H BIM RECONSTRUCTION IN CULTURAL HERITAGE: THE CASE STUDY OF THE CASINA CENCI GIUSTINIANI, ROME

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1. Introduction

The preservation of cultural heritage represents a multifaceted challenge that necessitates a deep understanding of historical contexts while simultaneously embracing future technological advancements. As articulated by Martinsson-Wallin [1], this endeavour transcends the mere conservation of physical sites; it encompasses the temporal and cultural significance of these locations. Within the complex contemporary framework of global changes, the goal of these protective efforts is to foster a more eco-sustainable and liveable built environment, ensuring the safeguarding of historical and cultural contexts [2], while coping with sustainability issues. The complexity of cultural heritage protection requires a holistic approach, necessitating coordinated actions among governments, stakeholders, and users [3]. These physical sites are, moreover, inextricably linked to broader social, cultural, and economic needs [4]. The global significance of cultural heritage protection was underscored by the UNESCO Convention of 1972[1], which sought to establish a global framework for recognizing, protecting, preserving, and disseminating cultural and natural heritage for future generations, while addressing urban and territorial planning as well as national directives [5]. In line with UNESCO principles, the European Union has developed a comprehensive framework for cultural heritage preservation that encompasses tangible, intangible, and digital dimensions, emphasizing themes such as remembrance, understanding, identity, dialogue, cohesion, and creativity [6]. The European Framework for Action on Cultural Heritage, as outlined in the new European Agenda for Culture, aligns with the Council of Europe's European Heritage Strategy and is built upon five key pillars, namely: inclusion, sustainability, resilience, innovation and partnership [7]. A comprehensive digital approach aligns with the European Union's emphasis on innovation within cultural heritage preservation, as it allows for more effective stakeholder collaboration and informed decision-making regarding conservation strategies [6]. Moreover, the use of advanced technologies can help to bridge the gap between historical significance and contemporary urban and societal needs, fostering a resilient framework that supports both preservation and adaptive fruition of heritage sites, ultimately contributing to a more sustainable urban envi-

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ronment [1,8]. Despite the evident international commitment to innovative and collaborative strategies for cultural heritage preservation, the responsibility for implementing these policies ultimately lies with Member States, as well as regional and local authorities, who must adapt the framework to their specific contexts. This topic holds great relevance in Italy, home to a vast array of cultural assets, including 4,026 museums, galleries, and collections, 293 archaeological areas, and 570 monumental complexes [9]. Italy is the country with the largest number of sites on the UNESCO World Heritage List. There are 60 recognised 'world heritage' sites and 19 on the representative list of intangible cultural heritage[2]. In this context, digital technologies play a pivotal role in the restoration and protection of cultural heritage, facilitated by advanced techniques such as three-dimensional scanning and architectural studies, which incorporate knowledge of ancient materials and construction techniques [10–13]. Recent innovations, including Historical/Heritage Building Information Modelling (HBIM) and Digital Twin (DT) technologies, have revolutionized the architectural and engineering fields [14]. Initially developed for new construction projects, these tools are now demonstrating their potential in the protection and restoration of historical structures [15,16]. Building Information Modelling (BIM) enhances management during the design and building phases by creating an accurate representation of the site, while Digital Twin technology enables continuous monitoring of the performance of historical structures, providing a comprehensive view of their current and future conditions through sensor data and simulation algorithms. However, challenges remain in standardization and definition, which may introduce uncertainties in the application of these technologies to cultural assets [17]. Thus, a shared and integrated approach is essential to tailor these innovative solutions for the preservation of the historical built environment. Moreover, the integration of digital technologies in cultural heritage preservation not only enhances restoration efforts but also fosters community engagement and education, thereby enriching the cultural narrative of historic sites. For instance, the application of Digital Twin technology can facilitate real-time data sharing with local communities, enabling them to participate actively in the preservation process and fostering a sense of ownership and responsibility towards their cultural heritage (5). Furthermore, the challenges posed by natural disasters, as seen in the aftermath of the 2016 earthquake of Amatrice and the 2019 earthquake in Aquila, highlight the necessity of employing these technologies, together with satellite data, to create robust risk assessment and management strategies that not only protect physical structures but also preserve the intangible cultural values associated with them [18,19]. By combining innovative digital solutions with community involvement, cultural heritage preservation can evolve into a dynamic process that not only safeguards the past but also enhances a sustainable future for urban environments. This paper is aimed at demonstrating how it is possible to develop a 3D HBIM model for a historical building from aerial photography and direct inspection using simple instrumentation such as laser distance measurement tools and cameras. The discussion starts with a presentation of what BIM is and the differences between BIM and Heritage/Historical Building Information Modelling (HBIM). It then looks at the case study of Casina Cenci Giustiniani located within the urban park of Villa Borghese in Rome, along with the procedure used to 3D reconstruct the building and the results obtained. The building will be refurbished next year thanks to a dedicated intervention founded by CNEL and coordinated by Sapienza University of Rome. The project will restore the old functionality of the building with the aim to create an innovative study centre. Within the goal of the project is the aim to develop a Positive Energy Building (PEB), one that is oriented towards sustainability and able to produce energy that can also be used by other neighbouring buildings.

2. BIM - Building Information Modelling for cultural heritage

The integration of BIM within the construction sector has marked a transformative phase, characterized by a shift towards digital methodologies that leverage computerized modelling and multiple data-driven collaboration. This approach encapsulates all pertinent information into a comprehensive 3D model, thereby enhancing the visualization of construction processes throughout the building lifecycle [20]. BIM was developed initially for use in new construction projects; however, nowadays its application has widened to encompass restoration efforts, including the preservation of private and historical structures [21]. In Italy, the increasing adoption of BIM is largely attributed to the national regulation related to its mandatory implementation in public utility buildings [22]. BIM models are more than a simple 3D representation of an object, they contain all the information related to the structure, from the construction techniques and materials used, up to the costs and final maintenance interventions. Another key aspect of BIM is its capability to enable different stakeholders to collaborate effectively across shared data environments. This collaborative approach reduces design discrepancies, improves project workflows, and enables real-time updates and communications. The use of BIM goes beyond simple 3D modelling; it also includes 4D (time), 5D (cost) and even 6D (sustainability) aspects, offering a complete view of project life cycles [23,24]. The UK government has mandated the use of BIM for all public sector projects that exceed £5 million by 2025, underlining its importance in ensuring high standards and efficiency in construction projects. Italy seems to be on a similar path: with Italian legislative decree 36/2023 and the subsequent 209/2024 decree, it will be mandatory to develop BIM models for new constructions and restoration projects for public administration. From January 2025 the thresholds are 2 million euros for new constructions and 5.382.000 euros for works on cultural heritage buildings. These regulations highlight the role of BIM in driving modernization and compliance with new industrial standards.

2.1. Limitations of BIM for cultural heritage

Despite the recent advancements in BIM technology, challenges persist in its integration into conservation processes, particularly concerning the incorporation of comprehensive information about the physical and mechanical properties of building components. While geometric modelling remains a focal point, the significance of data capture and management for cultural assets cannot be overstated. Such information is critical not only for conservation and restoration processes but also for preserving the historical knowledge of the construction techniques and materials used [24]. The current BIM framework, which excels in assimilating data from manufacturers of new constructions, encounters substantial barriers when applied to the restoration of ancient buildings. The requisite specifications for architectural elements often necessitate extensive diagnostics and studies, complicating the BIM integration process [25]. As the integration of BIM in cultural heritage restoration continues to evolve, it is crucial to explore the potential of collaborative frameworks that engage various stakeholders, including local communities, architects, and engineers. Such collaborative efforts can enhance the richness of the data incorporated into BIM models by incorporating diverse perspectives and localized knowledge, ultimately leading to more informed conservation strategies. For instance, the implementation of participatory design workshops can facilitate dialogue among stakeholders, allowing for the co-creation of restoration plans that resonate with the community's historical and cultural narratives [26]. Additionally, fostering partnerships between academic institutions and local authorities can lead to innovative research initiatives that address the challenges of integrating historical data into BIM frameworks, ensuring that the cultural significance of heritage sites is preserved alongside modern technological advancements. This holistic approach not only strengthens preservation efforts but also promotes a shared responsibility among stakeholders, enhancing the sustainability and resilience of cultural heritage management in the face of contemporary urban challenges.

The efficacy of a BIM model is intrinsically linked to the richness and accuracy of the information embedded within its geometric assemble. However, the limitations of the existing BIM approach for restoration projects highlight the need for a paradigm shift. This includes the integration of change tracking for materials and interventions, the incorporation of diagnostic data into BIM metadata, and the establishment of classification systems focused on restoration processes [27]. Furthermore, the adoption of standardized data formats, such as Construction Operations Building Information Exchange (COBie), is essential for facilitating collaboration among diverse stakeholders involved in restoration efforts [28]. To address the unique challenges posed by historical contexts, personalized BIM strategies must be developed, ensuring that the safeguarding of historical features is prioritized from the outset of the BIM process. This necessitates a collaborative approach among all parties engaged in restoration, emphasizing the importance of integrating historical and archaeological insights into the BIM framework.

3. HBIM - Heritage/Historical Building Information Modelling

In construction, buildings undergo distinct Life Cycle Phases (LCPs) from conception to completion, including design, construction, and operational phases, as described below.

- Design Phase: Conceptualization, economic forecasting, architectural and structural definitions, and specification setting.
- Construction Phase: Scheduling construction operations, contract finalization, and completion testing.
- Operational Phase: Use, management, maintenance, and potential dismantling or reuse.

Although they are general in application and scope, the traditional LCP analysis is not directly applicable for restoration purposes considering the lack of knowledge related to elements inside existing buildings that must be preserved in their integrity as far as possible. Indeed, the restoration and conservation of historical buildings require a meticulous and methodical approach to ensure the preservation of their original formal and aesthetic characteristics while maintaining their architectural and economic value [29,30].

According to the Italian Code for the Preservation of Cultural Heritage and Landscape, restoration involves operations aimed at maintaining the material integrity of a historical asset and safeguarding its cultural significance. Contemporary Italian regulations vary from approaches that emphasize a careful "reading" and preservation of every historical layer of a monument to those focused on requalifying missing parts or modifying elements to restore an idealized form of the monument [31,32]. Therefore, for historical buildings, the traditional LCPs must be adapted to restoration processes.

- Design and Diagnostic Phase: In-depth examination of the building's conservation status, including historical and evolutionary analysis, to set preservation objectives collaboratively with stakeholders, ensuring the protection of historical, cultural, and economic values.
- Intervention Phase: Execution of planned restoration actions focused on heritage protection, supervised by the same stakeholders.
- Maintenance Phase: Long-term management and systematic maintenance to preserve the building's integrity over time.

The first two phases, design/diagnosis and intervention, must be enhanced through HBIM to develop a concrete approach specifically oriented to the building under examination [28,33]. It is of mandatory importance to obtain an actual digital model of the building, comprehensive of all the materials used, the damage, and the construction process used.

The development of such a model, however, can be complex, because historical buildings, especially the oldest, usually lack documentation, due to the fact that the respective archives have often been lost or damaged [4,30]. Therefore, the study of the old construction techniques and the use of digital tools to reconstruct and examine the shape of the building, the stratigraphy, and the damage to structures and artworks it contained is of mandatory importance [15,18,34–36]. HBIM is also useful during maintenance, where any intervention performed can be tracked to the same digital model by showing any changes the building was subjected to during its lifecycle.

3.1. Advancements in HBIM

HBIM models can be also linked to Digital Twins (DTs), which allows continuous monitoring and management of the building's condition, supporting preventive maintenance and long-term conservation strategies. The scientific literature on the subject is full of examples [15,17,37–40]. One of the main applications of these two technologies together was during the fire of the cathedral of Notre Dame de Paris in 2019 [36,41–42]. During the event, over 200 tons of lead from the roof and spire melted, causing widespread environmental contamination. Using Digital Twins[3] as well as developing an HBIM model, the city of Paris was able to plan and perform one of the most challenging restorations in the history of cultural heritage.

They reconstructed the original shape of the building using 3D models from games and photography, developed a complex restoration plan using HBIM methodology, and performed the intervention inspecting the results in real time using Digital Twins. The restoration process was completed on December 7, 2024, and the cathedral is now open to the public. The digital twin model is still operating to prevent any further accident that may cause damage to the building, as well as to monitor the conservation state of the building itself.

Once an HBIM model is realized, it represents a digital archive of the building that can be maintained and updated constantly, efficiently increasing the knowledge of the structure also for further restorations. It also allows for rapid visualization of restoration proposals and efficient generation of quantity take-offs, facilitating transparent information exchange and compliance with existing regulations [14,18,43]. This also results in a reduction of costs by inspecting restoration alternatives and scenario [30,44]. This is also the focus of this paper.

4. The case study of Casina Cenci Giustiniani

The proposed case study is the Casina Cenci Giustiniani, a building located inside the urban park of Villa Borghese in Viale Davide Lubin n.4. It has been a listed historic building of the Municipality of Rome since 2025 and is currently used by the National Council of Economy and Labor (CNEL). Figure 1 shows the urban context on map. The CNEL presidency acquired the building from the municipality of Rome, which is located near its headquarters. With the acquisition, CNEL intends to open the building to the public, dedicating its spaces to the dissemination of its activities, and devoting the utmost attention to the restoration process, in order to make Casina Cenci Giustiniani the prototype for the highly sustainable restoration of a historic building in a valuable context.

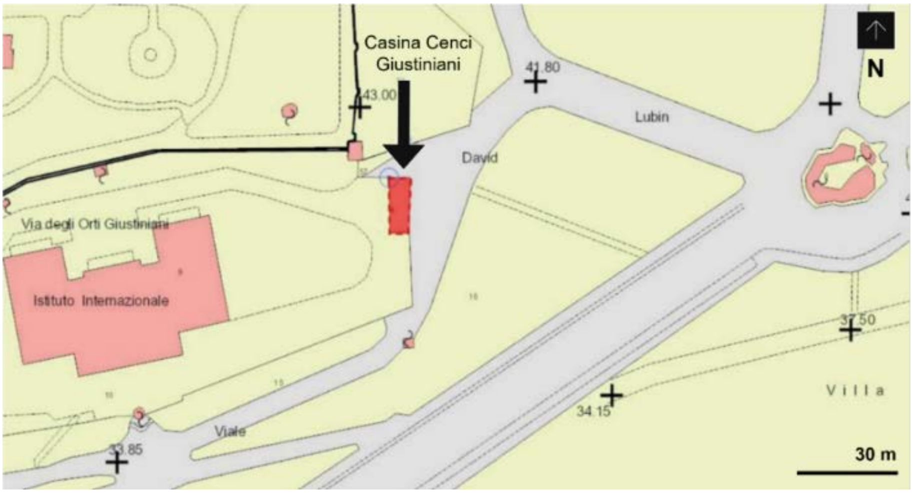

Figure 1. Urban context of the Casina Cenci Giustiniani within the park of Villa Borghese; the building is indicated by a red area under a black arrow.

The building is rectangular with a three-storey elevation, on the first floor is located a loggia open to the south, and the second floor has the shape of a tower. The overall surface of the building is about 150sqm.

The three floors are connected to each other by an internal staircase; the rooms are irregularly shaped with a variable ceiling height from 2,52m to 4,97m. On the first floor there is a barrel-vaulted ceiling while on the other floors there is a truss ceiling, the main room on the first floor has a fireplace on one side of the room that opens onto a south oriented small loggia supported by two stone columns. The second floor consists of a single turret composed of a small room with wooden ceiling. Figure 2 shows a photograph of the front of the building.

The layout of the internal spaces is documented in the land registry of the Municipality of Rome with the following cadastral identifiers: Sheet 554, Particle 8, Subaltern 501. As depicted in the cadastral map, the property is wholly owned by the municipality of Rome (Roma Capitale) and is classified as a building with a ‘special building typology’ (art. 26 of the Italian Consolidated Building Act).

Figure 2. Side view of the building Casina Cenci Giustiniani.

For the Italian regulatory body, the term special buildings and complexes of the historic city means archaeological-monumental complexes and individual and aggregated special buildings, including open spaces of relevance and public spaces (squares, streets, gardens) connected to them in a relationship of inseparable unity, which assume or can assume in the urban structure, a notable urban, morphological, symbolic and functional relevance.The interior planimetry, extracted from the cadastral map of the land particle is reported in Figure 3.

4.1. Historical context

According to the documentation retrieved from the CNEL archives, the building dates to the end of the sixteenth century and was rebuilt by the Giustiniani[4] family of Rome on a previous building. The structure stands on the land called *Orti Giustiniani*, previously owned by a female religious order. Formerly, the land had a prevailing agricultural purpose, and it can be assumed that the building originally served as a rural house for farmers (upper floors) and a tavern (ground floor). When the Giustiniani Family acquired the land, a large part of the agricultural area surrounding the small building was transformed into a formal late Renaissance Garden designed to showcase Marquis Giustiniani's collection of ancient statues and Roman marbles, making the garden one of the favourite destinations for “Grand tour” visitors coming to Rome between the 16th and 19th centuries as illustrated in Figure 4. One of the very few vestiges of the ancient Giustiniani Garden is today the large niche identified as the Giustiniani Nymphaeum by the Capitoline Superintendence for Cultural Heritage, located under the embankment of Villa Lubin, a few meters from the Casina Cenci Giustiniani[5]. Figure 5 shows the *Ninfa Egeria Giustiniani* statue in the garden, currently part of the Torlonia marble collection.

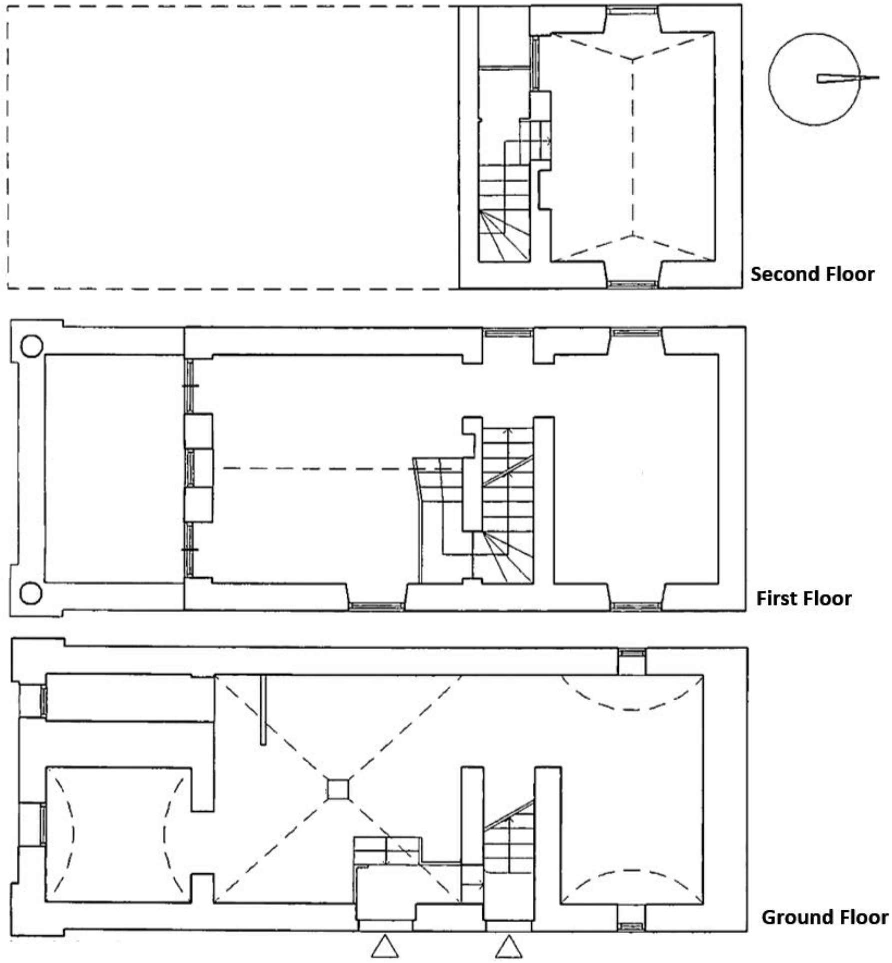

Figure 3. Planimetry from the cadastre of the building located in Viale David Lubin, number 4 in Rome (06/27/2017) (source: Land registry of Rome).

In 1820 the building was purchased together with the surrounding garden and agricultural land by the Borghese family and extensively remodelled to become part of the expansion program of the previous Villa Pinciana. The project was started in 1606 by cardinal Scipione Caffarelli Borghese (1576-1633), nephew of Pope Paul V (1605-1621). Subsequently, Villa Pinciana was continually expanded by the Cardinal's successors, with the largest expansion undertaken by Prince Camillo Borghese (1775-1832), the husband of Pauline Bonaparte and sister of Napoleon I, Emperor of the French. Prince Camillo also proceeded to acquire the Giustiniani vineyard towards Porta del Popolo, where the Casina is located. As it is rather problematic to identify the building from among several artistic paintings referred to as “Casina Cenci Giustiniani”, there is no verified information about restoration interventions performed over the centuries.

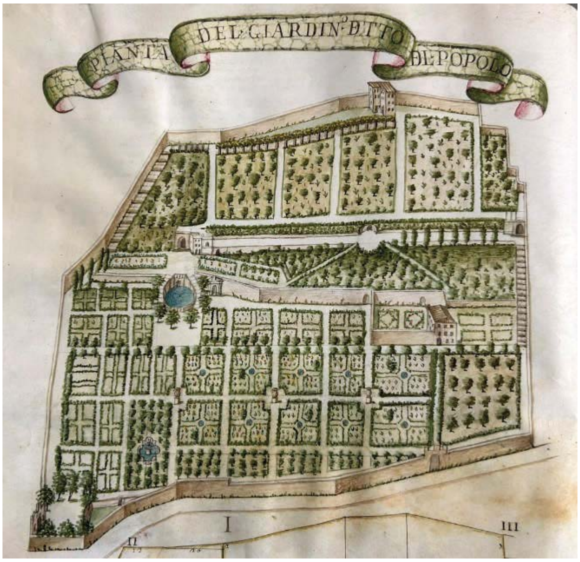

Figure 4. Plan of the Giustiniani Garden at Porta del Popolo. The plan is included in the "Cabreo" (from the Latin word for register) Giustiniani dated 1687 and held by the Italian National State Archive (courtesy of Claudio Mancini, CNEL).

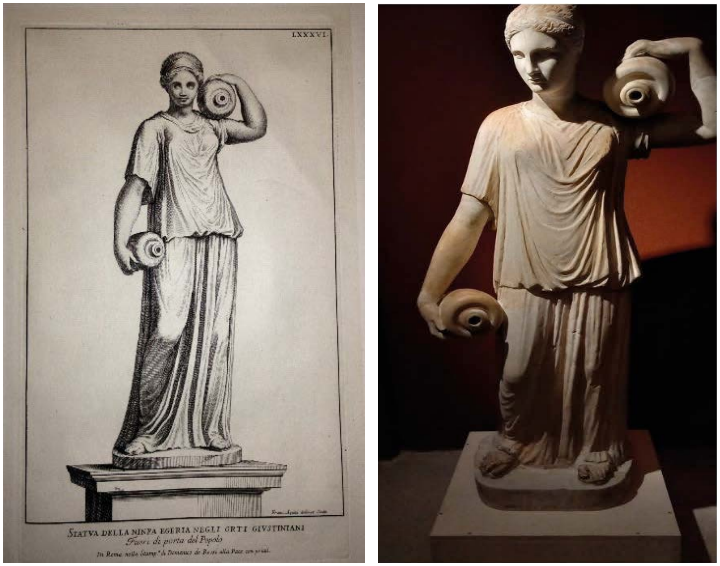

Figure 5. Antique print of the statue of the Nymph Egeria (left) and a 2024 photograph of the statue (right) currently part of the Torlonia marbles collection (source: CNEL archives 2025 and modern photo given to the authors by Prof. Roberto Valeriani).

This latter edifice, historically classified as the custodian's house within the Villa Pinciana (and subsequently integrated into Villa Borghese), shows a bipartite architectural composition comprising a lower volume with a sheltered loggia and an elevated turreted element. In 1901, the entire Villa Borghese park and all the buildings within it became the property of the Italian State, thus preventing, among other things, a speculative building project in the current area of Piazza di Siena [45]; the municipality of Rome later acquired the complex of the green area and some buildings from the State for 3 million Italian lire of the time, naming it "Villa Comunale Umberto I Borghese". The Casina Cenci Giustiniani was briefly, in 1907, the temporary headquarters of the International Institute of Agriculture promoted by the American philanthropist David Lubin[6] under the high patronage of King Vittorio Emanuele III of Italy, pending the construction of Villa Lubin, the building dedicated to the institute, and presently the headquarters of the Italian National Economic and Labour Council.

4.2. Current state of conservation

Casina Cenci Giustiniani is in a good state of preservation regarding its interior spaces. A relevant exception to the overall state is represented by the roof of the turret, which is in a severely deteriorated condition due to the fall of a tree branch that has punctured the covering. The only exception is the roof on the second floor, which was damaged by a tree branch (see Figure 2). The other areas do not exhibit significant signs of decay; in particular, the floors and masonry are well preserved without signs of cracks or subsidence. However, the wooden beams supporting the truss structures of the roofs on the first and second floors require a structural assessment to ensure their stability, especially considering the age of the building. Several images of the interior spaces showing the current state of the inside of the building are reported in Figure 6.

Figure 6. Interior of the Casina Cenci Giustiniani. As can be seen from the photos, the overall state of conservation is quite good.

It was impossible to get stratigraphical and technological data from archives regarding the materials and technological processes used to build the structure; therefore, the information was obtained from literature studies and direct on-site inspection. Drawing upon historical data concerning predominant masonry techniques employed in Italy during the sixteenth and seventeenth centuries, several significant characteristics can be identified for the case study of Casina Cenci Giustiniani [46–50]. The construction techniques reflect the empirical knowledge that characterized sixteenth century building practices. Sixteenth-century Italian walls typically utilized locally available materials, such as stone bricks, with construction techniques varying according to regional practices and building function.

- In accordance with standard Roman masonry traditions, stone bricks constituted the principal building material.
- The walls are primarily constructed of brick masonry arranged in regular courses.
- Lime-based mortar served as the standard binding agent, enhanced with pozzolanic materials to improve durability.
- Both interior and exterior wall surfaces featured lime plaster finishes. Given the building's primary function as the custodian’s residence, the indoor walls lack decorative elements such as frescoes or ornamental painting.
- A fresco is present on the exterior loggia. The decorative element is barely visible and covered by atmospheric dirt deposited over time.
- A timber truss system was used for the roof structure which supported a pitched configuration. The trusses were fabricated from substantial wooden beams, with secondary rafters and purlins providing support for the roof covering.
- Terracotta tiles, specifically the traditional Roman "coppi" and "tegole," constituted the waterproofing layer.

Considering the current state of the restoration project, the strategies oriented to preserve the building environment have not yet been defined, as well as the specific intervention for cleaning, consolidation, remaking of missing parts. This paper represents the step before the definition of such strategies, also orienting the intervention towards state-of-the-art building sustainability.

4.3. Urban framework

From an urban planning perspective, the property is subject to a landscape and wooded area constraint, classified under the category “territories covered by forests and woods” in accordance with Italian Legislative Decree no. 42/2004. Therefore, it is subjected to the landscape constraints reported in the following Table 1.

Table 1. Summary table of landscape constraints (Legislative Decree no. 42/2004)

Landscape Constraints	
Name	Land covered by forests and woods
Type of constraint	Landscape/wooded areas
Type of restricted asset	Land location
Regulatory references	Legislative Decree no. 42/2004 and subsequent amendments, specific regulatory reference art. 142 paragraph 1 letter g. (reference before Consolidated Law 431 of 8 August 1985)
The property is not inside an established green park.	

Within the current General Regulatory Plan (PRG) of Rome, the building is described in the prescriptive document "Systems and Rules" on a 1:10,000 scale, categorized under the "Settlement system – historic city – special buildings and complexes – historic villas." On a finer scale of 1:5.000, it is included in the "Systems and Rules" document within the "Settlement system – historic city fabrics of twentieth-century expansion with building subdivision points-shapes T7". Furthermore, in the "Quality Charter" (G1), the property is identified by the code 131.265, located within Villa Borghese, and classified among "Buildings with special building typology," specifically within the class of "Special residential, appurtenance" and typology "VI – Villa."

5. Survey methodology

For the creation of a digital model of Casina Cenci Giustiniani, an aerial survey was conducted using a DJI Mini 2 UAV (drone), with specifications detailed in Table 2, to capture the exterior of the building. Additionally, a verification campaign of the cadastral measurements shown in Figure 4 was carried out using a Leica s910 three-dimensional distance meter (specifications provided in Table 3) alongside photographic documentation obtained with a Nikon D810 camera with 35mm lens (Table 4).

Table 2. DJI Mini 2 UAV and camera specifications

TAKE-OFF WEIGHT	< 249 g
DIMENSIONS	Unfolded (with propellers): 245×289×56 mm (L×W×H)
MAX SERVICE CEILING ABOVE SEA LEVEL	4000 m
MAX FLIGHT TIME	31 mins (measured while flying at 4,7 m/s in windless conditions)
MAX WIND SPEED RESISTANCE	8,5-10,5 m/s (Scale 5)
MAX TILT ANGLE	40° (S). 25° (N). 25° (C) * Up to 40° under strong winds
GLOBAL NAVIGATION SATELLITE SYSTEM	GPS+GLONASS+GALILEO
HOVERING ACCURACY RANGE	Vertical: ±0,1 m (with Vision Positioning), ±0,5 m (with GPS Positioning) Horizontal: ±0,3 m (with Vision Positioning), ±1,5 m (with GPS Positioning)
STABILIZATION	3-axis (tilt, roll, pan)
OPERATING ENVIRONMENT	Non-reflective, discernible surfaces Diffuse reflectivity (> 20%, such as cement pavement) Adequate lighting (lux > 15, Normal exposure environment of indoor fluorescent lamp)
SENSOR	1/2.3" CMOS,: 12 MP
LENS	FOV: 83° 35 mm format equivalent: 24 mm Aperture: f/2,8 Focus range: 1 m to ∞
ISO	Video: 100-3.200 (Auto) 100-3.200 (Manual) Photos: 100-3.200 (Auto)

	100-3.200 (Manual)
SHUTTER SPEED	Electronic Shutter: 4-1/8.000 s
MAX IMAGE SIZE	4:3: 4000×3000 16:9: 4000×2250
PHOTO FORMATS	JPEG/DNG (RAW)

Table 3. Leica s910 specifications

WEIGHT	0,29 kg
DIMENSIONS	16,4 × 6,1 × 3,2 cm
ACCURACY / RANGE	1mm / 300m
BLUETOOTH	V4.0 Smart
FREE APPS	iOS/Android: DISTO Sketch, DIS-TO Transfer
RANGE	up to 300 m

Table 4. Nikon D810 specifications with 35mm lens

BODY TYPE	Mid-size SLR
MAX RESOLUTION	7360 x 4912
IMAGE RATIO W:H	5:4, 3:2
EFFECTIVE PIXELS	36 megapixels
SENSOR PHOTO DETECTORS	37 megapixels
SENSOR SIZE	Full frame (35.9 x 24 mm)
SENSOR TYPE	CMOS
PROCESSOR	EXPEED 4
ISO	Auto, 64-12800
BOOSTED ISO	32 - 51200
WHITE BALANCE PRESETS	12
CUSTOM WHITE BALANCE	Yes (6 slots)
IMAGE STABILIZATION	No
UNCOMPRESSED FORMAT	RAW + TIFF
FOCAL LENGTH	35 mm
APERTURE	f/1,8 - f/16
LENS CONSTRUCTION	11 elements in 8 groups
ANGLE OF VIEW	63°

The devices used for the in-field measurement campaign are shown in Figure 7.

Figure 7. The three different devices used during the measurement campaign: DJI Mini 2 UAV (left), Leica s910 (centre), Nikon D810 (right).

Given the substantial vegetation cover, the presence of tall trees, and the location of the building within a high-value area, the aerial survey was conducted entirely manually by the operator at an altitude of approximately 25 to 30 meters. This approach ensured that the captured images exhibited an overlap of approximately 70%, which is essential for optimizing the quality of data generated during subsequent software processing. High image overlap is critical for enhancing the accuracy and reliability of the outputs produced by photogrammetric software [35]. Moreover, given the small size of the building and the considerable tree cover in the area, aerial surveys were carried out exclusively by means of a low-altitude drone, the integration of satellite data was not deemed necessary. A total of 97 pictures were taken, the camera position with respect to the building is reported in Figure 8 where each triangle shows the shooting camera position and aperture. Acquired photographic data were subsequently imported into Structure-from-Motion (SfM) software (Agisoft Metashape) for processing. This workflow resulted in the generation of a dense point cloud comprising 7.626.192 points and a high-definition textured mesh consisting of 1.511.153 faces (Figure 9). All processed outputs were georeferenced to ensure spatial accuracy and to facilitate integration with other geospatial datasets. The average projection error, as calculated by the software based on satellite data and camera positions, was less than 3,27 cm. Furthermore, a selection of images is presented in Figure 10 to illustrate the aerial perspective of the building and to document the damage observed on the roofs. The average error across all measurements, including those from other floors, was lower, amounting to 2,23 centimetres.

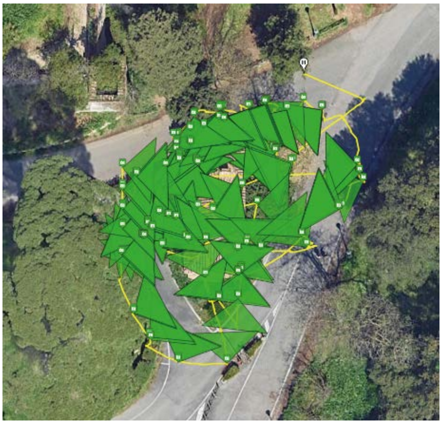

Figure 8. UAV flight plan, green triangles show the shooting positions.

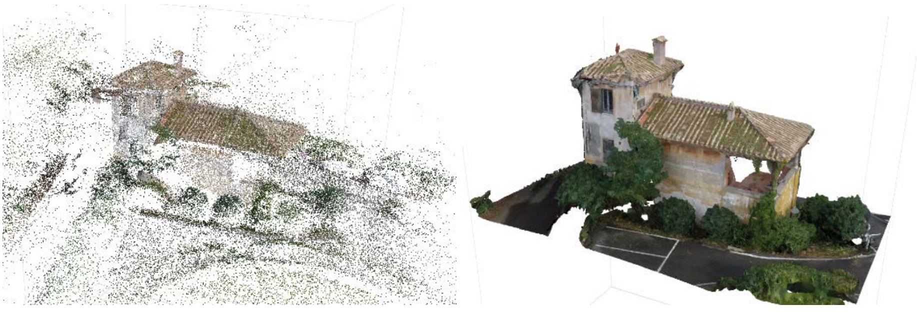

Figure 9. Sparse point cloud (left) and textured 3D model (right).

Figure 10. Aerial photos of the structure; damage to the roofs is clearly visible.

6. Results

The integration of the hardware and software technologies described in the preceding section, in conjunction with field investigations and archival and cartographic documentary research, facilitated the development of a comprehensive and current three-dimensional reconstruction of the historic Casina Cenci Giustiniani edifice.

The methodological framework employed for the generation of the HBIM model, along with the computational tools utilized, is delineated below.

This process has enabled the production of a parametric model of the structure, incorporating all requisite information to plan future restoration interventions.

6.1. HBIM of the case study

The initial phase of the methodology involves importing the point cloud data (Figure 11) into Autodesk Revit software to accurately capture the building's true dimensions. This serves as the foundation for the development of a simplified and appropriately scaled Heritage Building Information Model (HBIM). From the calculation, the internal area of the structure is 149 m^2. The representation was subsequently refined by incorporating planimetric measurements, thereby updating the cadastral data. This process was finalized through the integration of the photogrammetric model with the CAD representation. An example of this integration is illustrated in Figure 12, which depicts the overlap between the point cloud and the Computer Aided Design (CAD) *.dwg* file corresponding solely to the ground floor. The superposition and dimensioning procedures were applied to all floors of the building to verify the dimensional accuracy of the reconstruction and to assess the thickness of the walls. The methodology adopted thus enabled the creation of a reference model for verifying the constituent elements of the building system under investigation, as illustrated in Figure 13.

Figure 11. Point cloud imported into Autodesk Revit 2024 software.

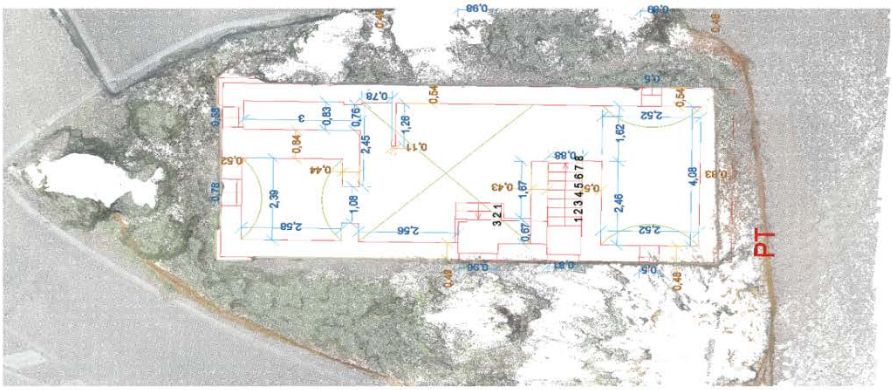

Figure 12. Combination of geometric data from the external and internal surveys.

From the model, four abacuses were generated, encompassing the geometric properties of the walls, to which technological information pertaining to the walls was subsequently appended. The technical systems were not integrated due to their non-compliance with current standards and thus necessitating their replacement. Furthermore, the building features only an exposed electrical system and lacks a heating system.

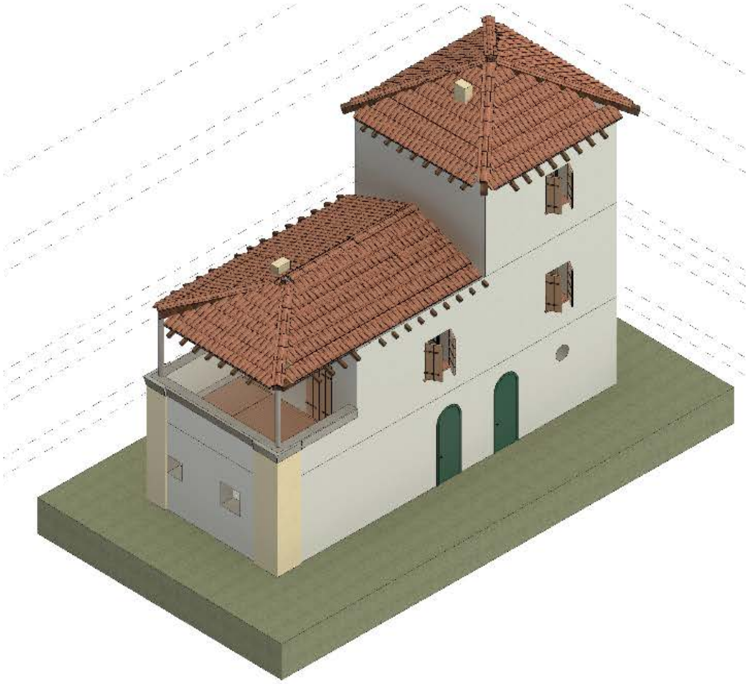

Figure 13. View of the parametric 3D model created with the Autodesk Revit 2024 authoring software.

6.2. Integration with technological data

The model developed thus far represents solely a 3D geometric reconstruction of the building, lacking information regarding the technological aspects of its construction.

The information reported in the "current state of conservation" section was used as a basis for the development of a parametric model, integrated with material and technological data.

This allows for a more accurate and detailed representation of the building's current state of conservation, allowing to plan precise restoration interventions using the same materials and techniques to preserve the original shape and functionality of the building. It is well known that old buildings are not very energy sustainable [43,51] with heat loss due to windows and doors frames, and the absence of insulating materials and thermal bridges.

Knowledge of the materials used, as well as of the geometry of the building is of mandatory importance to produce an accurate thermal model of the building, and consequently develop restoration strategies compliant with national and EU directives about energy usage in buildings, such as the Energy Performance of Buildings Directive (EU/2024/1275) and the revised Energy Efficiency Directive (EU/2023/1791) also known as the "Green Houses" directive [52]. The data was subsequently integrated with datasets derived from the UNI/TR 11552:2014 standard and the ENEA catalogue. This integration was performed to incorporate the thermophysical parameters of the building, thereby enabling comprehensive future energy performance assessments.

The building abacus relating to the vertical closing elements is reported as an example so as not to excessively burden the discussion (Table 5).

Table 5. Building abacus of the walls

Model Check		
STRATOGRAPHY	**THICKNESS [mm]**	**Notes**
Internal plaster 2 cm Bricks and stones 7 cm External plaster 2 cm	110	
Internal plaster 2 cm Bricks and stones 16 cm External plaster 2 cm	200	
Internal plaster 2 cm Bricks and stones 26 cm External plaster 2 cm	300	
Internal plaster 2 cm Bricks and stones 31 cm External plaster 2 cm	340	The 33 cm and 35 cm stratigraphy was replaced with the 34 cm stratigraphy deriving from the land registry pdf file.
Internal plaster 2 cm Bricks and stones 38 cm External plaster 2 cm	420	The 37 cm stratigraphy was replaced with the 42 cm stratigraphy deriving from the land registry pdf file.
Internal plaster 2 cm Bricks and stones 40 cm External plaster 2 cm	440	The 43 cm stratigraphy was replaced with the 44 cm stratigraphy deriving from the land registry pdf file.
Internal plaster 2 cm Bricks and stones 46 cm External plaster 2 cm	500	The 48 cm, 49 cm, 51 cm, 52 cm stratigraphies were replaced with a uniform 50 cm stratigraphy deriving from the land registry pdf file.
Internal plaster 2 cm Bricks and stones 50 cm External plaster 2 cm	540	
Internal plaster 2 cm Bricks and stones 80 cm External plaster 2 cm	840	The 83 cm stratigraphy was replaced with an 84 cm stratigraphy deriving from the land registry pdf file.

As observed, the 3D reconstruction measurements are inconsistent with the land registry records. Consequently, priority was given to the land registry data.

The resulting HBIM model can therefore be considered an accurate representation of the original building. Indeed, this model incorporates both geometric and technological information.

Finally, an exploded view of the building is presented, in which all architectural components and their respective dimensions are clearly visible (Figure 14). Each component is associated with actual stratigraphic data, thereby ensuring that the

HBIM model is appropriately tailored to the specific characteristics of the building under study.

Figure 14. Exploded view of Casina Cenci Giustiniani.

7. Conclusions

As stated initially, the preservation of cultural heritage is a complex and multifaceted challenge that requires a careful balance between historical fidelity and modern technological advancements. In the context of Italy, a country rich in historical and cultural assets, the necessity for a robust framework that accommodates both the preservation of historical integrity and contemporary urban needs is paramount. The European Union's commitment to cultural heritage preservation, and related comprehensive frameworks and strategies, underscores the importance of innovation and sustainability in this domain.

However, the successful implementation of these strategies at the local level relies heavily on the adaptability of Member States and their respective local authorities.

The case study of Casina Cenci Giustiniani illustrates the practical application of HBIM in reconstructing a historical building through a combination of aerial surveys, direct inspections, and advanced modelling techniques. The decision of the current CNEL presidency to acquire the small building on a long-term lease from the City of Rome and invest in it with an innovative restoration, appears to be of considerable cultural and social value, since it is aimed not only at addressing its own institutional purposes but also at experimenting with the highest sustainability criteria that can be applied to such an ancient building.

By capturing detailed geometric and technological information, the HBIM model not only facilitates future restoration interventions but also enhances community engagement and educational opportunities regarding cultural heritage.

Ultimately, the research aims to demonstrate that the integration of digital solutions, when coupled with collaborative efforts among stakeholders, can transform cultural heritage preservation into a dynamic process that not only protects the past but also fosters a sustainable future for urban environments. The HBIM model developed in this study will be used for energy evaluation of the building, leading to the development of simulations integrated with energy data and oriented at calculating in advance the energy use and class of the building using the elements contained in the HBIM model.

Notes

[1] The General Conference of UNESCO adopted the Recommendation concerning the Protection at National Level, of the Cultural and Natural Heritage on 16 November 1972. It brings together in a single document the concepts of nature conservation and the preservation of cultural properties. The Convention recognizes the way in which people interact with nature, and the fundamental need to preserve the balance between the two.

[2] The full list of UNESCO world heritage sites is available at: https://www.unesco.it/it/iniziative-dellunesco/patrimonio-mondiale/ [accessed on 3/5/2025]

[3] A digital twin is a virtual representation of a physical object, system, or process that is continuously updated with real-time data and used to simulate, predict, and optimize performance. They can be applied to any object or process, including buildings, where they represent one of the most advanced applications of digital technology to increase sustainability and resilience also in case of extreme events [37,53,54].

[4] The Giustiniani family was a prominent Genoese lineage whose influence originated in the fourteenth century through the aggregation of families engaged in trade with the island of Chios in the Aegean Sea. The family's ascent began in 1362, when they became central figures in the Maona Giustiniani, a trading company that governed Chios and managed its economic resources on behalf of the Republic of Genoa. Their administration of Chios, which lasted until the Ottoman conquest in 1566, brought considerable prosperity to the island, primarily through the trade of mastic and other commodities. In the sixteenth century, Giuseppe Giustiniani relocated to Rome, where he became one of the city's most influential bankers, leveraging the wealth accumulated from extensive commercial activities in the eastern Mediterranean. Among his sons, Benedetto Giustiniani achieved prominence as a cardinal, while Vincenzo Giustiniani distinguished himself as a significant art collector. In Rome, Giuseppe acquired the palace now serving as the residence of the President of the Senate of the Republic. The Giustiniani family also owned several notable properties

in Rome, including Villa Giustiniani Massimo, situated between Via Merulana and Via Tasso, and the Orti Giustiniani at Porta del Popolo, which is now incorporated into Villa Borghese, and where the Casina Cenci Giustiniani is located.

[5] Capitoline Superintendence of Cultural Heritage, printed on Tuesday, February 20, 2024. VB201 Location Ninfeo Giustiniani 1575 (post) - 1599 (pre) 16th century last quarter fountain tuff in blocks / peperino / travertine mnr Villa Borghese, below the semicircular terrace of the building that houses the C.N.E.L.- Villa Lubin Viale David Lubin District 3- Pinciano.

[6] David Lubin (1849-1919), an American merchant and philanthropist, promoted the founding of an international institution aimed at dealing with world food problems. After a meeting with Victor Emmanuel III of Italy, the young king gave his personal patronage to the project that led to the creation of the Rome-based International Institute of Agriculture, from which the Food and Agricultural Organization (FAO) of the United Nations would later emerge in 1945.

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Summary

This paper explores the application of Heritage/Historical Building Information Modelling (HBIM) as a transformative tool for the restoration and management of historical structures focusing on the case study of Casina Cenci Giustiniani in Rome. HBIM is an extension of Building Information Modelling (BIM) specifically designed for the documentation, management, and conservation of historic and heritage buildings, utilizing parametric 3D models enriched with both geometric and historical data. HBIM enables the integration of detailed survey data and archival research to create intelligent digital representations that support restoration, maintenance, and analysis of existing architectural heritage. The HBIM methodology is especially pertinent for architectural heritage, where a thorough and multifaceted understanding of the asset is indispensable for any restoration and conservation strategy. The implementation of HBIM facilitates the systematic organization of relevant data, supporting both the documentation phase and subsequent inspection and diagnostic tasks. The methodological process used in this paper involved a scan-to-BIM strategy to reconstruct the three-dimensional model of the building from oriented images, minimizing labour-intensive and error-prone manual operations. This has enabled the creation of an accurate as-built model that preserves critical information regarding external dimensions, material compositions, deformations, and structural conditions. The resulting digital model serves as a comprehensive repository, hosting and embedding multiple data sets that collectively constitute a robust informational framework for future conservation efforts.

Riassunto

Questo articolo esplora l'applicazione dell'Heritage/Historical Building Information Modelling (HBIM) come strumento trasformativo per il restauro e la gestione di edifici storici focalizzandosi sul caso studio della Casina Cenci Giustiniani a Roma. L'HBIM è un'estensione del Building Information Modelling (BIM) specificamente progettata per la documentazione, la gestione e la conservazione di edifici storici e di interesse storico, utilizzando modelli 3D parametrici arricchiti con dati geometrici e storici. L'HBIM consente l'integrazione di dati di rilievo dettagliati e ricerche d'archivio per creare rappresentazioni digitali intelligenti a supporto del restauro, della manutenzione e dell'analisi del patrimonio architettonico esistente. La metodologia HBIM è particolarmente pertinente per il patrimonio architettonico, dove una comprensione approfondita e articolata del bene è indispensabile per qualsiasi strategia di restauro e conservazione. L'implementazione dell'HBIM facilita l'organizzazione sistematica dei dati rilevanti, supportando sia la fase di documentazione che le successive attività di ispezione e diagnosi. Il processo metodologico utilizzato in questo articolo ha previsto una strategia scan-to-BIM per ricostruire il modello tridimensionale dell'edificio a partire da immagini orientate, riducendo al minimo le operazioni manuali, laboriose e soggette a errori. Ciò ha permesso la creazione di un modello as-built accurato che conserva informazioni critiche relative a dimensioni esterne, composizioni dei materiali, deformazioni e condizioni strutturali. Il modello digitale risultante funge da archivio completo, ospitando e integrando molteplici set di dati che, nel loro insieme, costituiscono un solido quadro informativo per futuri interventi di conservazione.