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From point cloud data to HBIM for public performance spaces knowledge, management and storytelling: Palazzo Olivieri in Pesaro.

The very latest lines of European research in the field of Cultural Heritage are mainly focusing on disruptive global transitions through value- and future-oriented strategies in a green and digital scenario. This approach stems from the concept of Heritage as a unique but non-renewable resource, featuring multilayer cultural contents (tangible and intangible), and evolving in close correlation with the constantly changing components in the territory.

Digitisation is increasingly confirming itself as an enabling factor for many practices involving cultural heritage. With specific regard to the built heritage, digital technologies provide functions that can catalyse and optimally support architecture knowledge and storytelling, which in turn enhance new levels of interaction, and can improve the active conservation and integrated management of heritage asset. Starting from this assumptions, Palazzo Olivieri-Machirelli in Pesaro (Italy) was studied for challenging trials. Nowadays, the historical building is used as a music conservatory thanks to the testamentary legacy of the Italian composer Gioachino Rossini and the homonymous Foundation, and incorporates the Auditorium Pedrotti, which is the focus of this research.

Thus, this architecture was selected as a testing case for inventive and immersive experiences as well as for long-term management solutions and systems, which exploit the paradigm of Heritage – or Historic – Building Information Modelling (HIBIM) and the robust technology of Augmented and Virtual Reality (AR, VR), taking advantage of solid base in the survey phase, which developed an high-detailed 3D numerical model.

Keywords:
HBIM; CONSERVATION; MANAGEMENT; STORYTELLING; EXTENDED REALITY

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1.INTRODUCTION

The very latest lines of European research in the field of Cultural Heritage are mainly focusing on disruptive global transitions through value- and future-oriented strategies in a green and digital scenario (Muench et al., 2022); moreover, as the European Commission stated, "successfully managing the green and digital 'twin' transitions is the cornerstone for delivering a sustainable, fair, and competitive future" (European Commission, 2022). This approach stems from the concept of Heritage as a unique but non-renewable resource, featuring multilayer cultural contents (tangible and intangible), and evolving in close correlation with the constantly changing components in the territory. Embracing this vision also means emphasising the importance of long-term conservation and preservation (Della Torre, 2021; Moioli, 2023) and recognizing the heritage crucial value for citizens and societies (Europe Council Treaty Office, 2005).
This strategic shift in our approach to heritage has triggered a rethinking of the way we manage it, offering significant opportunities in the digital domain. Digitisation is increasingly confirming itself as an enabling factor for many practices involving cultural heritage. With specific regard to the built heritage, digital technologies provide functions that can catalyse and optimally support architecture knowledge and storytelling, which in turn enhance new levels of interaction, and can improve the active conservation and integrated management of heritage asset (Architects' Council of Europe et al., 2018). Starting from this assumptions, Palazzo Olivieri-Machirelli in Pesaro (Italy) was studied for challenging trials. Nowadays, the historical building is used as a music conservatory thanks to the testamentary legacy of the Italian composer Gioachino Rossini and the homonymous Foundation, and incorporates the Auditorium Pedrotti, which is the focus of this research. The palace plays a pivotal role in programmatic initiatives related to both the forthcoming "Pesaro Italian Capital of Culture 2024" event (Pesaro 2024 - Candidatura, 2022) and the UNESCO city label, being in the UNESCO Creative Cities Network as "Creative City of Music" since 2017 (UNESCO, 2017).
Thus, this architecture was selected as a testing case for inventive and immersive experiences as well as for long-term management solutions and systems, which exploit the paradigm of Heritage – or Historic – Building Information Modelling (HIBIM) and the robust technology of Extended, Augmented and Virtual Reality (XR, AR, VR), taking advantage of solid base in the survey phase, which developed an high-detailed 3D numerical model. In addition, the palace represents a key example of a public performance space that resolves several instances typically affecting this built heritage, ranging from the narration of the intangible memory of historical theatrical performances to the matters of use and fruition, as well as from the control of people flows to the verification of compliance with the regulatory standards.
Therefore, the topic goes beyond digital representation and lies entirely within the issue of information systems and digital information modelling (ICOMOS, 2020; SIRA, 2023) and it is clearly included in the debate dealing to embed HBIM in the architectural heritage lifecycle process (Apollonio et al., 2017).

2. RESEARCH AIM

The advantage in using semantically ordered databases linked to 3D models of architectural heritage meets the need to project conservation practices into a preventive and predictive horizon. Enabling tools based on 3D data acquisition can in fact help to manage the complexity of historical buildings, and to model their knowledge in terms of history, construction materials and techniques, meanings and memory, ensuring their continuous updating and sharing among all stakeholders. Besides, they can guarantee heritage works of adequate quality, timeliness, and effectiveness, valid both in the case motivated by conservation needs, and in the case that the intervention is required for reasons of obsolescence and reuse, or active use as is often the practice for historical public performance spaces.

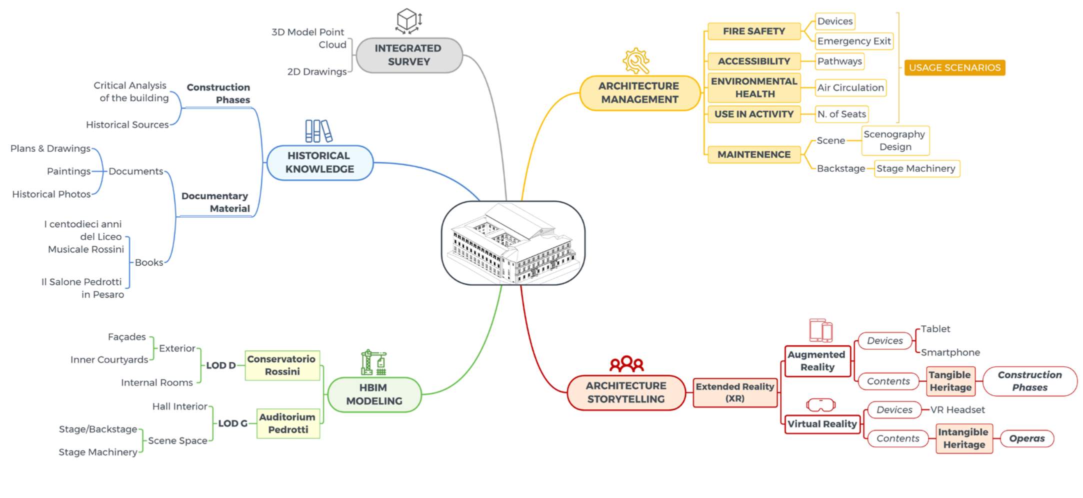

Fig. 1: Map of the methodology applied during the work.

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A HBIM was developed for Palazzo Olivieri-Machirelli with the primary aim of integrating information modelling strategies for conservation and management with communication and narrative aspects of the palace's tangible and intangible values. The process returned a digital twin that fulfils the needs of both the technicians in charge of preserving and managing the asset and the public users. An additional goal of the research is to experiment and assess a workflow able to transform the points cloud into a semantically aware model with different purposes and LODs, exploiting the 3Dmensional numerical model and making it intelligent. In this light, the paper presents different modeling strategies based on different outputs obtained by the integrated survey [Fig 1].

This experimentation was triggered by the results of a research program financed by Rossini Foundation of Pesaro and developed by the Department of Construction, Civil Engineering, and Architecture (DICEA) of the Università Politecnica delle Marche[1], in close collaboration with the Foundation, which is the owner of the building hosting the State Conservatory of Music. The research group investigated the most representative scenarios in the ordinary preservation and management of a public theatre such as the Auditorium Pedrotti, and then explored the elements that, according to a detailed historical-documentary analysis, could be the most pertinent to highlight the intangible attributes to be preserved and enhanced. Thus, the study was structured on a twofold objective: the physical management of architecture and immaterial storytelling, emphasizing the limits and potential of the digital technologies in use and seeking the best communication outcomes for cultural contents.

Fig. 2: The mansion during the first construction phase: (left) enengraving taken from "Plan and elevation of the various buildings in the city of Pesaro," 1790.; (right) watercolor by Liverani around mid-1800s ("L'Isauro e la Foglia. Pesaro e suoi Castelli nei disegni di Romolo Liverani." Pesaro, 1986)

3. CASE STUDY: PALAZZO OLIVIERI-MACHIRELLI AND THE AUDITORIUM PEDROTTI

The case study on which these issues were developed, as it represents a focal point within the municipal initiatives aimed at enhancing the city's cultural tradition as part of the "Places of Culture and Music". Pesaro has a rich tradition of theater and music dating back to the 17th century, and it is particularly well-known as the birthplace of Gioachino Rossini, the renowned composer. An itinerary traced in the historical center, also marked by urban landmarks, links all the significant parts of the Rossini heritage: the Rossini's Theater, Rossini's Birthplace, and finally the object of the present study, headquarters of the "G. Rossini Conservatory" and the homonymous foundation.

The complex of Palazzo Olivieri-Machirelli, as it stands today, is the result of two diachronic phases. The first phase dates to 1747 with the construction of the residence of Annibale degli Abbati Olivieri (1708-1789), a leading figure of humanism who lived in Pesaro. The Palace was built under the supervision of the architect and painters Gian Andrea Lazzarini (1710-1801), with the idea of creating not only a residence inspired by the classical canons of architecture, but also a library and an archaeological museum conceived as a public space. Evidence of that period has come down to us thanks to the correspondence established between Olivieri and Lazzarini, who was absent from the city during the first period of construction; those letters and drawings today constitute the most important documents for reconstructing the first phases of the building. After Olivieri's death in 1789, the residence was inherited by the Machirelli family and the rich collection was donated to the city with the intention of establishing a "Public Library" along with an archaeological museum, which continues to be a valuable cultural asset for the city till today [Fig. 2].

The second phase is represented by the building expansion, with the construction of the Auditorium Pedrotti, which was completed in 1892 but not actually completed until 1907. The building was designated to host the headquarters of the High School of Music, named in honor of Gioachino Rossini, and the "Ente Morale Liceo Musicale" (today the Rossini Foundation) to manage its heritage and fulfil his willing. As a result of the extension work, both the main façade and the rear elevation were redesigned, adapting the design of the façades to the new addition, in particular, a second portal which identical to the first was built on the main elevation to maintain the symmetry typical of the building in its first construction phase [Fig. 3].

The Auditorium consists of a single large volume divided into two levels by the gallery supported by cast-iron columns and has the stylistic features typical of 19th-century concert halls. The roof is supported by a series of trusses and is internally

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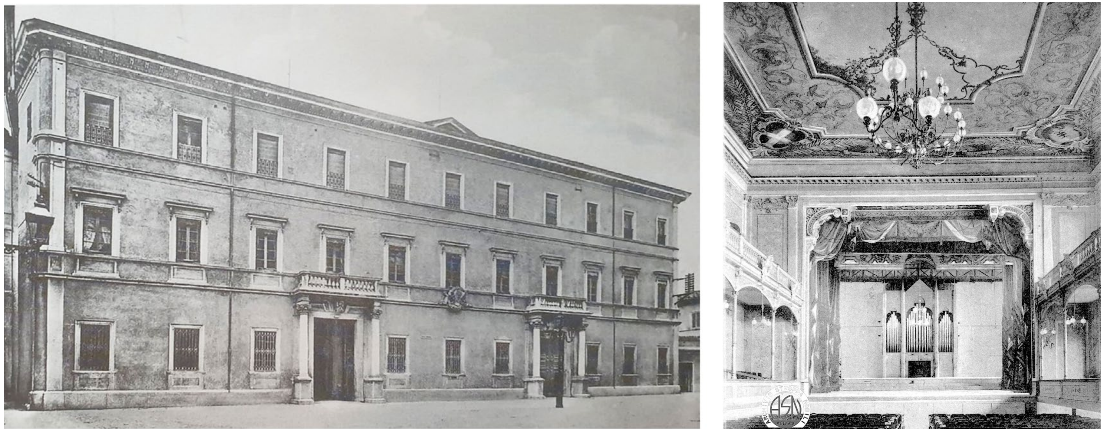

Fig. 3:The building after the construction of the Auditorium Pedrotti and the facade expansion (on the left around 1940). The interior of the hall dated back around 1930, with the original organ and the ceiling decorations (Archivio Stroppa Nobili)

covered by a flat ceiling, whose acoustics were directly studied and designed by the composer Carlo Pedrotti, the director of the Music School at that time. The hall was finally completed by the installation of the electric organ, installed in 1906, which was only later replaced in 1974, with a modern one that still exists today. The interiors originally featured decorations and frescoes are now lost due to the earthquakes of 1916 and 1930. Between 1966 and 1980, the auditorium was restored in compliance with new regulations, both for structural reasons and fire safety regarding public performance buildings. In 1984, after a series of works, the world premiere of "Il viaggio a Reims" was staged during the Rossini Opera Festival, to mark a new starting point for the hall.
In the following years, the Auditorium has undergone several renovation and adaptations, due to new regulations for its public use and to structural needs occurred over time. Nowadays, financing has been allocated for crucial operations concerning ordinary and extraordinary maintenance and other consolidation works, which will enable the auditorium to function properly again in the next years.

4. METHODOLOGY

4.1 THE ARCHITECTURAL SURVEY

The digitization is the first feat of safety, knowledge and management of Cultural Heritage and the metric documentation of architectural buildings and sites requires today the use of several integrated survey methodologies(Clini et al., 2019, Nespeca, 2018; Rinaudo & Scolamiero, 2021).
The case of Palazzo Olivieri-Marchirelli represents a typical example of integrated surveying application: TLS (Terrestrial Laser Scanning), high-resolution 360° imaging, and photogrammetry were combined to ensure geometric and colorimetric accuracy. Furthermore, the entire 3D survey was carefully planned to achieve uniform lighting, avoiding sharp shadows, and to cover all surfaces and levels of the asset.
Data acquisition lasted six days, during which time both laser scanning and collimated spherical photographic acquisitions were carried out simultaneously at the center of capture. This process involved two operators. The number and spatial distribution of individual scans were designed to ensure sufficient coverage of all inspectable spaces, including underground floor and attics. A total of 563 scans were performed using two different Terrestrial Laser Scanner (TLS) instruments: the Leica Geosystem P40 ScanStation and the RTC360. Acquisition resolutions were chosen to provide a uniform point density on all surfaces, while also being high enough to capture detailed features of the most decorated rooms, such as the Auditorium Pedrotti, the Marble Room, the Rossini Temple, and the Column Room, all located at the first floor. A density of 3 mm at 10 m was set for outdoor spaces, while for interiors, 3 mm at 10 m was chosen for the aforementioned richly decorated rooms, and 6 mm at 10 m for others. The RTC360 scanner, equipped with a sophisticated system combining an Inertial Measurement Unit (IMU) sensor and Visual Inertial System (VIS) Simultaneous Localization and Mapping (SLAM) technology, offers the capability of pre-aligning scans directly in the field using the Leica Cyclone FIELD 360 app on a tablet. Importing scans automatically generates a registration file, subsequently refined using an ICP algorithm in post-processing.
The spherical panoramas were captured using the internal camera in the case of the RTC360 instrument and an external SONY ILCE Alpha 9 camera in the case of the P40 scanner. This digital camera features a 35.6 x 23.8 mm CMOS sensor with approximately 24.2 megapixels. All images were captured by rotating the camera mounted on a Nodal Ninja 3 panoramic head to maintain the fixed nodal point aligned with the TLS sensor. Additionally, images were taken with an X-Rite ColorChecker Classic to correct white balance and adjust exposure for each set of images.
Once the TLS data acquisition campaign was completed, using Leica Cyclone Core software, each point cloud was colored using the RGB values from the corresponding 360° panoramic image taken from the scanning station. Subsequently, all individual point clouds obtained from the P40 scanner were aligned with each other, and the aligned group was integrated with other groups automatically obtained from the RTC360 scanner. The final registration exhibits an average absolute

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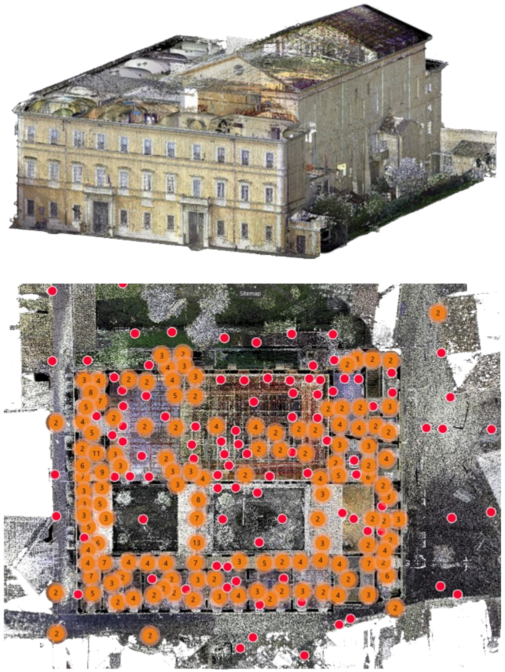

Fig. 4: TLS Survey: an axonometric view of the aligned and mapped point cloud (top) and a planimetric view with the scans positions (bottom).

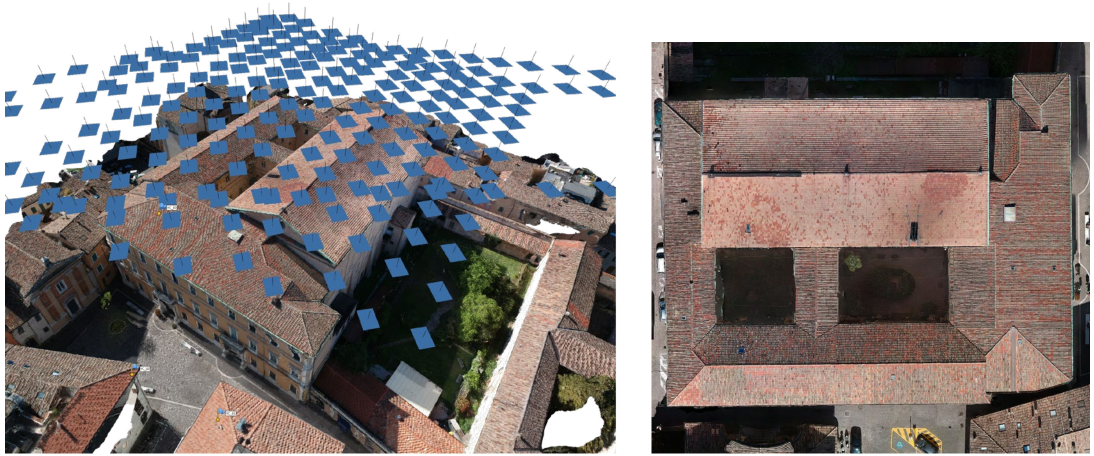

Fig. 5: UAV Photogrammetric Survey: a perspective view of the textured mesh model with marked locations of aligned images (left) and an orthophoto of the coverage of building (right).

error calculated based on the imposed constraints of 0.001 m, with a maximum error of 0.001 m, while the RMS values of individual cloud-to-cloud alignments range from 0.005 m to 0.012 m [Fig. 4].
An initial site assessment informed the flight strategy for capturing photogrammetric data. To ensure that the drone remained within visual line of sight, it was decided to initiate takeoff from a terrace located adjacent to the complex.
Unmanned Aerial Vehicle (UAV) operations were performed using a DJI Mavic Mini, equipped with a 6.17 x 4.55 mm CMOS sensor and has 12 megapixels. Initially, ground-based white and black targets were placed to define the reference system and be detected by an RTK (Real Time Kinematic) GNSS HiPER HR. A sequence of 227 images representing the upper parts of the building was captured at an altitude of 28 meters above ground level. Following the SfM-DMVR method, data processing, carried out within the Agisoft Metashape software, resulted in: 141,920 tie points, a ground resolution of 9.63 mm/px, a coverage area of 0.0141 km², and a reprojection error of 1.81 px. Georeferencing through the ground-detected GNSS markers yielded an average error of 1.34 px. In general, the acquisition distance, instrument characteristics, and flight design allowed for a highly accurate Ground Sample Distance (GSD), as clearly visible in the final orthoimage [Fig. 5]. The alignment phases, sparse point cloud generation, and dense point cloud generation produced another RGB-colored point cloud of the entire urban block's coverage surfaces.
Lastly, the coordinates of the black and white targets were used to georeference the TLS and SfM-DMVR point clouds to the WGS84 coordinate system, and then to merge them. The final point cloud was subsequently cleaned of irrelevant portions, appropriately filtered, decimated, or resampled as needed [Fig. 6]. Then, vector data for all significant outputs was generated using Leica CloudWorx for Autocad software. Specifically, 6 floor plans, 4 exterior elevations, 4 internal courtyard elevations, 4 longitudinal sections, and 1 transverse section were created through a week-long effort involving two operators [Fig. 7].
The achieved outcome includes a detailed 3D model of the entire building, which serves as a digital twin to obtain two-dimensional drawings and accurate as-built 3D modelling; both are essential for the following phases of Historic Building Information Modeling (HBIM) and XR experience.

4.2 HBIM FOR THE CONSERVATION AND ACTIVE USE OF HISTORICAL SPACES FOR PUBLIC PERFORMANCE

Thanks to the huge points cloud generated during the survey campaign, a scan-to-BIM process was applied for carrying out an information model, in particular with the aim of data enriching on the different uses of Palazzo Olivieri and Auditorium Pedrotti [Fig.8]. This model is a comprehensive

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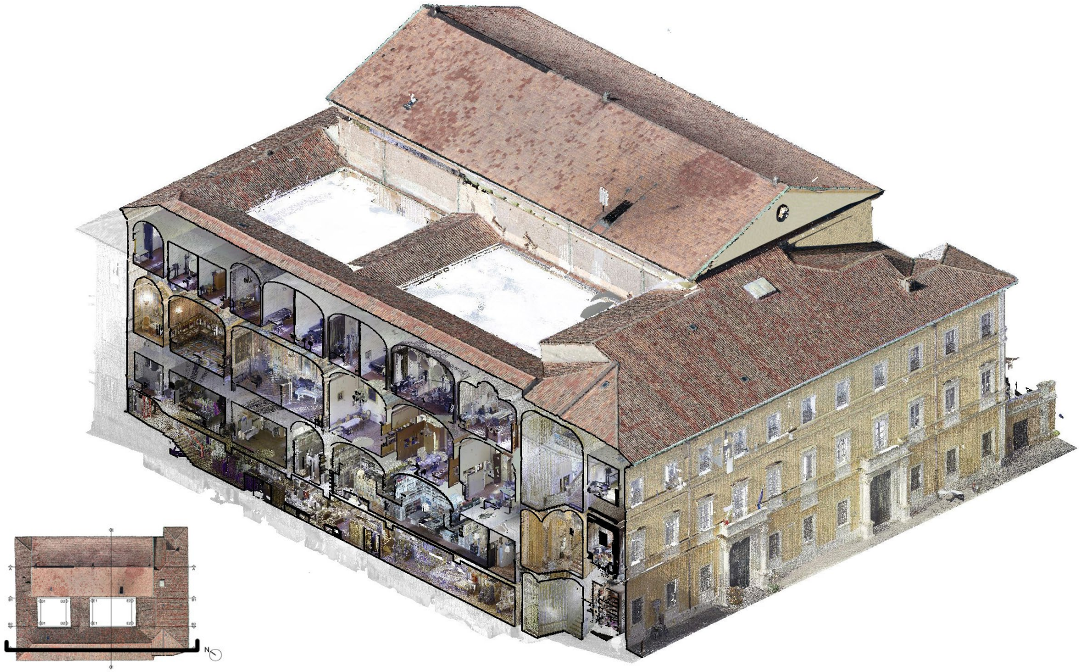

Fig. 6: Axonometric section of the final point cloud corresponding to the CC section plane.

Fig. 7: Two-dimensional drawings at 1:100 scale: longitudinal section AA and floor plan of the first level. Both show the Auditorium Pedrotti space.

data repository, serving various purposes, including heritage conservation, management, as well as communication and storytelling. The primary objective was to create a tool accessible to both professionals and non-professionals, allowing them to explore the digital model and its cultural contents.

Considering the size of the building and the richness of some of its rooms, in contrast with the simplicity of entire areas, such as the wings housing the conservatory classrooms, a critical evaluation of the asset was imperative to pinpoint the parts to focus on. The architectural complex was initially divided into two significant segments: the structure from the first building phase (17th century), which currently houses the Music Conservatory, and the subsequent volumetric addition of the Auditorium Pedrotti (late 18th century), which, in terms of usage dynamics and architectural features, partly constitutes an independent ensemble. Consequently, the research group opted for two distinct Levels of Development (LOD) as defined by the subdivision in (UNI 11337-4:2017) LOD D (detailed object) for the Conservatory while in LOD G (updated object) for the Auditorium Pedrotti.

Indeed, the Auditorium Pedrotti was considered an ideal testbed for assessing a workflow in which the complexity of the architecture and its details should be adequately represented. Besides a special attention was paid to achieve a model aware of the historical path of the building, while also trying to incorporate such intangible values. It was modeled with a high LOD, prioritizing not only geometric precision but also encapsulating the principal historical events in the evolution of the building. This choice was further validated by the potential to implement and enable a modeling workflow for buildings classified under Italian regulations as "public entertainment usage" (Circ. 16/51) such as cinemas, cinema-theatres, and recreational facilities. This architectural typology asks for the integration of maintenance, management, and conservation, all of which are vital due to the historical significance of the asset. These challenges highlight the maximum potential of an information model, designed to handle such complexity, while also configuring an "as-built" BIM data enriched and consistently updated, incorporating future works. In general, the main achievement of similar workflow is enabling the

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Fig. 8: The point cloud and the HBIM model obtained from the scan-to-BIM process

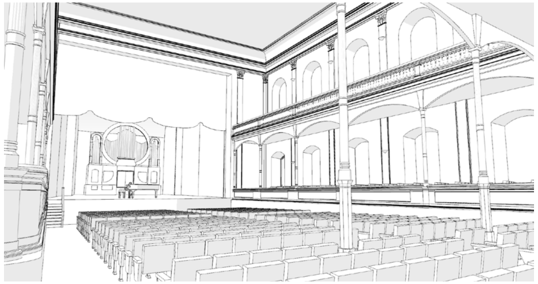

Fig. 9: Interior view of Auditorium (HBIM model)

Fig. 10: Entrance porch of the conservatory (HBIM model)

digital twin of the architecture.

To meet the information requirements and proposed goals, a hybrid approach was adopted during the modeling phase of geometric features. Specifically, the wings of the Conservatory, which required a lower Level of Geometry (LOG), were created on the basis of the bidimensional drawings produced by the survey. Conversely, a SCAN-to-BIM approach was employed for the Auditorium [Fig.9] space and external façades and the inner courtyards [Fig.10], concerning the importation of point cloud data suitably reduced to streamline model handling procedures, including file size considerations. Archicad was the selected BIM authoring software due to its compatibility with open interchange formats such as .xyz and .e57, requiring no prior data conversions. Nonetheless, the overall LOD for the Auditorium interior was determined in accordance with the intended model uses. While certain elements were meticulously modeled for geometric accuracy, such as moldings, most architectural elements achieved the appropriate LOD through the management of documents, photographs, data sheets, and survey data as the Level of Information (LOI). Therefore, according to the guidelines of (UNI 11337-4, 2017), the final LOD encompasses both LOG and LOI.

Once the modeling phase was completed, data enrichment followed, updating the previously created geometries as intelligent and informed BIM objects. This phase took into account the building's use scenarios, derived from discussions with the Rossini Foundation responsible for building management [Fig.11]. Key aspects such as fire prevention, accessibility, environmental health, and the public use and management of theater performances on stage were emphasized. For instance, data related to fire protection equipment, such as extinguishers, hydrants, and nozzles, was incorporated to facilitate inspections and maintenance. Additionally, fire ratings for furnishings and planned evacuation routes were documented. In the context of the stage and backstage areas, point cloud slices were utilized to illustrate stage machinery elements and plan interventions. Other decorative details and consolidation efforts carried out over time were indicated by attaching files linked to archival documents. The selection of building materials was based on a direct visual analysis or data from indirect sources, ensuring the representation of their current state of conservation.

Considered as a key element by the scientific community in the use of HBIM for management and conservation purposes, also the temporal dimension (4D) was integrated (Mammoli et al., 2021). Usually, trying to avoid difficulties and errors in knowledge, diagnosis and refurbishment the focus in Historic Building Information Modelling and Management (HBIMM) is to improve

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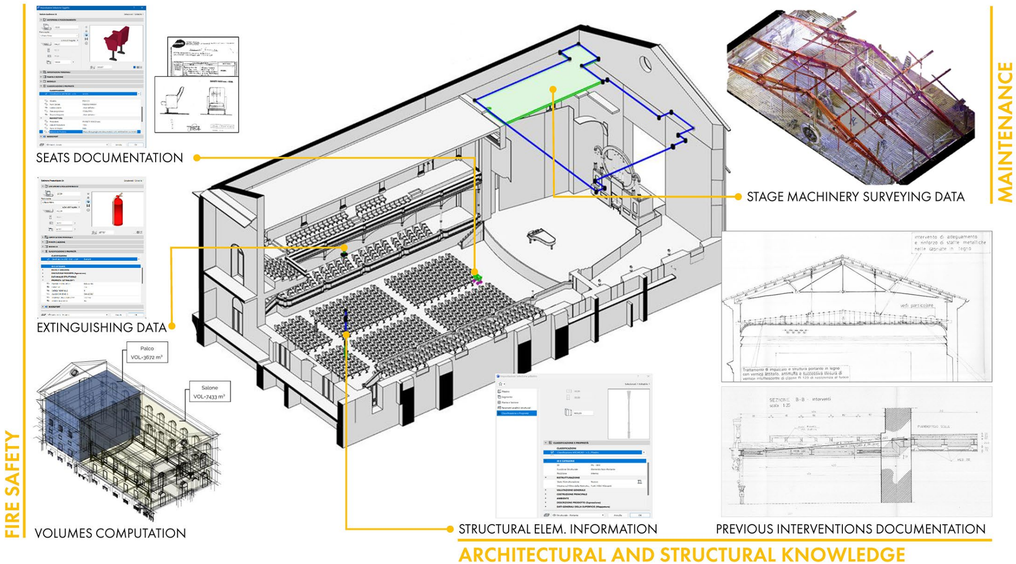

Fig. 11: Data types embedded in the geometry [® Authors]

Fig. 12: Construction phases associated within the informed model

the interoperability among information/data in different types and formats. For this reason, some operative methods have been tested for managing the historical buildings' knowledge system by using relational databases and time parameter creating a data-enrichment for diagnosis of architectural decay and settlements toward data computing (Bruno et al., 2021). In these cases, the information, as BIM parameters, refers to historical and constructive evolution, previous conservation and restoration works, crack patterns and degradation condition; while in our case a direct comparison between demolition and reconstruction was conducted, facilitating a critical analysis of the evolving processes and the building's life cycle over the centuries and associating construction phases (pre/post volume addition) [Fig.12].

4.3 THE INFORMED MODEL FOR BUILDING UP XR EXPERIENCES

The creation of information models represents a significant investment in terms of time and economic allocation when it comes to historical architecture. Besides, the consultation of information contained within the generated databases becomes one of the primary objectives of the digitalization process that involves such structures. Typically, this operation takes place within software primarily dedicated to professional matters, using proprietary applications or standardized protocols, with the goal of simplifying consultation and collaboration of the involved stakeholders. In parallel with these applications, broader forms of consultation can enable a 360-degree use of the model, with a holistic and systemic approach to provide both an in-depth understanding of the structure and a powerful tool for engaging the audience. Effective storytelling can play in fact a pivotal role in narrating building's history, standing as one of the most convincing methods for adaptively repurposing existing architectural assets (Banfi et al., 2019; Brusaporci et al., 2017; Lo Turco & Giovannini, 2020), with

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the purpose of enriching heritage significance and improving the enhance and conservation over time. The methodology, here presented, transformed the BIM model into an immersive experience that transcends the mere construction aspect, enabling users to virtually explore every facet of the building and its evolution over the centuries with different types of devices.
The integration of cutting-edge technologies regarding Extended Reality (XR), such as Augmented Reality (AR) and Virtual Reality (VR), offers compelling opportunities to express tangible and intangible values of cultural heritage, facilitating a seamless interconnection between the physical and digital and creating new ways of narration. In this perspective, the research focused on the selection of relevant content on which to develop storytelling strategies, taking into consideration the context of use and the availability of technological devices. By combining informed models, archive photos and multimedia, XR applications can bring history to life, allowing users to fully immerse themselves with an innovative approach that not only preserves the legacy of intangible heritage but also makes it more relatable for today audiences. The goal is to help general public to better appreciate and understand the cultural significance of these moments. To narrate the legacy regarding Palazzo Olivieri and the Auditorium Pedrotti, an AR app was developed to enhance the experience inside and outside the building, describing the tangible aspects of its history. Moreover, a VR experience was designed, also focusing on the intangible "Theatrical Heritage" of the operas performed on stage. These immersive experiences not only literally transport users to historical times and events, but also let them witness and interact with cultural contents that can't be touched, like performances, traditions, and emotions.
The development of both XR applications involved the exploitation of various software tools, testing an interoperable workflow that should be usefully re-used by scholars and practitioners. Initially, the HBIM model was imported into Unity software, the hub used to gather digital assets and create the

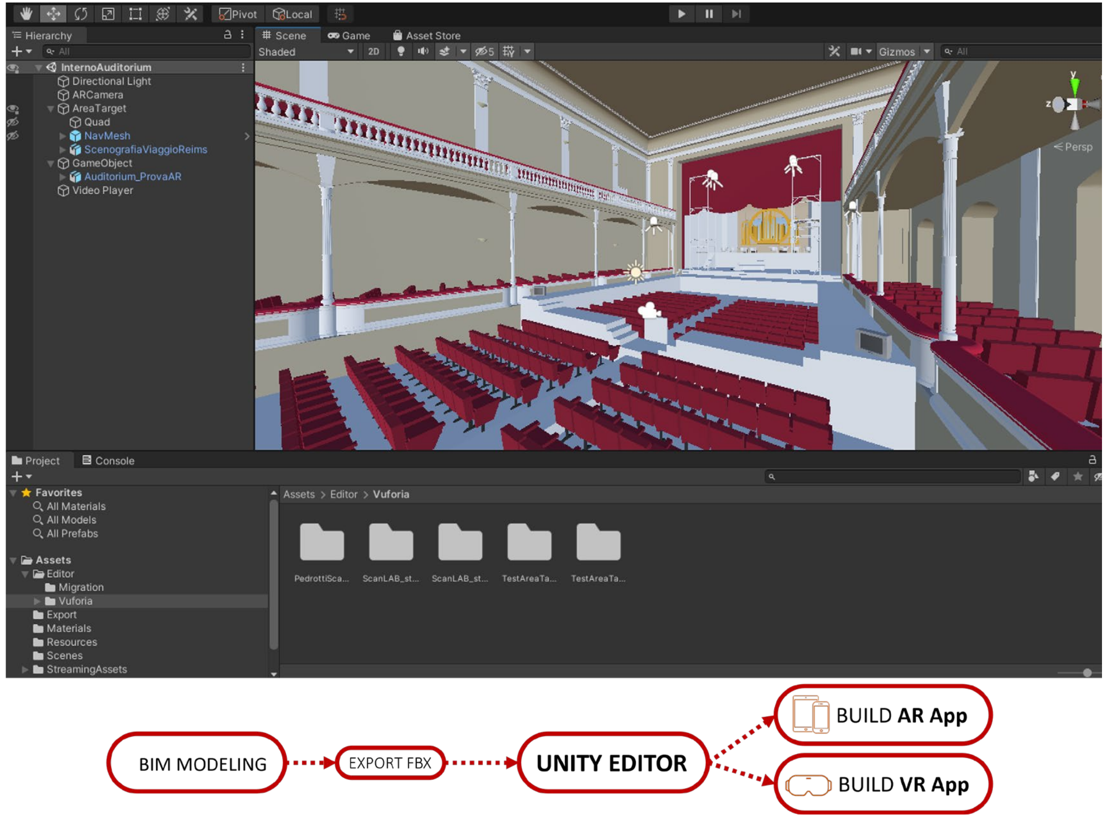

Fig. 13: XR applications workflow: from the HBIM model to the final build.

different virtual experiences [Fig.13].
The narrative for the AR app was structured around two themes, distinct for the exteriors and interiors of the asset. Outside, visitors can interact with a virtual reconstruction of the building's initial phase dated back to 1790, before the building expansion, when the original residence was designed with just one entrance framed by red granite columns. Inside, the app proposes a photographic representation of the Auditorium, dated around the 1930s, with the first electric organ and scenography, to reconstitute the emotional essence of the hall, as it was in the past. The application was built using the Vuforia plugin and mesh models of the building, based on laser scanner survey data, were used as a "model target" to ensure accurate 3D reconstruction tracking. This process was applied both for the exterior, using the entrance portal to match the 3D reconstruction of the façade on the current building, and for the interior of the Auditorium, using the actual organ as a reference to align

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the picture and provide a perspective view of his original design. The final step was to enable visitors to independently choose between these two digital environments, switching seamlessly from one scene to another [Fig.14]. The application was then tested on Android devices and, despite sometimes unstable tracking, users enjoyed the experience, both in terms of informative content and user interface design.
The VR app used a similar approach, starting from the information model imported into Unity, followed by the integration of the necessary interactions and assets (sounds, pictures, videos, animations, etc.). The user experience was structured around a series of hotspots, enabling visitors to immerse themselves in exploring the virtual environment by consulting archival materials, positioned in different points of the space. This choice allows to explore the evolution of the hall during the time, as an example showing the old ceiling decorations mapped on their original locations. Additionally, the application included the scene model reconstructed from the opera "Il Viaggio a Reims", designed by the Italian architect Gae Aulenti and premiered in 1984 during the Rossini Opera Festival, that could also be freely explored consulting original media gallery of photos and videos, designed to revive a unique and unrepeatable event that celebrated a new starting point for the Auditorium, reopening after a series of restoration works [Fig.15].

5.RESULTS AND FUTURE WORKS

This study delved into the potential of digitizing architectural heritage, by focusing on the significant role that Historic Building Information Modeling (HBIM) can play as a dynamic, multilayer, interdisciplinary, and shared data repository. The results explored HBIM applications in management strategies and storytelling of both tangible and intangible aspects of cultural heritage. A fully interoperable workflow was presented: starting from the integrated survey, based on TLS and SfM by UAV images, a high-quality numerical model was obtained, two different modelling strategies were designed for different final LODs according to the use of the areas, the resulting HBIM was thus displayed in different engaging applications, able to present to expert and non-expert the users the as-it-is model, as well as the palace's history and transformations during the centuries.
Therefore, the results were manyfold: firstly, the points cloud was transformed into intelligent objects and into a 3D semantically structured data-repository, the SCAN-to-BIM procedure was also validated in the light of the model's goals, finally the HBIM and its data-enrichment enabled XR experiences. In fact, the paper presented innovative applications with the aim of making such invisible concepts visible: via AR the different phases of the building (external and internal spaces) were narrated, as well as VR headsets-based brought

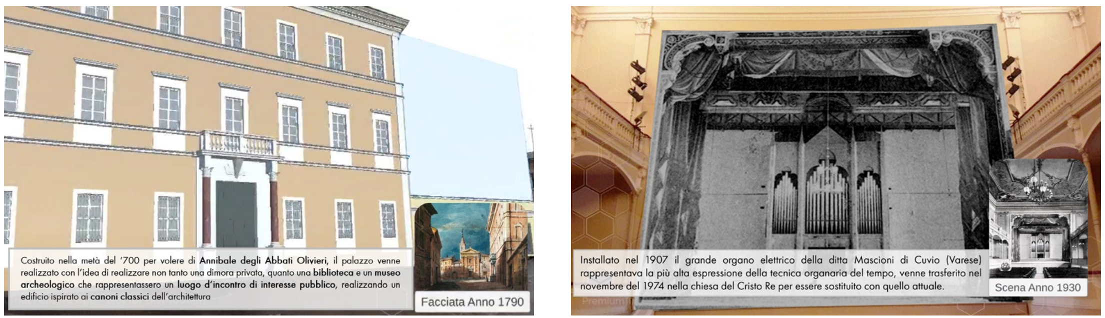

Fig. 14: AR application. The original façade reconstructed (left). The Auditorium with the original electric organ (right).

Fig. 15: VR application. Scenography reconstruction of the opera "Il Viaggio a Reims" (1984), originally designed by Gae Aulenti.

users in virtual spaces reconstructed by historical sources about one important performance, staged in the Auditorium Pedrotti in the 1980s. More in general, the developed applications demonstrated the power of using HBIM also for narrating the 4D of architectural heritage and keeping the memory of intangible heritage alive.
Considering the typology of the historical theater, and in general of historical public performance spaces, the study focused on the safe usage of spaces and fire prevention as central issues for strategic planning. Several parameters, such as environmental data and fire scenarios, were considered. The study emphasized the role of data collection in managing heterogeneous layers of information and datasets. The overarching goal was to minimize heritage risks and enhance the effectiveness of preventive measures and planned conservations works, boosted by the digital transformation of built heritage. Another achievement was the ability to record the historical phases of the building, and to collet archival documents related to restoration works as well as intangible aspects, which contributed to develop a knowledge-based model informed of its fourth dimension, describing the evolution of the architecture over time. Finally, enabling

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direct access to the model's data was crucial for creating an easily navigable digital twin, allowing professionals and public users to access its cultural contents. Furthermore, the model was adapted to promote heritage appreciation through XR technologies, expanding the field of application of HBIM.

The final model then stands as a basis for future expansion of the generated data, updating its contents and adjusting them for future interventions. Doing so would result in what is effectively called an "as it is" model, that is an updated and updatable representation of the building. This would make it possible to delve into aspects that were little analysed in the present research, including the modeling of the classrooms related to the conservatory with a greater degree of detail and, in parallel, an in-depth study of the masonry stratigraphies and materials, both of which would be useful in assessing the energy management of the building, an issue of no less important for a monumental heritage such as Palazzo Olivieri-Machirelli.

A further aspect to be improved is the graphical rendering of XR applications: to date, the achieved results do not guarantee the same level of visual quality reachable from dedicated modelling software. This can be the subject of specific modifications in the used workflow, or it can be addressed by subsequent texturing of objects and improved interactions in general.

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