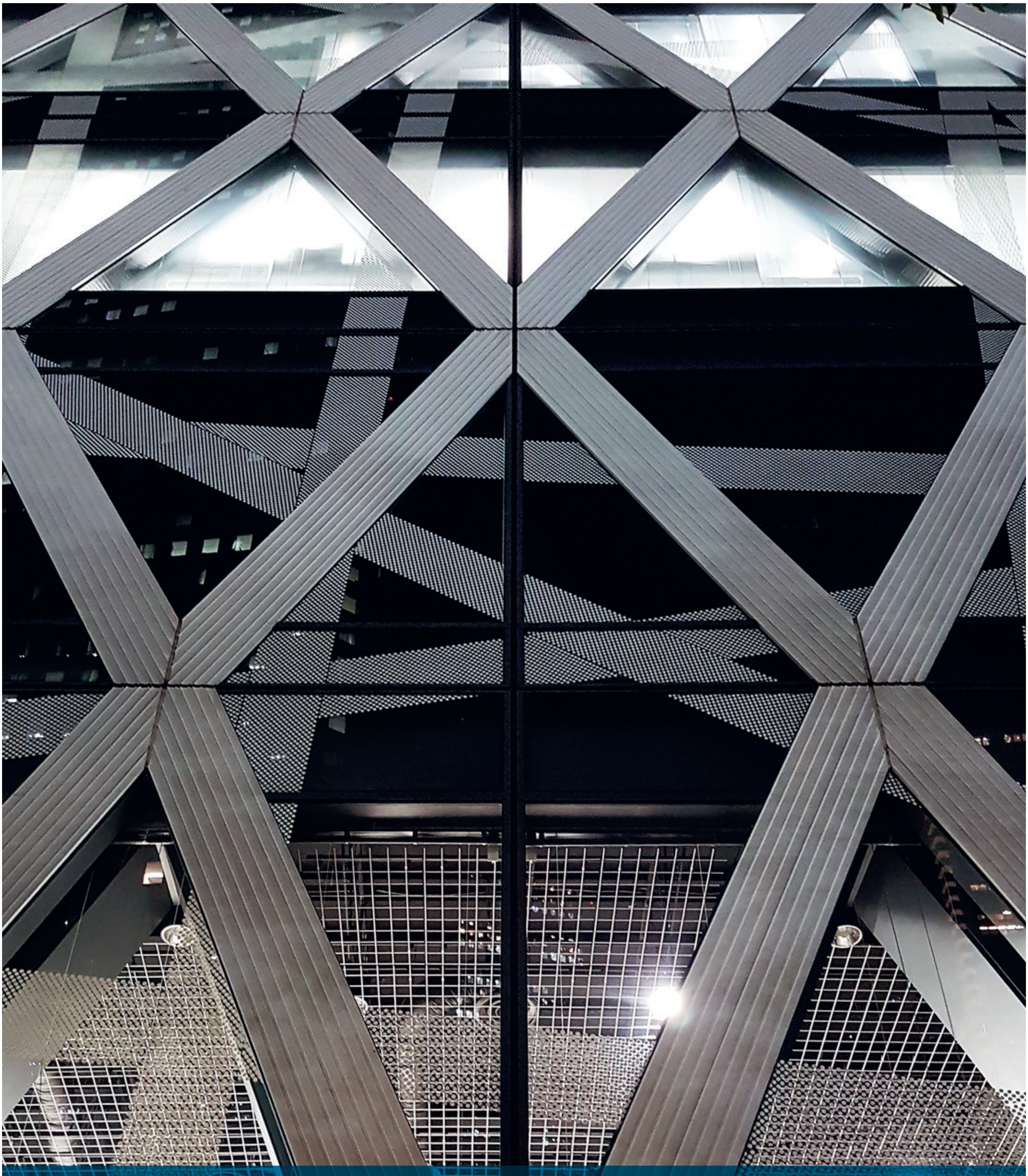

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# CONSTRUCTION AND ITS INTERCONNECTIONS

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**Cover illustration:** Mode Gakuen Cocoon Tower in the Nishi-Shinjuku district (Tokyo, Japan) by Kenzō Tange, external view. © Riccardo Gulli, 2018

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# DIGITAL METHODOLOGIES FOR ARCHITECTURAL HERITAGE PRESERVATION: INTEGRATING PHOTOGRAMMETRY, MOBILE LASER SCANNING, AND IMMERSIVE TECHNOLOGIES

Elisabetta Doria, Silvia La Placa, and Jolanta Sroczynska

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**Abstract**

This paper presents a digital documentation methodology designed for the conservation and adaptive reuse of built heritage, tested within an international educational framework. The approach integrates photogrammetry, Mobile Laser Scanning (MLS), drone-based imaging, and immersive technologies to generate interactive and metrically reliable digital outputs. Implemented through a collaboration between the University of Pavia and the Polytechnic of Kraków, the methodology was applied to the Hebdowski Palace in Kraków, an abandoned heritage site of architectural significance.
The study combines theoretical instruction with practical, on-site data acquisition and post-processing, enabling students to collect, interpret, and visualize spatial and material information using open-source tools. The workflow supports rapid generation of point clouds, 3D models, and immersive environments, suitable for both technical analysis and public engagement.
Key results include the creation of a multi-layered digital narrative structured around thematic scenarios, enabling detailed documentation of architectural elements, pathologies, and conservation needs. A 360-degree virtual tour consolidates this output into an accessible digital platform, facilitating both education and heritage valorisation.
Beyond its pedagogical role, the research demonstrates how fast, low-cost digital tools can contribute to broader heritage conservation strategies aligned with European frameworks such as the 2030 Agenda and the New European Bauhaus. This methodology promotes an interdisciplinary, open-access model of heritage documentation that bridges academic learning with real-world application, offering a replicable model for similar contexts across Europe.

**Keywords**

Built Heritage, Digital documentation, Building diagnostics, Immersive technologies, Virtual reality.

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## 1. INTRODUCTION: AIMS AND CONTEXT

The research presented aims to describe a methodology starting from a fast survey to a virtual reality application developed by interdisciplinary teams. The methodology is also suitable to support education activities for the regeneration of buildings in the digital age, with a focus on the use of digital technologies. While the application of digital tools in architectural heritage has expanded significantly, particularly within academic contexts, there remains a gap in integrating these technologies into replicable, outcome-driven educational models that address real-world conservation challenges. This paper aims to bridge that gap by presenting and testing a methodology that combines low-cost, fast survey instruments with immersive digital environments to document, interpret, and reimagine abandoned built heritage. The research situates itself at the intersection of architectural education, heritage conservation, and digital innovation in terms of the use of digital instruments for educational purposes in an official university course. Rather than focusing solely on pedagogy, the initiative seeks to demonstrate how interdisciplinary educational activities can produce metrically accurate, publicly accessible outputs that support heritage awareness, engagement, and adaptive reuse. The case study of Hebdowski Palace in Kraków offers a meaningful testbed to assess both technical performance and interpretative potential, thanks to its role as a case study and the numerous interdisciplinary analyses available. The focus of the paper is on the impact of the digital age today and on the documentation, valorization and reuse of abandoned architectural structures, with a specific focus on building technologies. The methodologies and techniques described were developed in an international collaboration between the Department of Civil Engineering and Architecture of the University of Pavia and the Department of History of Architecture and Conservation of Monuments of the University of Kraków.

### 1.1. THE DIGITAL ERA CONTEXT

The growth of the digital era in Europe has progressed through several key phases, with a significant acceleration beginning in the 2000s. The Lisbon Agenda (2000), aimed to transform the EU into a competitive knowledge-based economy, laying the groundwork for digital expansion, followed by the i2010 – European Information Society strategy (2005) for digital innovation and broadband infrastructure. A major shift occurred with the Digital Agenda for Europe (2010), part of the Europe 2020 strategy, which focused on digital skills, open data, and technological integration. Initiatives such as Europeana (2008-2010), funded under the *Connecting Europe Facility* (CEF), played a crucial role in the digitalization of Cultural Heritage. However, the most significant acceleration occurred after 2020, largely due to the COVID-19 pandemic, which drastically increased the need for digital solutions in education, culture, and work. In response, the 2030 Digital Compass outlined the EU's vision for the digital decade, setting targets for AI, cloud infrastructure, and cybersecurity.

The digitization of cultural assets is nowadays a key priority within the European Union's strategic framework for Cultural Heritage, as outlined in the Recommendation on a Common European Data Space for Cultural Heritage (2021/1970), which promotes digital access, preservation, and reuse of cultural resources. The European Framework for Action on Cultural Heritage (2018) further emphasizes the role of digital innovation in fostering sustainability and accessibility in the Cultural Heritage sector.

The digitization of cultural assets involves defining innovative forms and strategies for communication between Cultural Heritage (CH) and society, targeting a wider and more diverse audience. The Digital Europe Programme (Regulation (EU) 2021/694) and the New European Bauhaus initiative promote digital solutions that enhance heritage conservation, accessibility, and engagement. In this context, a growing need to educate new professionals equipped to handle technological advancements while fostering critical sensitivity toward architectural heritage, its conservation, and its enhancement is becoming increasingly urgent [1]. Educational approaches are evolving accordingly, aiming to introduce digital technologies into the skills needed required by students as the new professionals of the future. In documentation, reuse and technological area, it is necessary to integrate knowledge and skills related to the digital production of artworks, cities, and architectural artifacts. These approaches align with European best practices such as Europeana and projects like Time Machine Europe, which aims to reconstruct the past through big data technologies. These policy frameworks emphasize not only digital access and preservation but also participatory approaches and the democratization of cultural resources. However, their effective implementation requires scalable models that link technical workflows to public-facing platforms. This study responds to that need by translating European digital heritage goals into a replicable educational protocol that engages students as active contributors to heritage valorisation, while producing documentation that holds operational value for future restoration and public engagement efforts.

### 1.2. INTERDISCIPLINARY APPROACH

Starting from the digital context for construction and ongoing documentation, a shared path was developed between the authors for the structuring of a replicable methodology for teaching. A key element is the interest in the development of preliminary strategies for the reuse of historic buildings through non-invasive masonry monitoring and restoration work. An international educational pilot activity was developed focusing on heritage knowledge and digital documentation for sustainable reuse, combining interdisciplinary expertise from the fields of Design, Restoration and Building Technologies. These activities are aligned with European initiatives, such as the Horizon Europe research programme, which promote sustainable and digitally supported heritage conservation. Physical and virtual lectures were designed to create a structured, interdisciplinary knowledge-sharing pathway across three phases. The first phase consists of theoretical lectures, which provide students with a comprehensive understanding of digital methodologies for the documentation and analysis of abandoned buildings, including their historical, architectural, and structural characteristics. The second phase involves applied on-site sessions, where students use fast survey instruments, ranging from professional-grade equipment to low-cost and hybrid solutions, to collect spatial, material, and pathological data. The workshop phase is dedicated to processing the collected data using open-source software, enabling students to develop 3D models, digital archives, and analytical reports that can inform the adaptive reuse of these buildings.

This model aligns with the principles of Open Science and Open Data, as promoted by the EU Open Data Directive (Directive (EU) 2019/1024), which emphasizes the importance of making cultural and scientific data more accessible and reusable. By leveraging open-source tools and data-sharing platforms, students contribute to a broader ecosystem of knowledge exchange, where datasets, digital reconstructions, and analytical findings can be freely accessed, refined, and repurposed by researchers, professionals, and policymakers. This approach not only enhances transparency and collaboration in architectural heritage studies but also fosters innovation in the sustainable reuse of disused buildings, ensuring that digital documentation serves as a catalyst for informed, community-driven redevelopment strategies.

This project was designed not to conclude with conceptual design outputs or single-discipline documentation, but to produce real-world digital assets such as point clouds, 3D models, and immersive narratives that can inform restoration planning and serve public audiences. In doing so, it advances a hybrid model of practice-based learning, technical training, and civic engagement. This convergence is essential for preparing professionals who can contribute to the evolving field of digitally assisted heritage conservation.

This approach to heritage conservation and adaptive reuse integrates digital tools and methodologies to document, analyse, and reimagine abandoned buildings. By leveraging digital surveying techniques, open-source data processing, and interdisciplinary collaboration, it enables the development of informed strategies for sustainable restoration and rehabilitation. The methodology encompasses various aspects of digital applications in Cultural Heritage, from rapid surveying and pathology assessment to data-driven cataloguing and the creation of immersive storytelling techniques for heritage interpretation. These processes align with European best practices, such as the CHARTER Alliance project, which aims to establish a comprehensive framework for Cultural Heritage skills development, ensuring the sector’s sustainability and resilience in the digital era, and the CHARME Interreg Europe, which aims to strengthen local administrations’ knowledge of heritage digitisation through the support of trained technicians. By prioritizing accessibility, innovation, and long-term preservation, this approach supports a more inclusive and technologically advanced vision for the future of heritage conservation and documentation.

## 2. THE USE OF AGENDA 2030 INDICATORS FOR AN EDUCATIONAL APPROACH

The process was conducted in line with the objectives of Agenda 2030 and the New Urban Agenda [2, 3], in particular related to Goal 11, to connect students in a direct way with non-invasive protocols of action on heritage. The objectives outlined in Sustainable Development Goal (SDG) 11 "Making cities and human settlements inclusive, safe, resilient and sustainable" and Target 11.4 "Strengthen efforts to protect and safeguard the world's cultural and natural heritage" align closely with the digital and methodological framework developed for the documentation and adaptive reuse of abandoned buildings. The integration of digital tools in heritage conservation directly contributes to strengthening efforts to protect and safeguard Cultural Heritage by improving accessibility, data transparency, and interdisciplinary collaboration. Through non-invasive digital surveying, open-source documentation, and data-driven restoration strategies, this approach enhances the resilience of historic structures while promoting sustainable urban development. Furthermore, the emphasis on open data and digital education fosters greater public engagement and professional capacity-building, ensuring that conservation efforts are not only preservation-oriented but also socially inclusive and economically viable.

These methodologies reflect European best practices and policy frameworks, including the EU Open Data Directive and Horizon Europe's digital heritage initiatives, which promote the responsible use of technology to safeguard and repurpose built heritage. By aligning with SDG 11, this approach supports a broader vision of cities as adaptive, knowledge-driven environments, where heritage conservation contributes to sustainability, innovation, and community well-being. The UNESCO (United Nations Educational, Scientific and Cultural Organization) Indicators for Culture in the Agenda 2030 aim to quantify and monitor progress on the implementation of the Agenda 2030 Goals at the local or national scale [4]. Among them, underlining the topicality of the topic, the indicator "Information Systems for Culture" is the one most stressed during to develop a digital platform for the documentation and fruition of abandoned historic buildings and projects for reuse. The role of culture is indicated as a sector of activity, as well as a «transversal contribution of culture across different SDGs and policy areas» [5]. The UNESCO "Culture | 2030 Indicators" framework aims, among all, to "Make culture visible" and "Understand trends and build knowledge" in culture, and these specific objectives were chosen as a guideline in the structuring of the educational pathway for the enhancement of Cultural Heritage digital documentation and reproduction skills for undergraduate students.

As mentioned, the lack of data collection, measurement and monitoring processes represents an obstacle in pushing forward the importance of Cultural Heritage and creativity. The fragmentation of culture-related data produced by different institutions is another critical point that needs to be addressed to define unambiguous policies and shared methodologies. Bringing the data together and setting up more reliable measurement systems is an essential protocol to provide a better understanding of the multiple ways culture contributes to the economic, social and environmental dimensions of sustainable development. Strengthening cross-cultural Cultural Heritage visibility will help establish a coherent and strong storytelling on culture and its development that is evidence-based and can help decision makers and stakeholders. The action of collecting and analyzing quantitative and qualitative data in the field of culture, indicated as a fundamental protocol in Agenda Indicators, has been one of the main topics of the didactic activities tested as a collaborative international short course.

Architectural education, like the professional skills in demand, is evolving rapidly in the digital age, with emerging technologies and new tools reshaping traditional teaching methods. This can be observed in many fields, from built-related software and the use of digital tools for parametric design, including interactive and integrated solutions based on Augmented Reality (AR) and Virtual Reality (VR).

## 3. DIGITAL DOCUMENTATION APPLIED TO BUILDING HERITAGE

To respond to the growing requirement for the digitisation of physical spaces and knowledge modalities through dynamic and interactive visualisations [6], recent years have witnessed an exponential growth in methodologies and dedicated hardware and software tools. Among these, there is no shortage of products specifically designed for the study of the built environment. Fast survey methodologies, for example, have been increasingly developed and applied thanks to their ability to acquire a large amount of data in a short time, which can then be used for subsequent digitization processes [7].

The design of hardware to be used in these contexts is now oriented towards the production of instruments characterized by: increasingly compact dimensions, ensuring their portability for operators; enhanced technical performance, guaranteeing the colorimetric reliability of the acquired data; user-friendly management, making the instruments accessible to a wide range of users. This is the case with mobile laser scanners, which are now being used not only by engineers and architects but also by professionals from various fields who employ them to provide clients with metrically reliable three-dimensional models of the properties they are buying or selling in a short timeframe.

Other tools, initially developed for different purposes, are now widely employed for documentation at architectural, urban, and landscape scales, as well as for the development of knowledge-based or musealization products. While they are still used for rapid documentation, unlike mobile laser scanners, they come at a significantly lower cost, making them accessible to individual citizens who may not necessarily be experts in the field. This is the case with the now widespread use of cameras in photogrammetric techniques, as well as the more recent rise in popularity of remote-controlled systems and Insta360-degree cameras.

All this hardware is complemented by a vast range of proprietary and open-source software solutions for managing and processing acquired data for various purposes, including technical, structural, and material analysis, as well as promotion and valorisation.

The multitude of digital methods and tools, along with the fast rhythm of technological advancement, is shaping new training approaches for future professionals. Indeed, they will have to face the challenges of documenting, safeguarding, and transmitting heritage through a fully digitized approach [8]. For this reason, given the numerous possibilities for the use of mobile technologies, the focus of the short educational experience was on the application of methods, techniques, and expedient tools to the built heritage in a state of disrepair. Such heritage possesses characteristics (textural, preservation, but also historical and cultural) that allow for the development of research in both drawing and architectural technology, stimulating reflection on the possibilities for sustainable reuse within the city. Abandoned heritage is subject to various types of risk, including structural criticalities and the loss of identity and memory. This issue is significant, as it undermines the very concept of heritage itself, understood as an asset that must be passed down. Digital methods enable the development of innovative products that, on one hand, capture the condition of heritage sites at a specific moment in time, preserving their image for the future, and on the other, tell the story of architecture in a fresh and engaging way. This can spark renewed interest in places that, though abandoned, still carry deep meaning and identity for the community.

### 3.1. THE ABANDONED HERITAGE OF A CANONICAL HOUSE IN KRAKÓW

The interdisciplinary educational methodology was carried out using a case study: abandoned heritage in the city of Kraków, where the course took place. The case study chosen is Hebdowski Palace, an ancient building in Kraków city centre. The canonical house complex (Fig. 1), located at 7 Poselska Street, is owned by the Kraków Metropolitan Chapter. It was entered in the register of monuments under No. A-66 on September 14, 1961. The oldest parts of the complex date back to the Middle Ages and for centuries were inhabited by members of the nobility and clergy, it is located within one of the oldest suburban settlements in Kraków called Około, a part of the city of today's Kraków, stretching within the Old Town, between Poselska Street and Podzamcze [9, 10]. During this period, the palace was expanded and transformed, with repeated changes to the architectural style. In 1824, the interior was partitioned to make numerous apartments, which were rented out until the mid-1900s, when the complex was used as a textile factory for a short period. The truss and attic of the main building have recently been fully replaced. There are new reinforced concrete ceilings, wooden structure, dormers


Fig. 1. *Images from April 2024 showing the state of preservation of the palace's central courtyard. Below, location of the building on the cadastral map "Stare Miasto - plan obowiązujący" of the city of Kraków. Source: CC-BY SA [La Placa, 2024]; © 2025, Authors.*

and roofing (Fig. 2). The truss over the rear outbuilding was built in the 1960s during restoration work conducted there. It replaced a temporary truss, built in 1947 to cover the walls of the rear annex, destroyed by a bomb explosion. Its condition is bad-it needs replacement. Both the temporary post-war truss and the one built in the 1960s are much lower than the pre-war truss. By lowering it, the historic connection between the main building and the outbuilding through the porch, which was bricked up, disappeared. It would be advisable to restore the historic shape and height of the roofs, despite the restrictions written about prohibiting changes in roof height in the Local Development Plan. By the beginning of the 21st century, the building had fallen into a state of abandonment, and it was only partially

Fig. 2. *Images from April 2024: decorative elements and deterioration conditions of the building. From top clockwise: test for masonry stratigraphy; stone portals on the ground floor for access to the original chambers, wooden ceiling with tapestry typical of Kraków buildings of time, sample for masonry decorations. Source: CC-BY; © 2025, J. S.*

renovated in 2015. In its current configuration, the building features a tree-lined inner courtyard and comprises two floors above ground and one basement level. The palace had already been the subject of analysis and experimentation carried out by the Department of Architectural History and Historic Preservation at the University of Kraków.

Previous studies conducted by K. Stala and P. Pikulski (University of Kraków) had already produced a detailed analysis of the architectural elements of value and worth preserving, for example, vaulted systems and stone portals, frescoes and wooden ceiling decorations, antique panelled parquet floors, rhombus-patterned flooring from the 18th and 19th centuries, and eleven tiled stoves from the 19th century. These were supplemented in the 20th century with additional ceramic stoves, later converted to electric power towards the end of the century, with ten examples still present in the building today. The course was therefore developed with: lectures on the historical knowledge of the building, a fundamental part of the city of Kraków despite the conditions; theoretical lectures on the digital tools for documentation that can be used; field activities with archival documentation already acquired as a preliminary survey; workshop activities to acquire the technical skills to manage the software and tools; field and laboratory activities for material data acquisition and the development of the assigned project. The students were organised into working groups to enable them to experiment with as many technologies and methods as possible.

This approach aimed, on the one hand, to allow them to narrate the story of the heritage site in a captivating and innovative manner, and, on the other hand, to collect and process the technical data required for its restoration and adaptive reuse. The groups carried out their work on the interior spaces, the courtyard, and the details of the fixed historical furnishings. The results produced by the various groups constitute a database, created through rapid survey methods, from which a comprehensive narrative of the heritage site can be developed.

### 3.2. ACQUISITION AND MANAGEMENT OF DATA USING MLS

Among the many fast surveying tools available today, Mobile Laser Scanners (MLS) are among the most expensive and, consequently, the least familiar to young professionals, as are those most recommended in structurally critical buildings today to reduce operator dwell times in buildings. For this reason, their use assumes particular significance within educational programmes [10]. To document the heritage at risk at Hebdowski Palace, the researchers developed an acquisition methodology employing Leica's BLK2GO MLS instrument [11].

The characteristics of this instrument, designed for the fast documentation of interior spaces, were particularly well suited to surveying the abandoned complex, where even the external space, a central courtyard bordered on two sides by perimeter walls and on the other two by the palace itself, is configured as an enclosed environment. An initial study of the building and its surroundings enabled the pre-organisation of five survey routes: the first covered the two streets of the historic centre flanking the complex and the inner courtyard; the second focused on the courtyard, rooms, and south-east-facing apartments on the ground floor; the third covered the courtyard, rooms, and north-west-facing apartments on the ground floor; while the final two routes captured the upper floors. This preliminary study of the five loops allowed for more efficient fieldwork and ensured an adequate number of shared reference points between paths, which proved essential during the data registration and processing phases [12, 13]. The resulting point clouds were initially managed using Leica's BLK Data Manager software and subsequently registered within the proprietary Cyclone software environment (Fig. 3). The

Fig. 3. *Point cloud of BLK2GO Leyca Geosystem of the entire complex and inner garden. The acquisitions were realized following five different paths and registered together via Cyclone Register 360 software. Source: CC-BY SA [La Placa, 2024]; © 2025, Authors.*

consolidated dataset was then imported into the open-source platform Cloud Compare (free for students without the requirement of a temporary licence), where the three-dimensional model of the building was processed to produce various outputs. From the MLS-acquired database, students generated both two-dimensional drawings (to support the development of metrically reliable architectural plans) and 3D models with orbital mode (appropriately decimated for integration into online visualisation platforms).

These digital products, which are accurate in metric terms and produced in a remarkably short timeframe, represent a preliminary result that can be integrated with data captured through Structure from Motion (SfM) photogrammetry techniques. The outputs serve both to enhance technical knowledge of the at-risk heritage, providing a basis for future restoration efforts, and to increase the visibility of this currently abandoned historical complex, thereby fostering public awareness and appreciation of their local Cultural Heritage [14]. Beyond the aspects of data acquisition, the integration of MLS into the educational framework enabled a broader reflection on the role of high-performance digital tools in heritage conservation. By critically engaging with the entire pipeline, starting from planning scan positions or trajectories to post-processing dense point clouds, students gained not only technical skills but also methodological awareness. This exposure bridged the gap between academic environments and real-world conservation workflows, fostering a mindset that balances precision, efficiency, and accessibility. The validated point clouds and derived models are suitable for diagnostic analyses, preliminary conservation assessments, or integration into larger-scale Heritage Building Information Modeling (HBIM) environments.

### 3.3. LOW-COST TERRESTRIAL AND AERIAL DEVICES FOR ANALYSIS VIA SFM PHOTOGRAMMETRY

The use of affordable terrestrial and aerial devices was not only a logistical choice but also a deliberate strategy to test the democratization of digital heritage documentation. By showing that meaningful, technically robust results can be achieved with entry-level equipment and open-source software, the methodology reinforces a model of accessibility and inclusivity that are key values in both education and heritage policy. Three-dimensional photogrammetric processing software has been positively assessed in the existing literature for both its accuracy and rapid processing times. While numerous publications focus on the photogrammetric reconstruction of sites, including architectural structures, evaluations of such software for small-scale artefacts are less frequent and tend to be concentrated in the fields of archaeology and industry. In this specific case study, the precise and accurate identification of different areas of degradation required metrically validated data and high-resolution textures of superior quality [15, 16]. For this reason, photogrammetry was preferred over 3D MLS scanning techniques.

Nevertheless, the mobile 3D scanner was employed to ensure metric reliability, without necessitating detailed direct surveys. Photogrammetry was also selected as the preferred method for documenting the roof structures using ultralight drones. This choice also aimed to test educational activities employing more affordable tools than laser scanners, thereby enabling the methodology to be replicated even in contexts with limited budgets. The approach involved capturing architectural elements using various photogrammetric techniques, including DSLR (Digital Single-Lens Reflex) cameras, low-cost ultralight DJI drones, and cameras equipped with 360-degree optics, such as the camera model Insta360 X3 (Fig. 4). While MLS offers unmatched geometric precision, photogrammetry excels in capturing detailed textures and damage patterns. The combination of these approaches, along with student-led experimentation, supports a flexible, scalable framework applicable to a wide range of built heritage scenarios. The resulting data not only enriches the didactic experience but also represents a form of participatory conservation, wherein future professionals contribute directly to the digital memory of endangered architecture.

The identification of degradation processes and associated deterioration products at the selected pilot site provided the foundational documentation for subsequent conservation and restoration strategies, which were further explored within the framework of the university course, supported by already undertaken chemical analyses. The initial analytical phase focused on defining morphological and structural characteristics, specifically, establishing the relationships between surface degradation and the underlying substrate to deter-

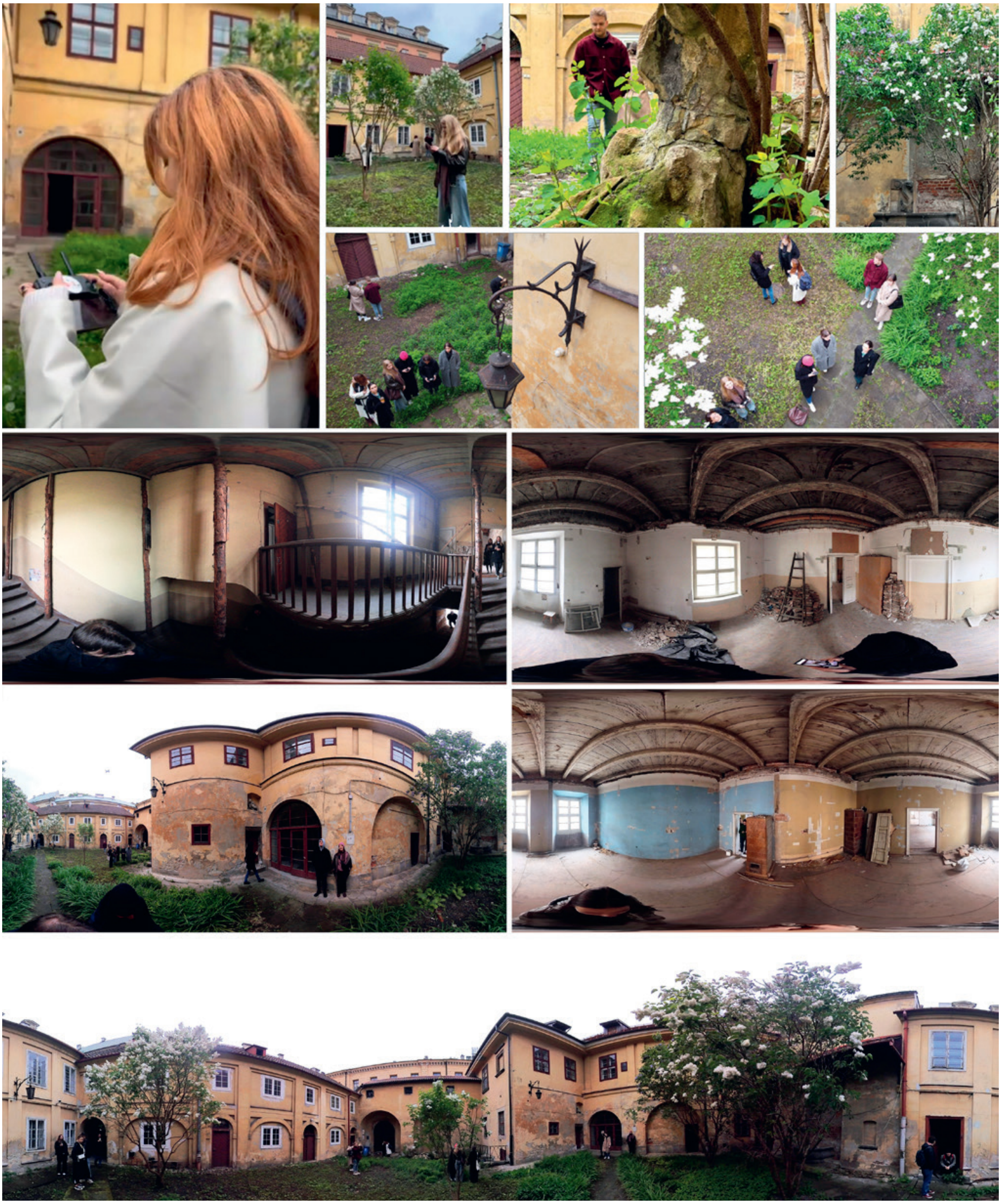

Fig. 4. *Photographic acquisition phases (Unmanned Aerial Vehicle – UAVs – and 360-degree cameras) conducted by students with the support of the authors and tutors of the activities. Source: CC-BY SA [La Placa, 2024]; © 2025, Authors.*

mine causal factors. Integration with 3D survey data enabled detailed documentation of the most severely affected areas, intending to develop a prioritization scale for intervention, based on both the extent and severity of the damage [17].

## 4. RESULTS: DIGITAL PATHWAY AND SCENARIOS FOR ARCHITECTURAL PRESERVATION

As part of the educational programme in architectural restoration, the students undertook the creation of digital scenarios employing augmented reality, virtual reality, and 3D models derived from site surveys, with the dual aim of enhancing both comprehension and preservation of the architectural heritage (Fig. 5). The documentation activities were structured around distinct themes or scenarios, each developed by different student groups participating in the intensive course. In particular, four separate 3D photogrammetric documentation campaigns were carried out, one for each group, which were then combined into a single digital experience:

- general architectural analysis – focusing on the overall context, spatial distribution, typological characteristics, and identification of major structural vulnerabilities;
- inspection of exterior surfaces and roofing – addressing criticalities arising from natural and anthropogenic degradation processes, and their impact on the underlying materials;

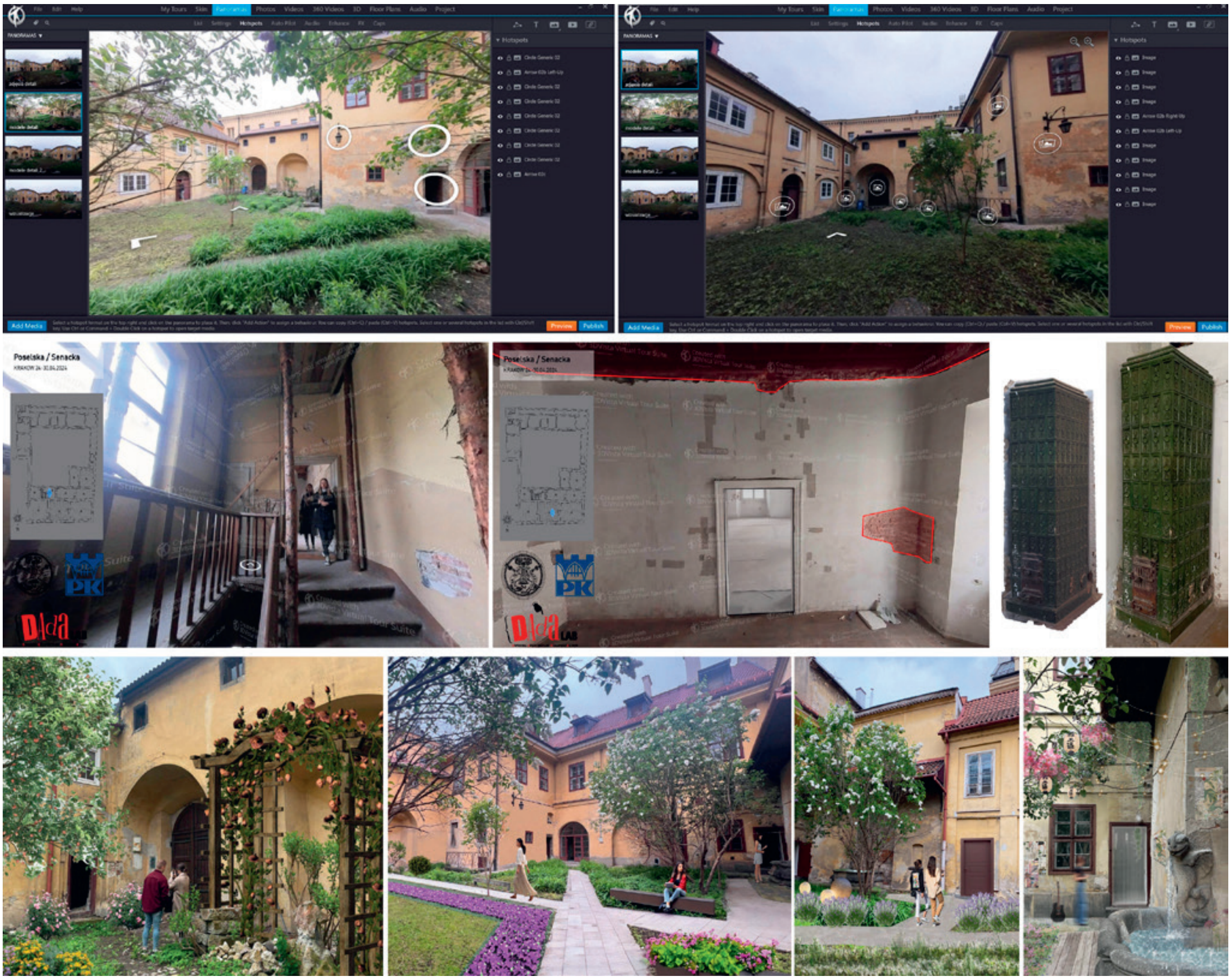


Fig. 5. *Output obtained at the end of the intensive course (5 days of work, one day for presentations and conclusions, for a total of 48 hours of in-person course). Source: CC-BY; © 2025, Authors.*

- detailed documentation of interior decorative elements and technical construction elements – with particular attention to the valuable historical features, such as the collection of 18th-century Russian and Saxon ceramic stoves originally used for heating and cooking or the wooden ceiling;
- analysis of vaulted and portal systems – construction analysis of vaulted systems, of which preliminary stratigraphic analyses were available, and analysis of wall intersections, visible where the finishing layer is missing.

In parallel to the activities, a photogrammetric acquisition campaign with 360-degree cameras was conducted with the aim of generating complete models of the architectural complex, testing the creation of 3D models and assembling a virtual tour that would serve as an integrated information platform and consolidate the results of the previous scenarios. The decision to prioritise three-dimensional photogrammetry was informed by the need to capture fine textural details efficiently, produce outputs rapidly, and maintain affordability, even while integrating laser scanner data to ensure correct orientation and accurate scaling relative to direct surveys [18]. Each documentation scenario was conceived not merely as a survey exercise but as a narrative element to be embedded within the virtual tour developed. This holistic approach enabled the integration of diverse areas of investigation into a unified, interactive digital tool, allowing users to explore the building at varying levels of detail. Within the final virtual tour, these scenarios coexist yet are distinguished through individual thematic pathways visible in the navigation interface. This design facilitates multiple interpretative routes, some more technically focused (e.g., material conditions and degradation analysis), and others more oriented towards historical context or spatial organization. In this way, a singular but dynamic narrative was crafted, enabling layered readings of the architectural site and promoting its value within the urban fabric of Kraków. The immersive 360-degree virtual tour application was further enriched by incorporating design principles aimed at fostering interactive and educational experiences. These included the formalization of design tasks, a systematic approach to content development, and adherence to a set of methodological guidelines for creating engaging immersive environments [19, 20]. The virtual tour functions as a digital counterpart to a traditional urban walking tour, offering enriched interpretative content about the space, its architectural details, and its historical significance, while providing an interactive user experience [21].

Beyond their pedagogical value, the virtual environments created during the project serve as digital archives that can support strategic planning and decision-making processes for heritage institutions. By embedding technical analysis within interactive and accessible formats, the project offers a replicable template for other abandoned sites and the university buildings involved, especially those in urgent need of visibility, funding, competitive calls for tenders, and adaptive reuse proposals. The virtual tour developed in this project is grounded entirely in real-world data, derived from photogrammetric captures of the existing environment, without reconstruction of non-existent spaces. Rather than aspiring to create a fully operational digital twin for real-time simulations, the project focuses on providing an accessible, data-rich digital environment for visualising authentic, surveyed conditions. Additionally, as an extension of this modelling experiment, the students developed a digital conservation proposal for the palace, integrated directly into the virtual tour. This included the ability to view a before-and-after comparison of the rooms through two-dimensional imagery, further enhanced by 360-degree visualizations that allow users to experience the intended restoration outcomes within the context of the original space. The methodology presented in this study is characterized by its focus on high-impact, low-barrier digital workflows. Its originality lies in combining rapid survey techniques, open-source tools, and immersive design within a short academic timeframe to produce outputs of real operational value. The project framework responds to both educational and heritage-sector needs, and its flexibility allows for replication across different institutional and geographic contexts.

Moreover, the approach challenges the traditional separation between documentation and interpretation by proposing a hybrid workflow that culminates in an interactive, multi-scenario virtual tour. This represents not only a pedagogical innovation but also a practical strategy for enhancing public access to heritage knowledge, particularly in underfunded or at-risk sites.

## 5. CONCLUSION

This interdisciplinary initiative has successfully demonstrated the significant potential of integrating fast digital survey techniques within architectural and engineering curricula, particularly in the context of heritage documentation and conservation. By employing a combination of accessible technologies, including drone-based photogrammetry, mobile laser scanners, and 360-degree imaging, the process involves students, enabling them to deal with real-world scenarios, developing both technical proficiency and a critical understanding of heritage values. The immersive application of these tools facilitated a deeper appreciation of materiality, structural behaviour, and the pathological processes affecting historic buildings. Furthermore, the opportunity to produce metrically accurate, high-resolution models enabled the students to work with a level of precision necessary for informed conservation decisions. These digital outputs supported the development of both specialist restoration strategies and accessible communication tools, enhancing the understanding and appreciation of Cultural Heritage among diverse audiences.

A key outcome of this experience lies in the creation of interactive virtual tours, which proved highly effective as both educational and dissemination tools. The structured layering of thematic scenarios within the virtual environment allowed for multi-level exploration of the site, fostering a richer, more contextualised comprehension of architectural history, construction techniques, and conservation challenges. This active learning approach not only reinforced theoretical knowledge but also cultivated essential soft skills, such as critical thinking, collaborative design, and audience awareness – competencies vital for future professionals in architecture and the Cultural Heritage sectors. Moreover, the adoption of low-cost, scalable technologies ensures that such methodologies are replicable and adaptable across varying educational and operational contexts. It promotes a more democratic access to advanced documentation techniques, supporting their integration even in institutions or projects with limited resources.

Unlike previous educational initiatives in digital heritage documentation, this study proposes a scalable, interdisciplinary methodology that combines real-time mobile laser scanning with immersive platform design. The originality lies in its integration of professional-grade digital workflows into a compressed academic timeframe, enabling not only technical skill development but also the co-production of dissemination tools. The digital outputs – such as metrically reliable point clouds and virtual tours – transcend the academic setting by serving as foundational resources for future restoration or policy-driven reuse initiatives.

Looking forward, the promising results of this pilot project suggest numerous paths for future research and application. These include the development of more advanced immersive environments integrated with diagnostic and monitoring data, greater interoperability with conservation science tools, and the creation of collaborative platforms that bridge academic learning with professional practice. Ultimately, this blended approach between digital innovation and Cultural Heritage tradition not only enriches architectural education but also strengthens the future of heritage preservation in the digital era.

This project also addresses a gap in heritage conservation practices: the lack of real-time, affordable, and pedagogically embedded documentation workflows. By connecting students with disused heritage sites through cutting-edge tools, the methodology fosters a sense of ownership and civic responsibility. Moreover, its alignment with SDG 11 and the EU Open Data Directive suggests wider applicability as a model for participatory heritage valorization strategies.

Several promising topics for future research can be identified. There is potential to explore the integration of real-time monitoring data within immersive environments, enabling dynamic visualisation of structural health and environmental conditions alongside historical and architectural information [22, 23]. Further development of collaborative, cloud-based platforms could enhance interdisciplinary cooperation, allowing students, researchers, and practitioners to interact within shared virtual models, fostering a collective approach to heritage conservation.

Moreover, the educational impact of these technologies deserves further investigation, particularly to assess the long-term retention of knowledge and acquisition of skills through immersive and interactive learning environments. While the study successfully demonstrated the feasibility of the proposed approach, limitations remain in terms of scalability, interoperability with ongoing restoration platforms, and integration with diagnostic data. Future research will explore the use of Artificial Intelligence (AI)-assisted damage classification, integration with Building Information Modeling (BIM)-based restoration pipelines, and long-term monitoring of heritage structures through Internet of Thing (IoT)-enabled sensors. Further investigation is also required to assess the pedagogical impact of immersive technologies on long-term knowledge retention in architectural education. Exploring the application of these digital methodologies across diverse Heritage contexts could contribute to establishing scalable, adaptable frameworks for heritage education and preservation in the European context.


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## Authors contribution

Conceptualization, Authors; Methodology, E.D., S.L.P.; Validation, E.D., S.L.P.; Investigation, E.D.; Resources, J.S.; Data Curation, E.D.; Writing – original draft preparation, E.D.; Writing – review and editing, E.D.; Visualization, E.D.; Supervision, J.S., E.D.; Project administration, E.D., S.L.P., Funding acquisition, E.D., S.L.P. Logistical support and management of the spaces to be analysed, as well as student organisation, was handled by J.S. (Kraków). The activities to be carried out were planned in collaboration with E.D. and S.L.P.; the survey activities were planned by S.L.P.; the technological surveys, analyses of the state of conservation and VT design for conservation and spatial design were managed by E.D. (University of Pavia).


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