, which created uncertainty when issuing technical recommendations based on virtually obtained data the students themselves had not captured or processed. These difficulties, far from compromising the results, reinforce the pedagogical value of the proposal, based on real building problems, as an experience that contributed to developing critical observation skills and sharpening interest in further study of technological tools.

Regarding the quantitative and qualitative data on public use of the online materials, it should be noted that the number of accesses to the tours on the Matterport platform, since their publication in 2023, has exceeded 5,000 visits. However, much like the metrics collected through Instagram – where the 'OURO PRETO FOREVER' project maintains an account – it is considered that access numbers fall short of the initiative's full potential. User comments and interactions remain consistently positive, yet they help reveal the need for joint efforts in promotion and the development of more partnerships and experiences like those conducted with IFMG.

5. Conclusions

This study demonstrated that the application of digital documentation technologies transcends mere data preservation and establishes itself as a fundamental pedagogical engagement tool for cultural heritage. The "OURO PRETO FOREVER" project provides evidence that the convergence between reality capture technologies and heritage education is not only viable but essential for safeguarding complex sites like Ouro Preto.

The main outcome of this research emerged from the collaborative experience with the Technology in Conservation and Restoration program at IFMG. The hybrid methodology, which combined virtual and on-site inspections, enabled students to elaborate complex technical reports, overcoming access barriers and deepening their diagnostic capabilities. The encountered challenges proved to be an integral part of the learning process, fostering critical thinking and professional accountability among future conservators-restorers. The partnership model between the technological sector and educational institutions establishes a replicable precedent for other historical sites. Furthermore, by making the digital collection publicly available, the project democratizes access to Ouro Preto's heritage and offers a precise database for conservation planning.

For the future, the research points to the need for developing more in-depth metrics to evaluate public engagement with virtual tours and for exploring the application of other technologies for automated pathology analysis from the collected data. The expansion of the methodology to include participatory processes also presents itself as a promising path. The "OURO PRETO FOREVER" project demonstrates that digital heritage documentation is not an end, but a dynamic starting point: a foundation for education, an invitation to public exploration, and an essential guarantee for safeguarding history for future generations (Figure 17).

The project is on constant development and updating its database with new reality capture efforts for complementary measurements by new technologies. The initiative aims to be a perpetual effort in preserving the history of Ouro Preto, Brazil.

Figure 17. Ouro Preto Forever protects heritage sites for next generations.

Acknowledgements

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