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THE ROLE OF ARTIFICIAL INTELLIGENCE WITHIN THE PROCESS OF KNOWLEDGE, CONSERVATION, DESIGN AND DIFFUSION OF THE RESTORATION OF INTERIOR SURFACES.

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Abstract

The restoration of the interior surfaces of historic buildings of cultural significance is subject to a continuous process of updating the tools and techniques used. In recent years, the introduction of artificial intelligence as a support to human work has defined new perspectives for technological evolution in the field of heritage conservation. This thesis proposes an in-depth study of the possible applications of AI to the restoration of interior surfaces, considering its potential and the limitations that currently hinder its large-scale diffusion, to conduct a study of the state-of-the-art of restoration and understand the direction in which the inexhaustible process of technological evolution will take us.

Specifically, this thesis aims to deal with the topic described by promoting interaction between human intellect and artificial intelligence, while maintaining a critical view on the issue of ethics. The use of AI-related tools should not be seen as a substitute for human work (and role), but as an advanced technological support capable of offering unprecedented performance. An ethical and responsible application, capable of maintaining a balance between 'traditional' methodology and innovation. To investigate the possible forms of integration of artificial intelligence into our field of interest, it is necessary to consider the restoration process as a unique cycle composed of several interconnected phases.

Among these, we can mention for our research: the survey and reproduction of architectural objects, the design and management of conservation interventions, scheduled maintenance, archiving, and divulgation. So, what contribution can artificial intelligence give to the different stages of the restoration process? What kind of contribution can it actually make to existing methodologies and advanced technologies?

Our research starts from these questions and proposes a reflection through the analysis of some case studies representative of a new desire for conservation experimentation that seems to be growing progressively.



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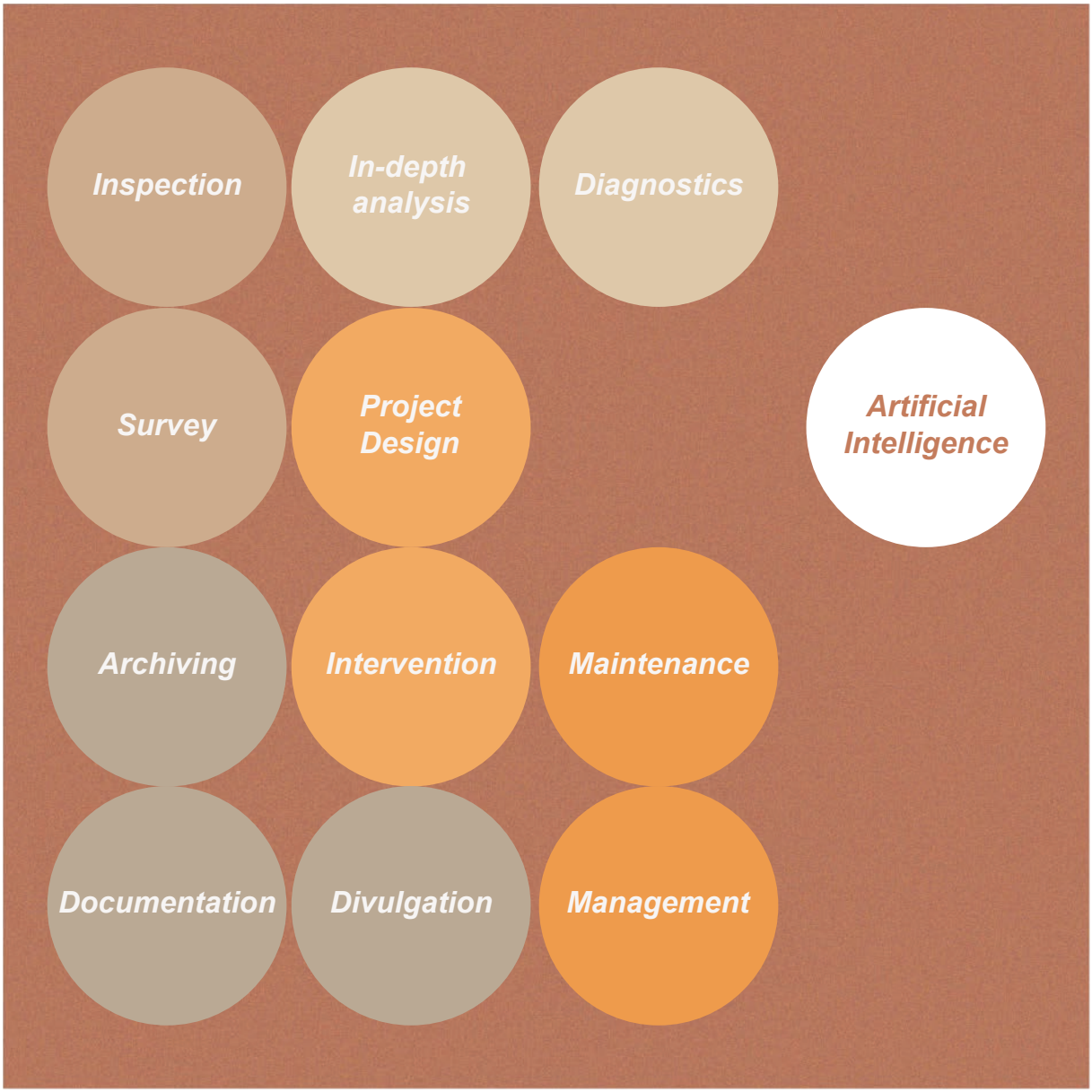
Introduction

The following pages offer an analysis of research on the application of artificial intelligence in the restoration process of the interior surfaces of historic buildings. To place this topic correctly within the state of the art of restoration, we can begin by reflecting on the historical, cultural, and technological context in which our research is located. In particular, the current context is characterised by the progressive and continuous digitalisation of more and more fields of human knowledge. The transition from the first digital revolution, defined by the advent of computers, to the second, with the invention of the Internet, and the third, with the spread of mobile devices, has enabled the rapid expansion of new technologies, transforming social and cultural habits. The introduction of artificial intelligence represents a further step that marks the beginning of the so-called Fourth Digital Revolution[1].

In the field of architectural restoration, the digitalisation of processes related to the conservation of heritage, combined with the use of AI and advanced technologies, is a powerful support tool. A tool capable of finding a meeting point between technological innovation and the protection of cultural heritage through the improvement of restoration work performance and the simplification of human work.

[1] D. Luraschi, C. Sangiorgi, *"Futura praeteritus". Reflections on artificial intelligence in the context of the project, ideas for the programme of the next Collegium Council (2024-2027)*, REC Magazine no. 181, 2024, pp. 28-30


Inspection
In-depth analysis
Diagnostics
Survey
Project Design
Artificial Intelligence
Archiving
Intervention
Maintenance
Documentation
Divulgation
Management

Some of the experiments we will discuss in this thesis demonstrate the intention to refine and redefine methodologies in the various stages of the restoration process: the survey and knowledge of historic buildings and their surfaces, conservation work and the management of their life cycle, and the collection and dissemination of their material.

Our investigation, therefore, aims to explore the various forms of AI applications in the field of architectural restoration of interior surfaces, with a particular focus on their possible future developments. In this sense, we can hypothesize a future evolution of these technologies and a consequent probable reorganisation of the methodology that we will call 'traditional'. From this perspective, the use of artificial intelligence is to be understood as a support tool, aimed at expanding and improving human experience and sensitivity in the restoration process, and not as a substitute for it.

Considering the described context, we can begin our research by stating that the state of the art, related to the topic under analysis, is a system in continuous development and evolution, and that, therefore, it can only be studied through the tools and evidences available at the time of our research.



PROMPT CHAPTER 1:

The application of artificial intelligence in the restoration process of interior surfaces

The restoration of the interior surfaces of historic buildings is divided into several phases that can be considered both individually and as parts of a single cycle, to be understood as a process strictly aimed at preserving and handing down the integrity of the object of study over time. Specifically, the conservation process begins with the inspection and survey phase, characterised by the graphic reproduction of the object, supporting an in-depth analysis of the history and stratigraphy of the surfaces, with identification of materials and decay pathologies. This is followed by the design phase of the restoration intervention and the detailed planning of the techniques to be used based on the diagnosis of the materials. The execution phase consists of carrying out the planned interventions with the support of the chosen techniques, while the post-intervention documentation phase concludes the conservation process, as it focuses on the scheduled maintenance of the object and the management of the heritage over time, as well as the cultural divulgation of its material.

Considering the conservation cycle described above, artificial intelligence can contribute significantly to the various phases. Its integration can, in fact, bring greater precision and efficiency to the tools used in the survey and analysis, design, and monitoring of architectural objects and their surfaces. To investigate the possible applications of AI within the restoration process, we will analyse the individual phases.

1.1 AI-related techniques in surveying and graphic reproduction

In the survey phase, we know that there are already well-established techniques for surveying the geometry and surfaces of historic buildings. In the field of AI application, we can mention its integration into sophisticated systems, such as drones and autonomous vehicles, for surveying and mapping inaccessible points. In particular, *"drones equipped with intelligent sensors allow us to reach the most inaccessible parts of a building and take photographs and acquire 3D point clouds, which can then be imported into modelling software for the construction of H-BIM models*[2]*."* In this way, AI reduces survey times and increases the safety of personnel in the sector, as the drones can be piloted directly by operators.

Artificial intelligence can also be integrated into laser scanning technology, speeding up the process of surveying and processing point clouds. AI algorithms enable computers to automatically distinguish the main elements of the cloud: walls, floors, roads, and vegetation. *"This approach reduces the time spent on manual classification, increasing the accuracy and efficiency of modelling. With the support of artificial intelligence and cloud technologies, laser scanning is therefore confirmed as one of the most advanced technologies for surveying* [3]."

[2] From web article https://biblus.acca.it/ai-conservazione-architettonica/

[3] From web article https://cloud4bim.com/laser-scanner-e-intelligenza-artificiale-innovazione-nei-rilievi-e-nella-post-elaborazione/

Alternatively, artificial intelligence can be integrated to automate the Scan-to-BIM process. In this regard, we can make an introductory reflection on BIM in restoration. As we know, BIM is a well-established technology in the field of new architectural and engineering design. In the field of restoration, H-BIM (*Heritage Building Information Modelling*) has only recently established itself, as the complexity of architectural forms hindered the comprehensive digital reproduction of certain historic buildings.

This representational difficulty can be seen in the early experiments with H-BIM technology. In this regard, we can mention the restoration project of the interior surfaces of the Basilica of Santa Maria Assunta in Gallarate, carried out in 2018. The project, aimed at restoring dry paintings, frescoes, stuccoes, mosaics, and flooring in the church, used H-BIM to reproduce a 3D model based on laser scanner and point cloud surveys. Once the geometric model was completed, the problem of coding the individual elements arose. The initial model was based solely on the spatial forms of the basilica and did not consider the categorisation of the various elements from a technological-functional and material-surface point of view[4]. It was therefore necessary to remodel the 3D model.

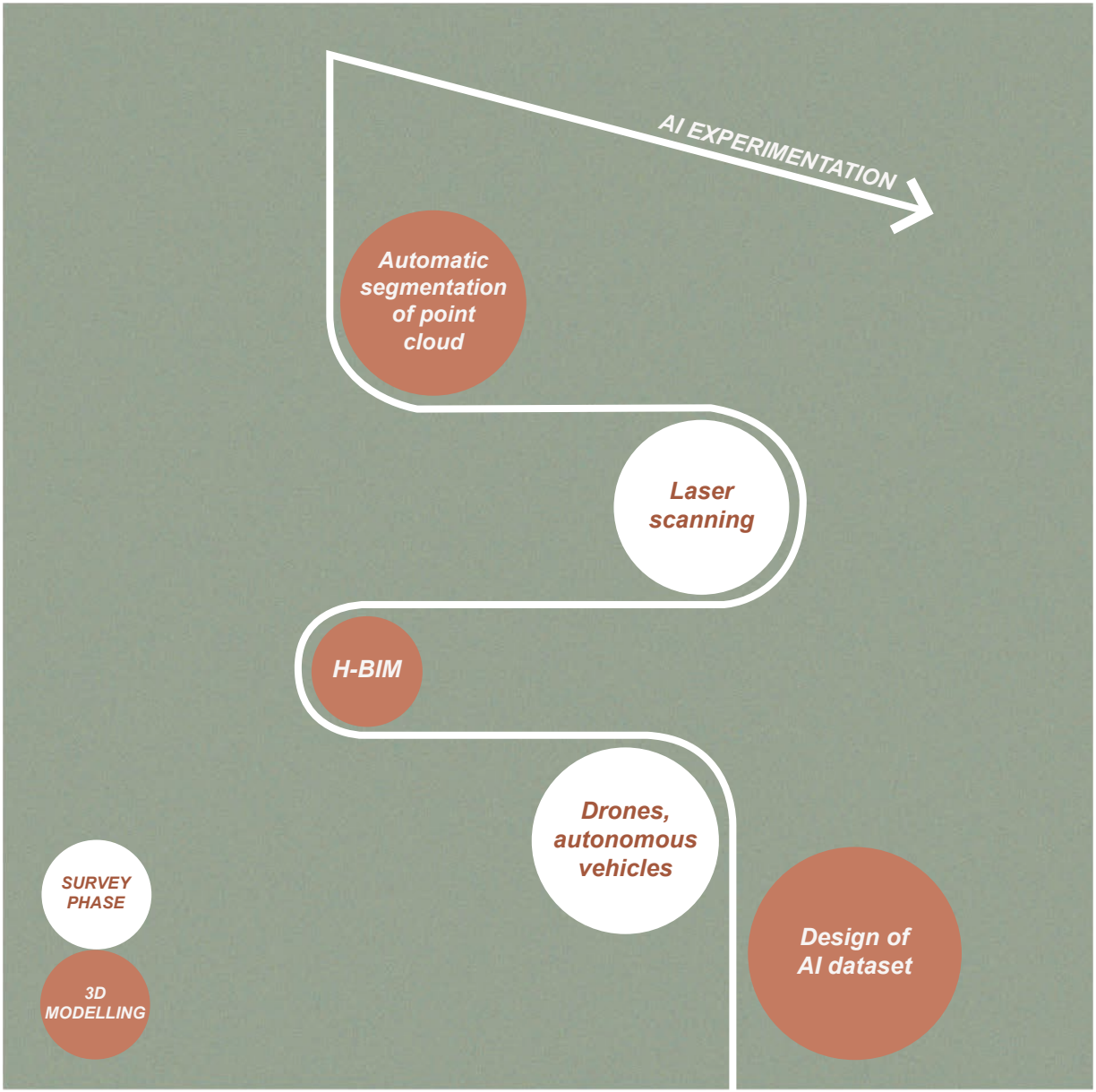
[4] The initial model was created with the aim of producing a model that was spatially and aesthetically faithful to reality. Considerations regarding the coding system and subsequent allocation of information emerged in the subsequent analytical phase of the work. From P. Gasparoli, F. Pianezza, M. Torri, *BIM in the restoration of historic surfaces. The case of the Prepostural Basilica of Gallarate*, REC Magazine no. 150, 2018, pp. 35-42

This problem caused a general slowdown in graphic reproduction times, raising doubts about the potential costs. Similarly, the restoration project of Palazzo Gagliardi-de Riso in Vibo Valentia, carried out in 2019, encountered the same difficulties in digital reproduction[5]. It is important to note, however, that in both cases, once the final 3D model of the architectural objects and their surfaces was obtained, there was a significant improvement in the performance of the interventions.

In the following years, H-BIM technology has evolved considerably, becoming a significant support to the general restoration process, as it is an effective tool for organising and managing the intervention. Specifically, *"H-BIM consists of creating a digital model that associates each geometric element with a series of data: materials, chronologies, costs, and construction phases. In restoration, this model is adapted to all the various issues related to historical heritage: geometric irregularities, stratifications, and changes over time.*[6]*"* The result is therefore a model that not only presents the three-dimensional object, but also information and data. However, we must recognise the technological difficulty associated with the use of BIM technology, which requires a high level of expertise on the part of operators. In this context, artificial intelligence is an experimental addition to H-BIM technology.

[5] E. Pata, A. Scriva, *H-BIM application to the restoration project. The example of Palazzo Gagliardi-de Riso in Vibo Valentia*, REC Magazine no. 156, 2019, pp. 89-96

[6] From web article https://www.latestatamagazine.it/2025/10/restauro-e-nuove-tecnologie-ia-e-3d/


AI EXPERIMENTATION
Automatic segmentation of point cloud
Laser scanning
H-BIM
Drones, autonomous vehicles
Design of AI dataset
SURVEY PHASE
3D MODELLING

Specifically, it would be possible to automate the semantic segmentation of the point cloud generated by the survey to create actual tags or labels for each 3D point (column, capital, floor, etc.) to classify them into different categories and create the corresponding digital elements[7]. Through the design of specific datasets, AI could then guide BIM software in the recognition and automatic reproduction of the architectural object. "*In workflows, AI is not only supportive, but acts as a driving force that guides and optimises modelling, significantly reducing potential errors and increasing operational efficiency*[8]." Current documentation allows us to cite the case study of a stone bridge along the historic disused railway in the municipality of Sambuca in Sicily, carried out in 2025, which involved experimenting with the use of AI in the graphic rendering phase using BIM.

In the case study, the point cloud generated by the survey was processed with Open3D, using a dedicated Python script to translate the points into tags and facilitate geometric operations. This methodology was integrated with a *deep learning* artificial intelligence component (AtlasNet model), designed to generate 3D surfaces from partial point clouds.

[7] V. A. Cotella, *From 3D point clouds to HBIM: Application of Artificial Intelligence in Cultural Heritage, Automation in Construction*, 2023

[8] L. Inzerillo, A. Pisciotta, F. Acuto, K. Mantalovas, G. Di Mino, *Beyond Traditional H-BIM: AI-Powered Modelling for Heritage Bridges*, The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XLVIII, 2025

"The use of this platform has significantly improved the quality of the reconstruction, particularly in the presence of incomplete or deformed geometries.[9]*"* Considering this experiment, we can say that the application of AI in the processing of point clouds transmitted to BIM models is an interesting methodology under development.

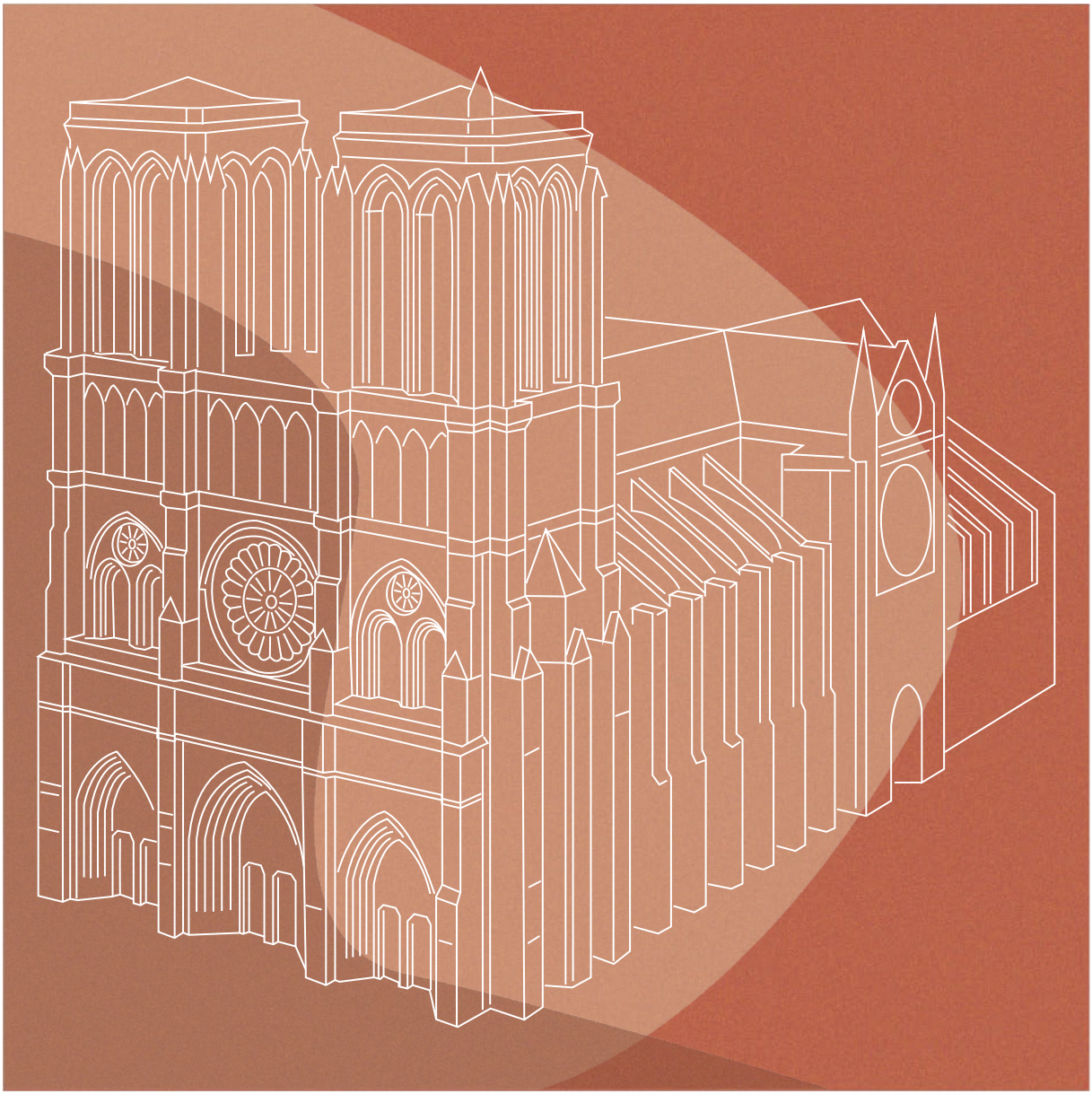
The possibility of integrating artificial intelligence into H-BIM could lead to significant practical improvements in the various stages of the restoration process in the future. This is also thanks to the potential of BIM itself. To list a few, BIM files can be exported in *.ifc* format, which is compatible with the software that operators in the sector use for structural, plant engineering, accounting, and safety calculations[10]. This advantage allows for easy conversion of the BIM system into the everyday tools of professionals in the sector. In addition, *BIMx* technology allows the model created to be viewed directly from smartphones and tablets, facilitating the use of the material during the construction phase.

[9] L. Inzerillo, A. Pisciotta, F. Acuto, K. Mantalovas, G. Di Mino, *Beyond Traditional H-BIM: AI-Powered Modelling for Heritage Bridges*, The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XLVIII, 2025

[10] D. Simeone, S. Cursi, I. Toldo, G. Carrara, *B(H)IM – Built Heritage Information Modelling Extending. BIM approach to historical and archaeological heritage representation. Digital Heritage*, Vol. 1, 2014, pp. 613-622

In addition to supporting restoration work, BIM can also be used for archiving and disseminating the 3D model. It can be uploaded to the BIM Explorer platform, a globally connected database that provides an archiving function for BIM materials that can be consulted on an ongoing basis[11]. From this perspective, artificial intelligence associated with BIM could represent a further technological advantage capable of improving its performance.

[11] D. Del Curto, A. Grimoldi, *'Pre-digital' information models and their recent developments. From Raumbuch to BIM in Final Conference of 'Build Heritage* Information', 2010

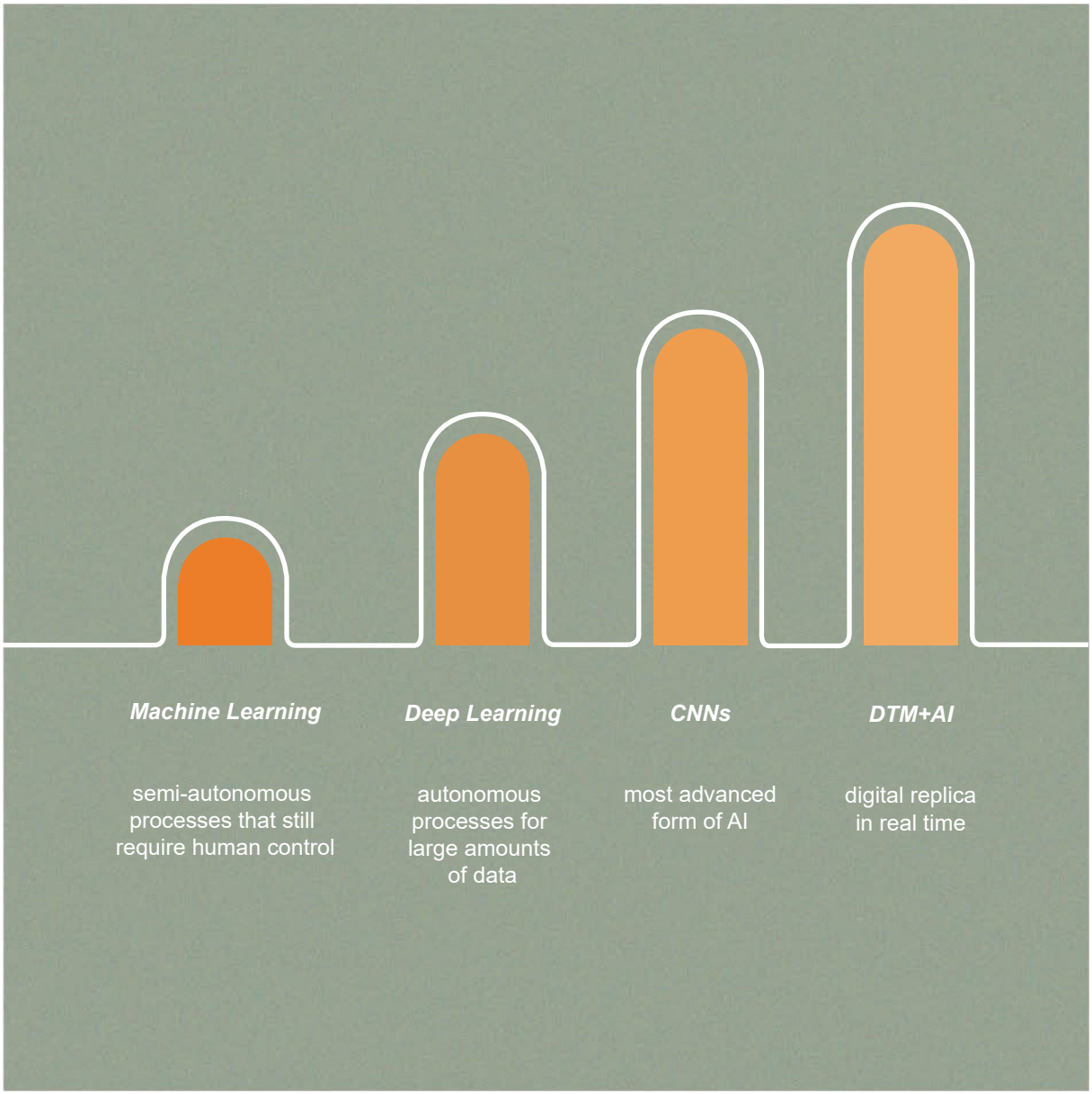


1.2 AI in surface analysis and diagnostics

In the analysis and diagnostics phase, artificial intelligence takes on a more important role thanks to *machine learning* and *deep learning* systems. Specifically, machine learning is the branch of AI that supports automatic learning by machines through the imitation of the way humans learn, in order to automate certain processes and improve performance. In this way, trained algorithms become capable of autonomous decision-making aimed at predicting and classifying data, with the possibility of subsequently optimising the adopted model and reducing any discrepancies.

Unlike machine learning, deep learning does not require a labelled dataset, as it is able to process unstructured data in its raw form, automatically differentiating the distinctive characteristics of information such as text and images. Deep learning can therefore be used to analyse larger amounts of data obtained from inspections and surveys of historic buildings, while machine learning requires the input of datasets by humans to supervise the automatic work[12]. These two forms of artificial intelligence are particularly effective during the analysis of interior surfaces, as they are able to use *computer vision* to enable trained machines to see as well as think.

[12] From web article https://www.ibm.com/it-it/think/topics/machine-learning

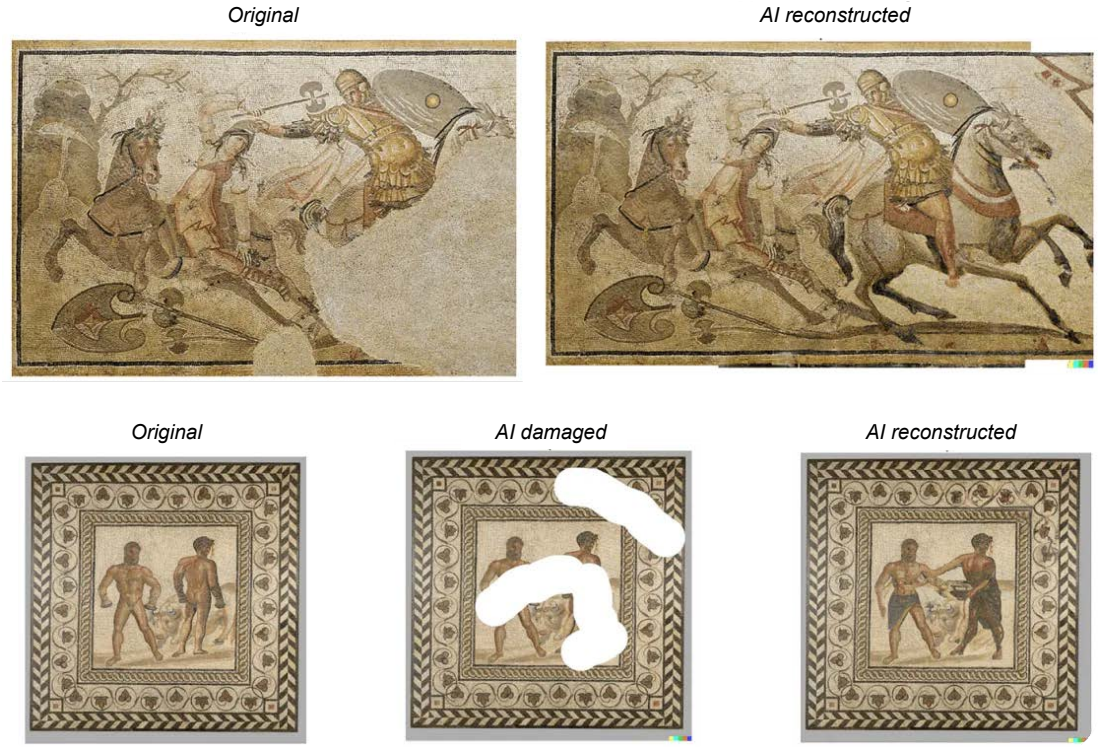

Machine Learning
semi-autonomous processes that still require human control
Deep Learning
autonomous processes for large amounts of data
CNNs
most advanced form of AI
DTM+AI
digital replica in real time

Specifically, it is possible to transfer visual and video images to the machine for automatic inspection to recognise the desired elements and perform analyses of surfaces and their decay. Within the computer vision process, convolutional neural networks (CNNs) represent the most advanced form of intelligent technology. They can fragment the images received into pixels corresponding to tags and labels, which are used to perform convolutions of arithmetic functions and make predictions about what the machine sees.

The convolution process consists of "*treating the X-ray image as a matrix of pixel values, onto which another matrix of weights (parameters that control the influence that a given input feature has on the model's output) is superimposed and applied to an area of the image, with a scalar product calculated between the input pixel values. In this way, the filter moves across the image to extract features. Each filter is optimised to respond to specific patterns, such as edges, shapes, or textures, allowing the CNN to learn multiple visual features at the same time*[13]." This process represents a significant contribution of AI to the analysis and diagnostics phase, as it allows for a considerable reduction in time and automation of image processing in order to return a complete mapping of anomalies, degradation or micro-cracks before they become visible to the human eye, as well as variations in original and recent overlapping pigments, facilitating the monitoring of assets and any timely interventions.

[13] From web article https://www.ibm.com/it-it/think/topics/computer-vision

Computer vision technology also allows colours and textures to be simulated on the basis of the preserved decorative layers. In this regard, we can cite the study carried out by La Sapienza University in Rome on the façade of the Colosseum, in which AI-based image recognition was used to check for cracks and erosion and digitally reconstruct the missing portions of the decorations analysed[14]. The application of artificial intelligence in the analysis and diagnosis of surfaces, therefore, provides considerable support to the process of understanding history, stratigraphy, and degradation pathologies.



Comparison between the original damaged surface of the Colosseum and its restored version with AI.
source from www.ultralytics.com

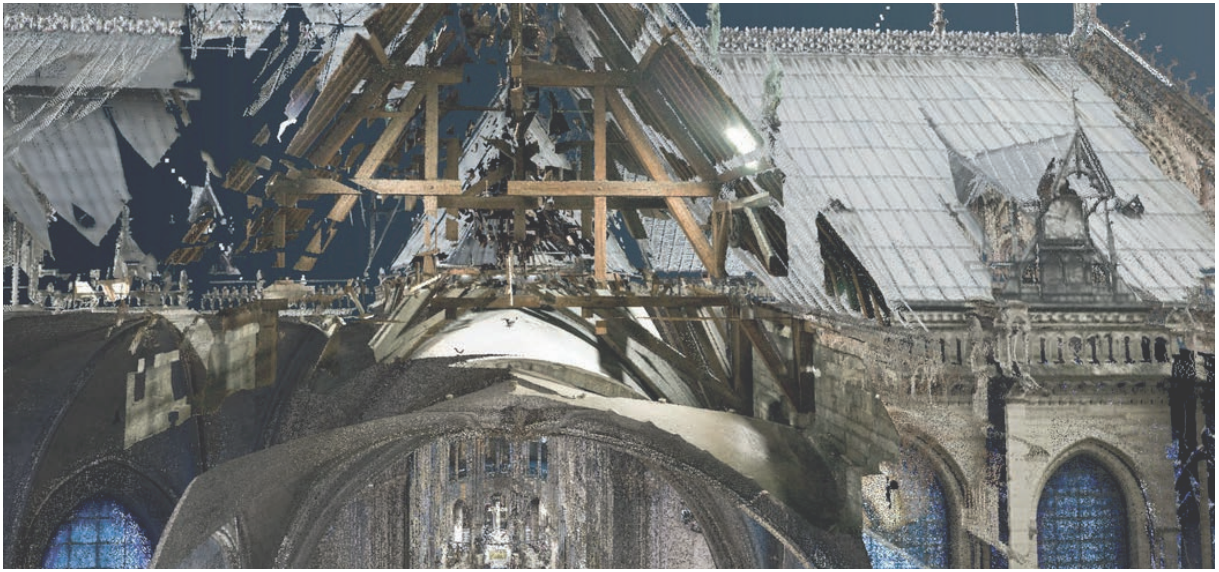
[14] From web article https://www.ultralytics.com/it/blog/ai-in-art-and-cultural-heritage-conservation

Finally, we can mention the recent project to restore the lost portion of Notre-Dame Cathedral in Paris, destroyed during the 2019 fire. In this case, the application of AI deep learning was fundamental to process all the information obtained from the survey and the more than 14,000 photographs taken by drones. Through integration with the *Digital Twin Model* (DTM), it was possible to create a digital replica of the cathedral, capable of evolving in real time with the structure of the building. This step subsequently allowed the functioning and behaviour of the replicated object to be monitored, inspected, and simulated, hypothesising scenarios and providing information on potential vulnerabilities[15].

Livio De Luca, Research Director at the *Centre National de la Recherche Scientifique* (CNRS), explained that the use of artificial intelligence and DTM played a crucial role in the restoration project, stating that *"deep learning approaches help to introduce new methods for more effectively correlating multi-scale and multi-temporal observations, saving considerable time in specialist work. This made it possible to create a digital replica of inestimable value for an iconic monument*[16]*."*

[15] F. Cinquepalmi, *Using Digital Twin Models (DTM) for managing, protecting and restoring historical buildings, Conservation Science in Cultural Heritage*, Vol. 22, 2022

[16] E. Shein, *Creating Digital Replicas of History with AI*, web article, 2025





Digital Twin Model of Notre Dame Cathedral

source from Violette ABERGEL / MAP / Vassar College / Chantier Scientifique Notre-Dame de Paris / Ministère de la culture / CNRS

He adds that "*this knowledge will continue to enrich scientific research into heritage, also serving as raw material for future studies of artificial intelligence systems that can be extended to other buildings*[17]."

Considering the mentioned cases, we can say that the use of artificial intelligence during the analysis and diagnostic phase can be understood in two ways. In the first, AI supports operators in the sector during the study of objects of interest for restoration purposes; in the second, it contributes to knowledge and cultural dissemination as a graphic communication tool, even for missing portions.

[17] From web article https://emag.archiexpo.com/interview-notre-dame-de-paris-as-a-case-study-for-ai-in-architecture/

1.3 Design and execution of interventions: examples of AI applications

Currently, the design and execution phase of restoration projects is seeing increasing experimentation with applied intelligent systems capable of identifying areas of interest and simulating the behaviour of architectural objects in various scenarios. We have seen how the integration of artificial intelligence with H-BIM technology can facilitate planning and execution on site, just as machine learning and deep learning systems are capable of making predictions through computer vision and identifying anomalies that can be addressed manually or through machines.

This experimental drive demonstrates a general interest on the part of the industry community in researching further intervention methods capable of revolutionising the world of restoration, starting with a positive approach to advanced technology. In the operational phase, avant-garde examples include intelligent systems capable of providing detailed mapping and reconstructing portions of damaged surfaces. In this sense, robotic technology provides an interesting tool for applying AI to restoration work.

An example of such an application can be found in the conservation work carried out by Lawrence Technological University of Southfield (USA) in collaboration with the University of Ferrara in 2019, which aimed to analyse a wall gap in the Woodward Avenue Presbyterian Church in Detroit and then complete the restoration using *an additive* manufacturing process via a robotic system[18]. The project involved the initial modelling of the robot's workspace (*work cell*[19]) using a grid of points and the subsequent creation of a model of the gap in question. The use of plug-ins allowed for high precision in the conservation analysis of the object, with subsequent verification of any collisions and control of the chosen material (clay). The integration of AI machine learning was decisive in training the robotic arm, which was used to successfully repair the gap in the wall.

[18] S. Codarin, *Digital Manufacturing and Cultural Heritage (part II). An experimental workflow for digitising restoration sites*, REC Magazine no. 152, 2019, pp. 67-73

[19] Digital modelling was carried out using Rhinoceros V6 software, while algorithmic programming was carried out using the Grasshopper plug-in for Rhinoceros.



Robotics + AI, RePAIR project

source from Archive of the Archaeological Park of Pompeii

We can also mention the RePAIR project[20] (*Reconstructing the Past: Artificial Intelligence and Robotics meet Cultural Heritage*), which we will explore in more detail in the next chapter, aimed at bringing to light the forgotten frescoes of Pompeii. Launched in 2021 and completed in 2025, this technological experiment achieved the expected result through the interaction of a robotic infrastructure with intelligent systems that enabled the recognition of the various fragments of the frescoes analysed and their recomposition. The two projects mentioned above, therefore, demonstrate active experimentation in the intervention phase, indicating the intention to improve research work and revolutionise practical methodologies in the future.

Parallel to the field of architectural restoration, the field of artistic restoration is also seeing increasing attempts to apply AI. These include the use of polymer films that can be applied directly to the surfaces to be restored. Alex Kachkine, a researcher at the Massachusetts Institute of Technology, recently restored a damaged oil painting on wood attributed to the Master of the Prado Adoration, dating from the late 15th century. Traditional restoration of this work would have required approximately 200 hours of work and high costs. Kachkine hypothesised a new form of art restoration that could be carried out quickly and at low cost.

[20] Project partners included: Ca' Foscari University of Venice, Ben-Gurion University of the Negev in Israel, IIT – Italian Institute of Technology, Associacao di Instituto Superior Tecnico Para a Investigacao e Desenvolvimento in Portugal, Rheinische Friedrich Wilhelms Universitat in Bonn, Ministry of Culture



Damage map of the painting

photograph by Alex Kachkine, MIT - source from theguardian.com

An initial scan was used to create a digital replica of the painting, which was then analysed using artificial intelligence combined with other computer tools that highlighted over 5,000 separate sections requiring intervention. A digital mask was then created in Adobe Photoshop, and the work was restored using AI. The missing paint spots were reproduced on this mask with chromatic reference to the surrounding pigments, while the damaged areas were reproduced by identifying similar patterns in the painting and the artist's style. Finally, the transparent polymer film was printed and applied to the work, which was then restored using micro-instruments and sprayers to deposit the pigments present on the AI-generated mask. Once the restoration was complete, the film was removed without leaving any traces.

Although this experiment raised some doubts about the universal effectiveness of this technique, which at the time of our research cannot be considered reliable enough to be used on works of enormous value, we must once again recognize the desire to seek innovative restoration methods. Prof. Hartmut Kutzke of the Museum of Cultural History at the University of Oslo said of the experiment: *"The method is likely to be more applicable to paintings of relatively low value, which would otherwise be stored in closed locations, and may not be suitable for famous and valuable works of art*[21]*"*, while recognising the potential of this AI-associated technique and the possibility of making restored works accessible again.

[21] From web article https://www.theguardian.com/science/2025/jun/11/researchers-create-ai-based-tool-that-restores-age-damaged-artworks-in-hours

If we project this form of intervention into the restoration of interior surfaces, we can hypothesise its use in the case of wall frescoes, mosaics, wall decorations and flooring. It therefore represents an interesting methodological starting point for future research developments.

1.4 The use of AI for ethical scheduled maintenance

Following restoration work, we enter the architectural object's life cycle management phase, in which monitoring and supervision play a central role in preserving the asset. In this context, artificial intelligence is increasingly present through its integration into predictive 3D models, capable of identifying future risks and structural vulnerabilities caused by environmental and climatic factors. Its application becomes relevant when associated with GIS (*Geographic Information System*) systems, which allow a specific asset to be placed in a precise territorial context and georeference all information based on its state of conservation.

The integration of GIS and AI, called *GeoAI*, offers further precision and accuracy in data analysis thanks to machine learning and deep learning, which can process information from GIS systems and transform it into insights. An example of a GeoAI application can be found in the monitoring of Milan Cathedral, which uses an H-BIM model equipped with GIS systems capable of constantly recording any environmental damage such as acid rain, erosion, and smog, allowing operators to predict the areas of greatest exposure of the marble and plan preventive interventions[22].

[22] From web article https://www.latestatamagazine.it/2025/10/restauro-e-nuove-tecnologie-ia-e-3d/

Similarly, the integration of IoT (*Internet of Things*) systems[23] into Digital Twin models allows for the continuous collection and processing of data in real time, using environmental and structural parameters such as temperature, humidity, vibrations, and deformations, analysed through machine learning to identify existing anomalies and predict future decay[24]. An example of their application in the field of urban prevention can be found in the *Enheritage* project[25] for UNESCO heritage buildings in Genoa. The project experimented with the use of Digital Twins associated with IoT sensors and Earth observation satellite data, through which it was possible to monitor the condition of historic buildings and provide a complete picture of any future deterioration.

For our information purposes, we can mention other forms of AI application aimed at asset maintenance that are worth mentioning. Among these, *TensorFlow* by Google is an open-source framework that uses machine learning for spatial analysis and predictive modelling. *DeepScene* by Microsoft specialises in semantic segmentation and tagging of large geographic datasets to create thematic mappings. *MapSCII* by IBM can develop location-based scientific data models for real-time monitoring.

[23] From website https://episensor.com/knowledge-base/iot-innovations-in-cultural-heritage-preservation/
[24] D. L. Carnì, C. Scuro, R. S. Olivito, M. C. Crocco, F. Lamonaca, *Artificial Intelligence based monitoring system for historical building preservation*, International Conference on Metrology for Archaeology and Cultural Heritage Trento, 2020
[25] From website https://www.libelium.com/libeliumworld/success-stories/digital-twins-for-the-protection-of-unesco-architectural-heritage-in-genoa/

Finally, *usBIM.geotwin* is a platform that integrates AI, open BIM, GIS and metaverse in order to perform spatial and territorial assessments for maintenance interventions[26].

Considering that these forms of application are constantly being updated and developed, we can say at the current state of research that artificial intelligence is a tool with considerable potential in the preventive maintenance phase, capable of facilitating real-time monitoring and providing useful forecasts for planning specific interventions.

[26] From web document https://www.ingenio-web.it/pdfs/gis-openbim-e-ai-per-digital-twin-geospaziali-delle-citta-del-futuro-il-caso-d-uso-di-milano-acca-software.pdf



1.5 Post-intervention documentation and cultural divulgation: digitalisation associated with AI

The post-intervention documentation phase concludes the restoration process cycle. This last step is an important one, as the correct and complete collection of materials relating to a specific intervention allows for better future consultation and comprehensive preservation of the history of the asset. In this regard, we can briefly reflect on the current state of the Italian restoration system.

In general, the Italian restoration landscape is characterised by fragmented archival information concerning cultural heritage. Sources are often incomplete due to previously partial documentation. Furthermore, local authorities often do not have sufficient resources and staff to carry out scheduled maintenance controls, even for the purpose of documenting the state of the property. This lack led to an economic and cultural problem that has resulted in a progressive fragmentation of archival information over time[27]. The urgent need to organise an archive that is universally accessible to operators in the sector is therefore an aspect to be explored in our investigation.

[27] D. Luraschi, S. Sangiorgi, *Conserve or preserve?* REC Magazine no. 177, 2023, pp. 70-72

Over the last decade, this general need in Italy has led to some interesting experiments with open-source cloud platforms, such as the SACHER (*Smart Architecture for Cultural Heritage in Emilia-Romagna*) project. Developed in 2019, the platform was intended as a digital archive of the region's architectural heritage, designed to be consulted and updated by operators in the sector and to divulge cultural information to the public[28].

Specifically, the web platform featured a series of accessibility levels aimed at protecting sensitive project data. The following levels were set up:

I. A public access level: consultation of technical data sheets on the assets, based on Google Maps
II. A private access level depending on the operator's role:
guest: read-only
member: read and download
operator: content upload
project manager: access and management of a specific project
administrative manager: access and management of all projects
admin: access and management of the entire platform

[28] The pilot case chosen was the Palazzo del Podestà in Bologna. The 3D model was created using data shared by Leonardo S.r.l. on the 2014-2016 restoration. CIRI ICT research group (manager: F. I. Apollonio; photographic campaigns, image processing and topographic survey: M. Ballabeni; photogrammetric modelling, semantic partitioning and rendering: S. Bertacchi; detailed image-based models: G. Bertacchi) .

Once logged in, the consultation involved simultaneous viewing on multiple devices in real time, thus facilitating the transfer of information during construction activities[29], and viewing 3D models, floor plans, and sections using combined reference plans. This example of digital archiving demonstrates an interesting attempt to systematise the restoration process and document it for both industry operators and citizens.

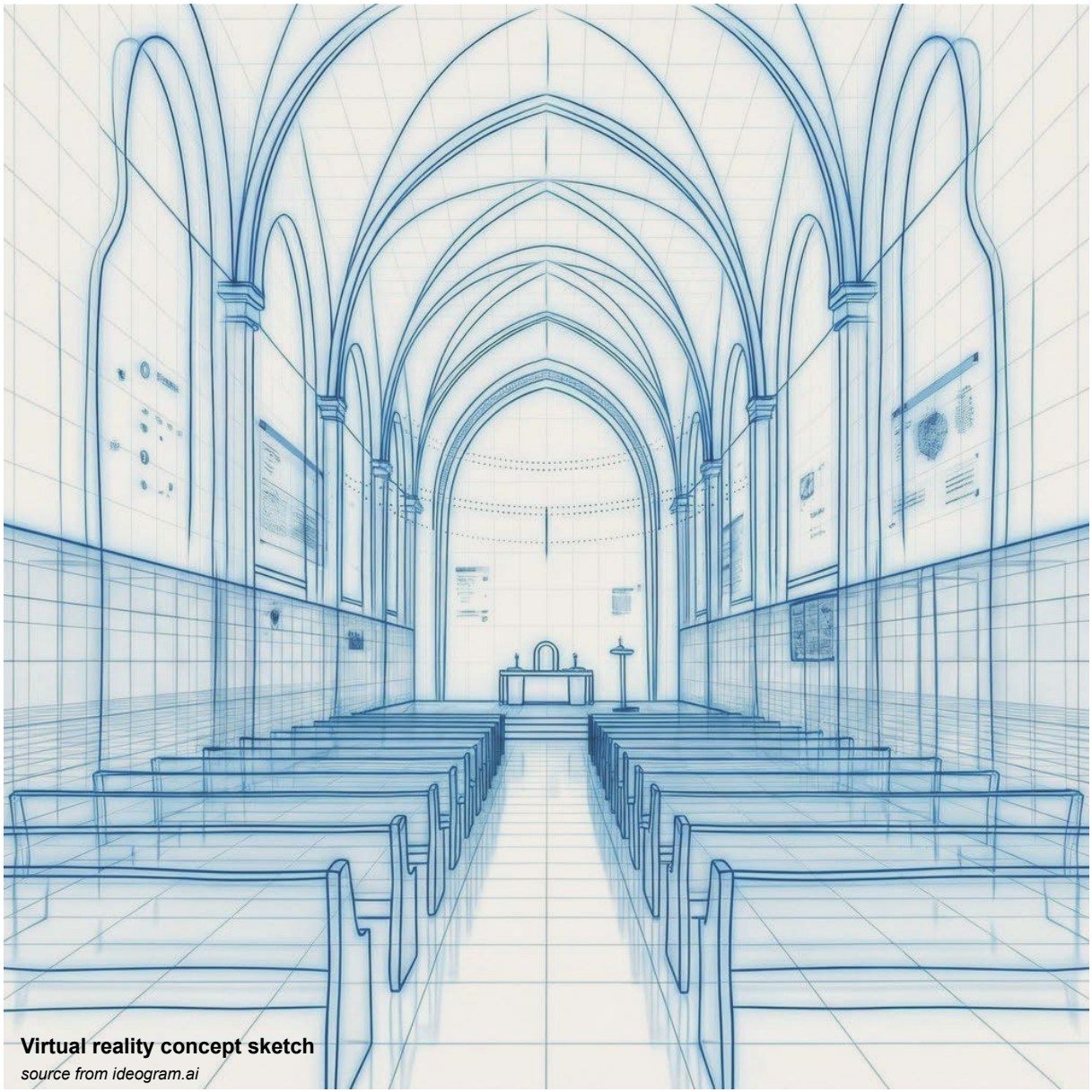
In the current context, the role that artificial intelligence can play in the post-intervention documentation phase is that of an automatic organiser of the materials collected during the previous restoration phases. Again, through machine learning and computer vision, AI can view documents and divide them into different sections according to preferences. It is, therefore, a mechanical activity that could run parallel to the entire restoration process, starting with the survey and analysis of surfaces.

[29] The SACHER 3D CH service was implemented in collaboration between SOFTECH-ICT for the development of the DB (manager: C. Grana; service: A. Corbelli, M. Cancilla) and CIRI ICT for the modelling of the service (manager: F. I. Apollonio; service: S. Bertacchi), interface design (manager: F. Rizzo; design: G. Dall'Osso) and CSS design (manager: S. Mirri; CSS: L. Monti). From F. Apollonio, S. Bertacchi, G. Bertacchi, M. Ballabeni, M. Torello, R. Montanari, L. Saragoni, *SACHER Project, Cloud Platform for Cultural Heritage and Integrated Services for Restoration*, REC Magazine no. 147, 2018, pp. 68-75

The post-intervention documentation phase is also linked to that of cultural divulgation and publication. In this area, we are gradually witnessing the evolution of advanced technologies that can support and tell the story of historical works and buildings.

Among these, we can mention the application of AI in virtual reality technology, which has been established for years in the field of video games. In restoration, its use is therefore intended exclusively for entertainment purposes. However, this form of application deserves further study due to the exceptional level of interaction that artificial intelligence can bring to the field of mass divulgation and tourism. Indeed, AI can contribute to the creation of an immersive 3D digital model, making it interactive and dynamic, whereas VR alone would produce a static view. In museums, this form of application allows visitors to enjoy a total and innovative experience, as they themselves become the main actors in the process of spatial knowledge.

An example of this application is the restoration of the Church of San Paolo in Ferrara, aimed at bringing to light the frescoes hidden behind the chapels in the right aisle. Once the survey was carried out using a laser scanner, lowered from the top of the domes into the inaccessible area to the human eye, it was possible to process the stratification of the building, which had remained hidden for over four hundred years. Through the use of virtual reality combined with artificial intelligence, the part of the church of interest was then digitally reconstructed, making the frescoes visible to the public through 3D viewers.



Virtual reality concept sketch
source from ideogram.ai

This technology allows for virtual viewing both on site, where visitors walk through the space and discover fragments of memory, and remotely, viewing an interactive browser that displays a selection of multimedia content. Andrea Griletto, director of Assorestauro[30], said that *'the immersive experience is not only a technological marvel, but also a way of enhancing cultural heritage... the aim is to raise public awareness of the importance of protection and thus make heritage accessible to all*'.

[30] Assorestauro was one of the partners promoting the project. From D. Tombari, S. Vallese, *The Church of St. Paul in Ferrara. A virtual journey to discover hidden frescoes*, REC Magazine no. 187, 2025, pp. 48-50



Pompeii Archeological Park view
source from Archive of the Archaeological Park of Pompeii

PROMPT CHAPTER 2:
The RePAIR project to bring Pompeii's lost frescoes back to life

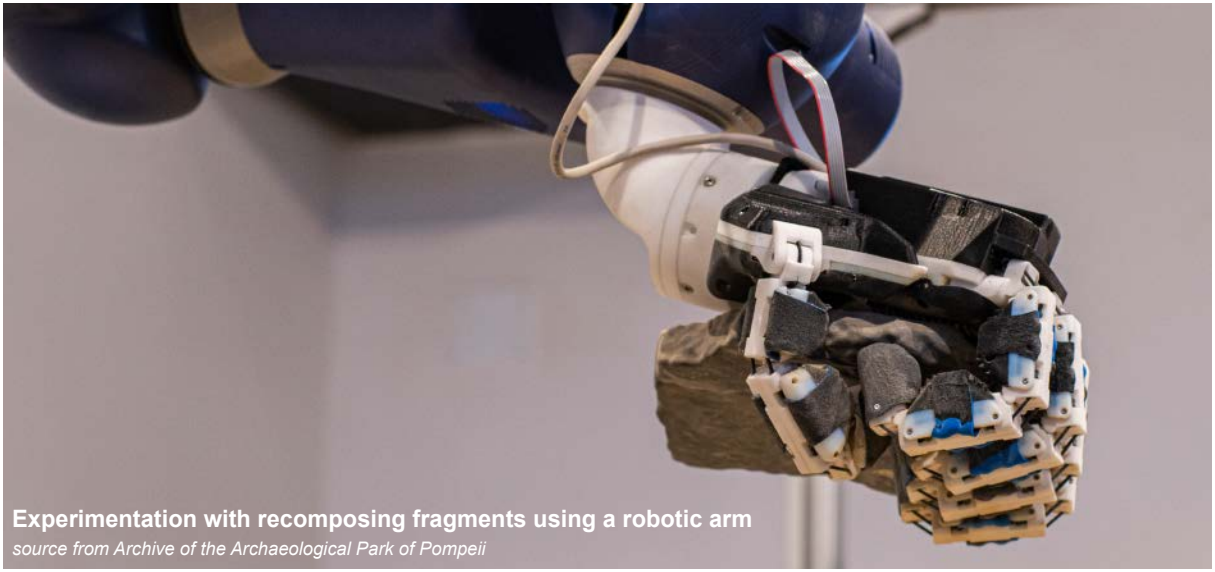
Of all the cases mentioned in the previous chapter, one in particular deserves closer attention. The RePAIR (*Reconstructing the Past: Artificial Intelligence and Robotics Meet Cultural Heritage)* project is the result of collaboration between the archaeological site of Pompeii and Ca' Foscari University in Venice, to experiment with the use of artificial intelligence combined with robotic systems in the reconstruction of fragmented portions of frescoes.

Launched in 2021 and funded by the European Union, RePAIR focused on training a robotic arm equipped with *soft hands* through *machine learning*, to reconstruct the lost frescoes of the House of the Painters at Work in the Insula dei Casti Amanti, damaged by the eruption of 79 AD, and the frescoes of *the Schola Armaturarum*, destroyed by the collapse of the building in 2010[31]. The project was successfully completed in November 2025, establishing an important result in the world of archaeological restoration.

[31] P. Gasparoli, *Algorithms and heritage: restoration in the digital age. Speech and opening of the conference - Milan, 26 May 2025*, REC Magazine no. 188, 2025, pp. 46-49

The intention of the project was, therefore, to test the robotic equipment associated with AI during the operational phase of the restoration. As Marcello Pelillo, Professor of Computer Science at Ca' Foscari University and Project Coordinator, states: *“After four years of work, an international collaboration has come to an end that has brought together seemingly distant worlds: the most advanced techniques of artificial intelligence and robotics, with archaeology and the preservation of cultural heritage, the heritage of humanity. It represented a first, pioneering step towards an ambitious goal: to eliminate one of the most laborious and frustrating activities in archaeological research, thus allowing valuable energy and skills to be channelled into more strictly scientific and creative activities*.”





Experimentation with recomposing fragments using a robotic arm
source from Archive of the Archaeological Park of Pompeii

2.1 Robotic analysis and experimentation

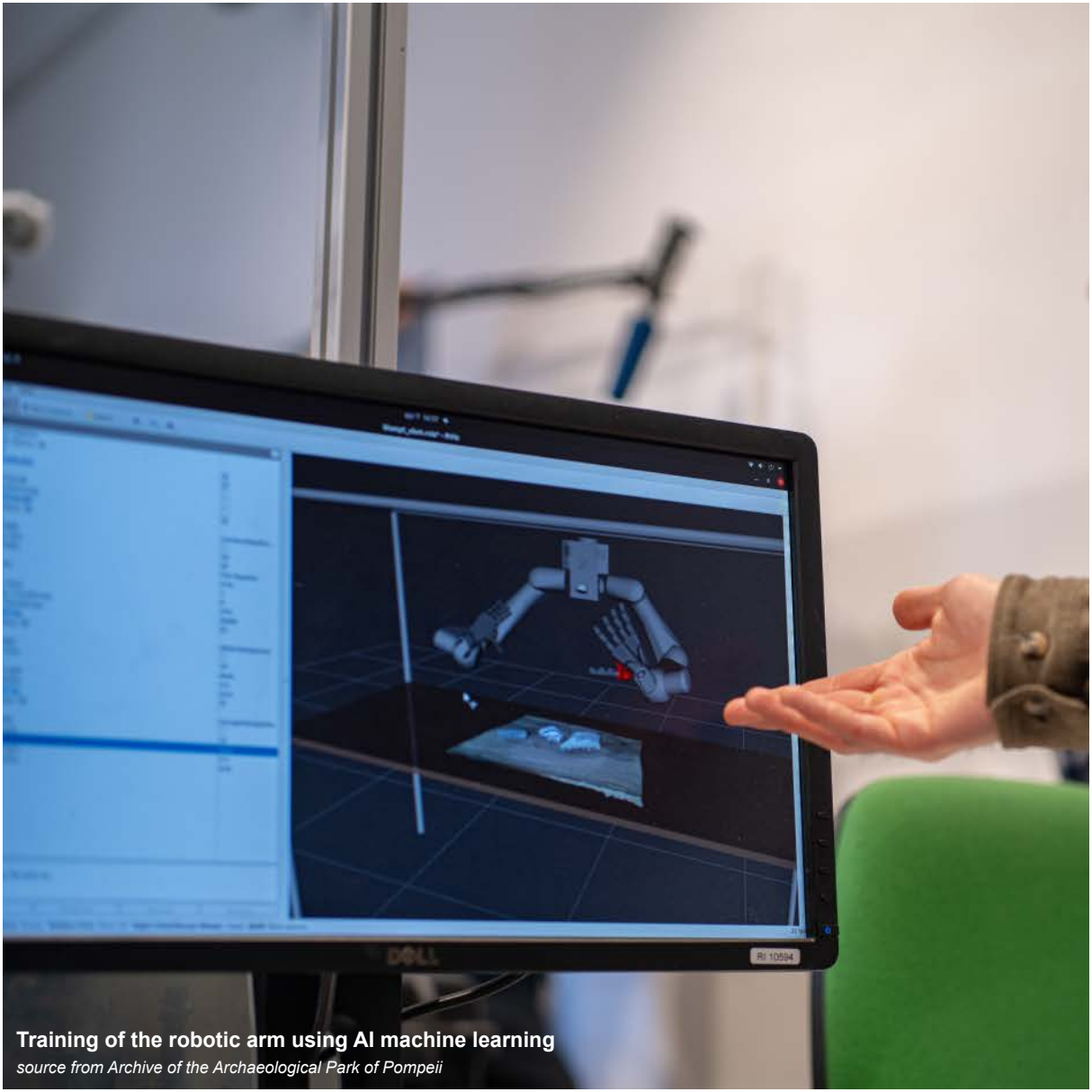
The research project consisted of an initial phase of analysing the wall fragments using laser scanners. The data acquired was transferred to the robotic infrastructure using algorithms. The use of 3D digitalisation systems, combined with artificial intelligence, enabled the robot to be trained, making it progressively autonomous in recognising and reassembling the different portions of the two frescoes under study. In this way, the 'intelligent' robot correctly acquired the information received and created associations between the digital image of the fresco and the physical manipulation of the fragments.

It is important to emphasise the complexity of this process, as the project dealt with over 10,000 pieces severely damaged by time, without any real idea of the final result. As Prof. Pelillo explains, *"there is, so to speak, no picture on the box to guide the work. Furthermore, the recovered pieces often represent only a portion of the original work, making large or numerous gaps in the reconstruction inevitable. To further complicate the process, there is the difficulty of establishing their actual provenance, as it is not uncommon for fragments belonging to different works to be mixed together*[32]."

To address these technical difficulties, the RePAIR team created an interface for dialogue between archaeologists and the AI system, which proved to be fundamental to the success of the project. The role of humans, therefore, remains essential in the process.

[32] *Pompei, RePAIR – the research project for the recomposition of fragmented frescoes using an 'intelligent robot' comes to an end*, web article, 27.11.2025

RePAIR can be defined as a pioneering experiment, which made it possible to verify the feasibility of an integrated approach between digital technology and advanced robotics, applied to a case study involving the reconstruction of large decorative surfaces. The success of the project, therefore, provides the basis for further computer science, scientific, and technological studies on algorithms, aimed at the possible automation of certain phases.



Training of the robotic arm using AI machine learning
source from Archive of the Archaeological Park of Pompeii

2.2 In-depth analysis of the techniques used: robotics combined with AI

The digitalisation of the analysed fragments was the longest and most complex phase of the RePAIR project. In order to proceed in the best possible way, this process was entrusted to a specialised laboratory at the Archaeological Park of Pompeii, called Casina Rustica, which dedicated itself entirely to this task. The creation of the dataset was therefore essential to achieving the subsequent objectives. Thanks to the combined information of the 3D geometry and textures of the fragments, it was possible to coordinate the details of the individual pieces (thickness, surface layers, colours and patterns) and provide the correct dataset to the computer.

Specifically, to acquire the digital model of each part, a space was set up consisting of two photo boxes with diffused lighting and rotating platforms[33], in order to avoid any shadows. Each fragment of the frescoes was scanned using 18 different views. Despite this precaution, this operation was not sufficient to achieve the desired result, as the structured light used to capture the geometric shapes did not offer a high level of chromatic detail.

[33] A Polyga H3 scanner was used in the 3D scanning phase, which uses structured light technology to recognise geometries. A 24.2-megapixel Sony a7c camera was used in the photogrammetry phase. From S. Campana, D. Fernadi, H. Graf, G. Guidi, Z. Hegarty, S. Pescarin, F. Remondino, *The RePAIR Project: datasets for archaeological and restoration studies in Pompeii*, Digital Heritage, 2025

Each fragment was therefore further reconstructed using traditional photogrammetry, employing over 120 images. Thanks to the combination of 3D scanning and photogrammetry, the RePAIR team was able to digitally replicate the analysed portions in the best possible way.

Once the digital models of the fragments had been obtained, the dataset was set up on the iconography of Pompeii. This process was carried out using high-resolution orthophotos, to which descriptions of the iconographic motifs to be labelled were added. To carry out this process, the Archaeological Park of Pompeii and Ben Gurion University of the Negev adapted the Computer Vision Annotation Tool (CVAT) so that the decorative motifs of the Roman frescoes could be annotated manually. In particular, CVAT is an open-source platform that allows users to enlarge and edit basic orthophotos, highlighting areas of interest with boxes, and finally exporting the files in COCO and YOLO formats, which are widely used in archaeology.

To correctly label each fragment analysed, a glossary of 110 labels was used to universally identify the present iconography. To understand the complexity of this phase, we can highlight the numerical data. Out of a total of 318 scans, over 8,000 decorative motifs were annotated. Each fresco, therefore, had an average of 25.07 motifs. Despite the considerable heterogeneity of the elements analysed, the RePAIR team was able to complete the operation, demonstrating its determination to achieve the set goal.

Thanks to this complex phase, the generated dataset made it possible to create the AI deep learning model to train the computer. To do this, the previously annotated images were divided into digital fragments to be transferred to artificial intelligence for recognition testing. This process required additional time in the project, as the computer had to demonstrate that it could correctly reassemble all the segmented images before proceeding to test the actual fragments.

Considering the application of this methodology, we can say that it constitutes an innovative model of archaeological restoration which, thanks to its success, provides a basis for future improvements. It is also important to recognise that this success was made possible by experience in the field of archaeology and conservation, which is always the starting point for technological applications. The preliminary phase therefore, remains essential in order to train artificial intelligence and make it autonomous in recognising and reassembling a huge quantity of fragments. A further aspect to consider is the possibility of cataloguing and storing a specific dataset for future reuse, thus ensuring a significant reduction in the time required.



A detail of fragments from the frescoes of Pompeii
source from Archive of the Archaeological Park of Pompeii

2.3 An ethical use of artificial intelligence

This technological experiment has not only enabled the achievement of a first milestone in the evolutionary process of the world of restoration, but also an understanding of the ethical use of advanced technologies and AI. This use does not discredit the professional work of archaeologists but becomes a true extension of human experience in the conservation of heritage.

The director of the Archaeological Park himself, Gabriel Zuchtriegel, states that *"robots cannot replace the human mind and creativity in reading, interpreting and telling history... the future of archaeology presupposes the ethically correct use of artificial intelligence, which helps us to deal with the complexity of materials and will play a central role in archaeology in the future*[34]*."* The application of AI should therefore be understood as technological support to be used responsibly and ethically, to respect the value of human work and maintain a moral and practical balance between man and machine. Considering this reflection, we can say that this issue will be the future condition that will allow the effective consolidation of artificial intelligence in the world of conservation, a world deeply linked to the theory of 'good restoration'.

[34] Interview with G. Zuchtriegel, *AI arrives in Pompeii and restores two frescoes*, Tgcom24 report, 04.12.2025.https://www.bing.com/videos/riverview/relatedvideo?q=progetto+repair+pompei&mid=9BAAB67D15A741862F159BAAB67D15A741862F15&ajaxhist=0





Other images of fragments from the frescoes of Pompeii
source from Archive of the Archaeological Park of Pompeii

In this regard, we can open a parenthesis to better explain what is meant by 'good restoration'. The term, introduced in the principles of the 1964 Charter of Restoration, aims to define an intervention that is appropriate from a critical point of view, reversible, and respectful of the value and authenticity of a cultural asset. The international document establishes for the first time the fundamental principles of modern restoration, making a universal distinction between the concepts of conservation and restoration. In particular, *conservation* means maintaining the current state of the asset without alterations, while *restoration* means an intervention aimed at safeguarding historical and artistic authenticity[35]. With this statement, all intellectual, humanistic, and scientific disciplines available to preserve the state of the asset are promoted, avoiding stylistic distortions and any phenomena of degradation.

We can affirm that technological experimentation in the field of restoration is to be viewed positively, while remaining aware of the primary and irreplaceable role of humans. Recognising the ethical significance of the conservation process, the RePAIR project is a pioneering example not only from a technological and scientific point of view, but also from a theoretical and cultural one.

[35] The Venice Charter was drafted during the First International Congress on the Architecture and Restoration of Monuments and Sites, establishing the universal principles of modern restoration. From https://www.docenti.unina.it/webdocenti-be/allegati/materiale-didattico/576167

PROMPT CHAPTER 3:
The application of AI in the diagnosis of decay pathologies and in the analysis of materials: the example of Villa Sottocasa

The proposed case study provides an example of the application of artificial intelligence in the analysis of interior surfaces. The chosen building for this analysis is Villa Sottocasa in Vimercate, a historic building characterised by a long series of interventions due to numerous changes of property. Starting with the Sfodrani family in the 18th century and arriving at the Ponti family in the 20th century, the villa has undergone continuous spatial changes, which have deeply transformed its identity and the stratigraphy of its walls and decorations. Thanks to its history, central location, and the prestige that has always accompanied it, Villa Sottocasa can therefore be defined as a true historical and cultural site in the area and deserves to be explored in depth in this chapter[36].

In particular, the building is perhaps one of the most significant examples of "ville di delizia" in the Vimercate area. Attached to an English garden, its planimetry is U-shaped, with the central section initially intended for representative functions, while the two side wings were used for the villa's services. Although not ideal, its current state, fortunately, allows us to still clearly see the internal spaces and their historical functions.

[36] All information regarding the history of the Villa, its stratigraphy and structure, refers to the documentation produced following the study of the building, conducted during the *Architectural Preservation Studio* course in 2021-2022.



Entrance courtyard of Villa Sottocasa, Vimercate
own source from on-site inspection

Externally, the villa has a neoclassical style, typical of the 18th century, for which we have the earliest documentation. The entrance façade is characterised by two twin pillars framing the main door, surmounted by a tympanum. On the opposite side, the façade is much simpler and devoid of decoration. What is really interesting is the interior character of the villa: the main body features decorative elements dating back to the 19th century, such as the central circular foyer, with a hemispherical vault installed in a previously rectangular space, as well as in the reception rooms and bedroom on the upper floor, both adorned with false vaults of various shapes.

There is also a basement, which is believed to be the oldest part of the structure still in existence, with studies showing that it was first built in the 15th century. Part of the Villa only became public property relatively recently, in the 1980s, when the town of Vimercate began the acquisition process. This process was only completed at the beginning of the new millennium, when the entire property finally became the property of the municipality, which opened it to the public. Today, the eastern wing of the Villa houses the MUST, the Museum of the Vimercate Area: a museum focusing on the local culture of that particular part of Brianza.

3.1 The history of Villa Sottocasa: transformations and changes of property

The history of the Villa is long and complex and has seen it pass from owner to owner. The first records date back to the 18th century, when the property passed from the Sfodrani family to the Marquis Vidoni. Thanks to the land registry of 1721, we can trace this transfer of land. After the Vidoni family, the Villa was inherited by the Visconti di Brignano family, who commissioned the building of the current 'villa di delizia'. Construction certainly took place before 1778, the year of Alberto Visconti's death, and it subsequently passed from owner to owner until it became the property of Marquis Girolamo D'Adda in 1812. The latter sold the property to Siro De Petri in 1828.

To De Petri we can attribute the 19th-century renovation, which broke with the rigid rectangular layout, with the construction of spectacular vaults and new decorations in keeping with the trends of the time. However, the Villa did not remain in his possession for long: it was sold in the mid-19th century to the family of the industrialist Ponti, married to the Countess Elisabetta Sottocasa, who transformed it into a permanent residence. At the beginning of the 20th century, many rooms were renovated and adapted to modern use. The 19th-century decoration was then covered with a new decorative layer. The public acquisition of the Villa is only the latest stage in a historical journey spanning several centuries.

After all these changes of ownership by people with different visions and styles, who lived in distant historical periods and contexts, it is logical that the building has undergone significant changes, from the organic growth of its volume to internal renovations and changes in its intended use. Through these transformations, its value and importance within the community have grown. The rich history of the site is well reflected in our particular area of investigation, room 106 of the Villa: here, the complex stratification of the interventions mentioned above can be clearly perceived.



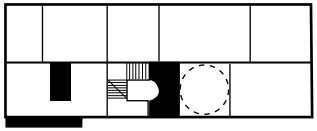
Detail of the entrance foyer
own source from on-site inspection

First floor

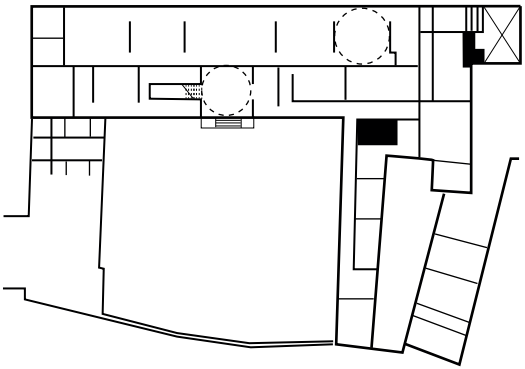
Room 106



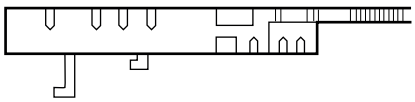
Mezanine floor



Ground floor



Basement



3.2 The interiors of the Villa: the stratigraphy of room 106

Considering the complex history of the building, we can now delve deeper into our specific case study: room 106. Located on the first floor of the Villa, this room was one of the many bedrooms created during the renovation carried out in the 19th century under the ownership of De Petri. On that occasion, sophisticated interior elements for the time were introduced, such as camorcanna vaults, suspended interior partitions, and neo-Greek decorations.

This historic renovation left a rather evident mark on the structure of Villa Sottocasa, as well as on the shape and appearance of room 106. Following this work, the room underwent further modifications between the late nineteenth and early twentieth centuries, which often damaged the underlying structural layer. An elliptical window was opened in the central wall, wallpaper was applied directly over the previous dry wall paintings, and the vaults were repainted with geometric and floral motifs of a completely different stylistic quality.

The result is a room that directly shows the coexistence of two layers: the wallpaper has come away, revealing the decoration underneath, but often damaging it because the glue has torn away the less resistant pigments of the dry paint; the 20th-century ceiling painting has peeled off in some areas, allowing us to see the older design; near the window, variable humidity has peeled off the outer finish of the paint, revealing yet another motif.

It is as if the room itself would like to tell us its story by subtly removing parts of its most recent layer and revealing clues about its past. In particular, the coexistence of decorations created in two different centuries, with different styles and techniques, encloses the history of the room's surfaces: yellow walls with Greek-style motifs, a delicate blue ceiling decorated with floral motifs born of early 20th-century sensibilities; contrast is the key to understanding the room and the Villa: a private place, transformed by changing sensibilities.



A wall of room 106
own source from on-site inspection

3.3 Diagnosis of surface decay pathologies: comparison between a 'traditional' approach and an example of the application of artificial intelligence

Before proceeding with the diagnosis of surface decay using an AI platform, we must conduct our study of stratigraphy and phenomena using a 'traditional' approach. In this way, we will be able to produce maps of certain areas and then compare them with those generated by artificial intelligence. It should be noted that this attempt at analysis is not intended to replace the work carried out by professionals in the field but is aimed at verifying the level of accuracy and reliability currently available to advanced AI tools.

Thanks to existing documentation, we know that the walls of Villa Sottocasa were built with a masonry core, composed of bricks and mixed stone elements held together by mortar. In room 106, only two walls are load-bearing: the wall of the external façade of the villa and the partition-wall between the room and the adjacent one (107). Their structure starts from the basement and reaches the top of the attic floor.

To better understand the subsequent analyses, it is important to consider the hypothesis that the façade wall of Villa Sottocasa is subject to a slow detachment from the building, probably caused by the failure of the wooden T-joints between the external wall and the internal partitions, or by other widespread problems affecting the foundation system.



Mapping of decay pathologies
own analysis

As we shall see, the effects of the structural changes that the room has undergone over time are recognisable in the state of deterioration of the surfaces. To analyse the proposed wall of room 106, let us first consider its structure and history. Most likely, the wall was built using a mixed masonry technique (brick and stone) like the other vertical structures of the Villa. Its construction can be attributed to the 19th-century intervention that affected the rooms on the first floor, which were divided into smaller rooms by adding internal partitions such as this one. We can also observe the presence of false vaults at the corners.

Analysing the present pathologies, we can identify the following phenomena:

I. **Passing cracks:**
   -in the central part of the wall, with vertical development
   -at the right end, along the connection between the wall and the façade
   -in the lower left corner, developing diagonally

II. **Wall lacuna:**
   -in the upper right corner of the wall and in various other parts in the centre
   -in the upper left corner

III. **Detachments:**
   -In the central part of the wall, the wallpaper laid at the beginning of the 20th century is still visible. Due to material incompatibility with the underlying layer, it has gradually lifted, revealing the 19th-century decoration.



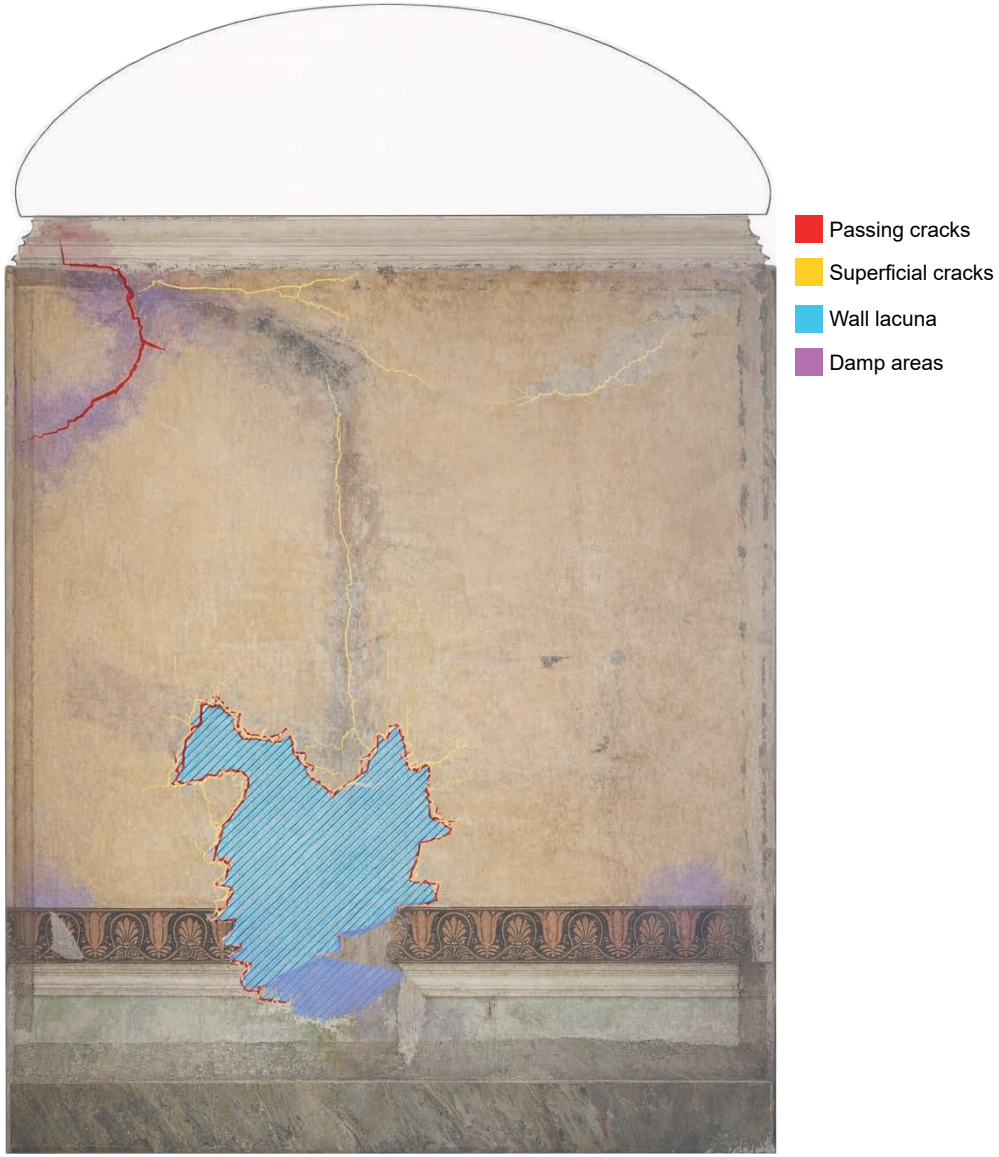


Detail of the passing crack
own source from on-site inspection

Considerations on the cracks:

Although the surface cracks could be due to harmless internal movements of the masonry, the level of deterioration of this wall has likely been caused by structural shifts in the external load-bearing wall to which it is connected, which is slowly moving forward, detaching itself from the internal partition wall. This is evident when observing the point of contact between the two walls, where a deep vertical crack is visible.

Looking at the image in detail, it is difficult to correctly interpret the causes of the deterioration, as the thick layer of mortar, presumably applied before the wallpaper, is still visible. However, we can assume that the crack between the façade and the internal partition wall is the least stable.



AI mapping of decay pathologies
source from ArchGPT

To conduct the analysis of the pathologies using artificial intelligence, we choose the ArchGPT 5.2 platform, linked to ChatGPT, as it allows free use of the system. As we know, there are more advanced, high-performance software programmes that are more specific to the restoration sector and are available for a fee. For the purposes of our investigation, we choose this platform, asking it to recognise the general phenomena of decay in the image of the wall previously analysed, to describe them, and to create a map. Below is the response from the artificial intelligence.

ArchGPT - Identifiable deterioration phenomena:

I. ***Passing cracks*** *(most relevant from a structural point of view):*
-central vertical crack: marked vertical crack running from top to bottom; probably due to: differential settlement of the masonry, structural movements, thermo-hygrometric variations over time. The presence of dark halos suggests possible water infiltration along the crack.
-crack in the upper left corner: marked discontinuity along the junction between the wall and the upper moulding; could indicate a point of concentration of structural stresses or construction discontinuity.

II. ***Superficial cracks*** *(mainly affecting the finishing layers):*
-widespread micro-cracks in the plaster: irregularities and fine lines are visible in various areas of the painted surface; these could be caused by: shrinkage of the plaster, ageing of the binders, cycles of humidity and drying.

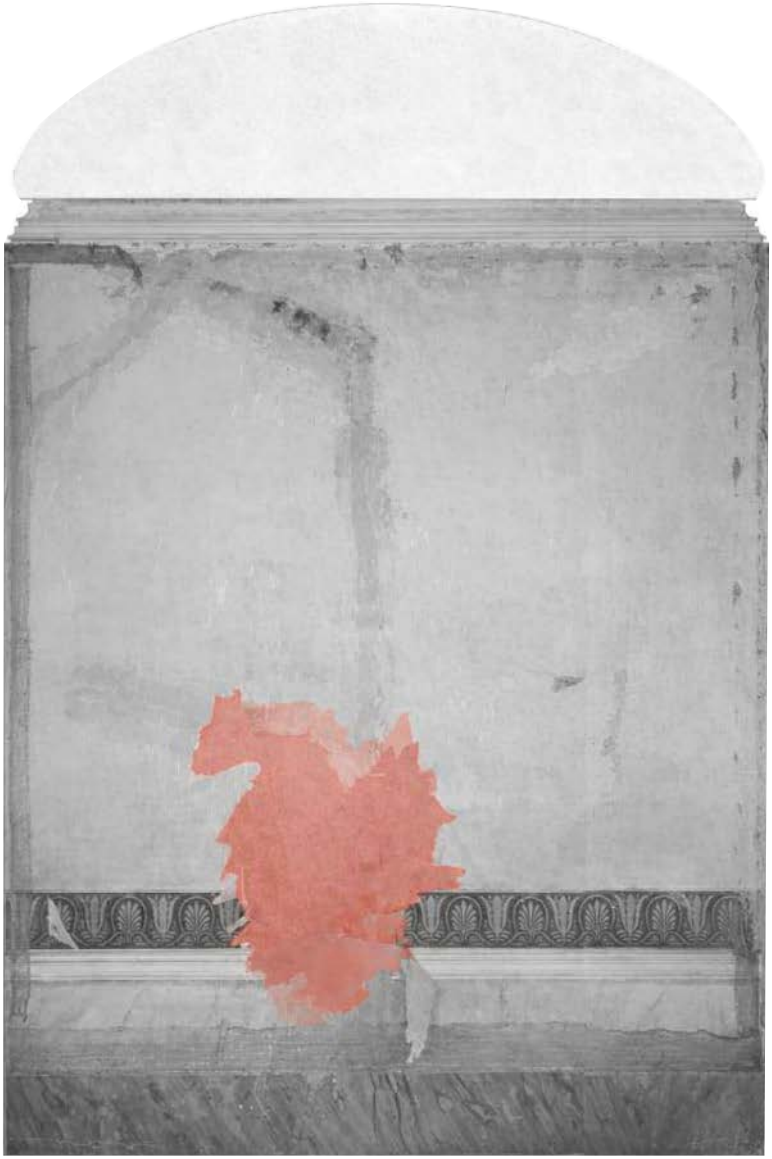
III. ***Detachments:*** *near the stained areas and halos, there are signs of detachment of the paint layer, with probable loss of material between the wall support, the roughcast layer and the decorative finish.*

IV. ***Wall lacuna*** *(significant loss of material):*
-extensive gap in the lower central portion: large area
-marginal gaps and widespread flaking: especially along the edges and in the decorative baseboard; these could be caused by: capillary rising damp, water infiltration.

Overall architectural view: *the wall shows a typical picture of:*

I. *Rising damp in the base area*
II. *Percolation from above highlighted by dark marks*
III. *Interaction between material degradation and structural micro-movements*

The building to which the analysed portion belongs is probably a historic building, without barriers against moisture and characterised by inconsistent maintenance over time.



AI mapping of wallpaper area
source from ArchGPT

Comparing the analysis of decay pathologies carried out by AI, there is a general ability to recognise the main phenomena visible in the image, such as the passing crack running along the central part of the wall and the upper left corner, superficial cracks, and loss of material. However, we must recognize that AI does not provide a precise analysis and graphic mapping, as it fails to identify the large vertical crack between the external façade and the dividing wall, which is probably difficult to see in the image.

It should be remembered that AI cannot replace human observation, which is essential in identifying certain invisible surface pathologies that cannot be detected by the AI platform, as they can only be recognised through on-site inspection. Furthermore, as no information was provided on the stratigraphy of the surfaces, the AI recognised the portion of wallpaper still attached to the wall as a gap in the wall, as it is probably incompatible with the decoration visible on the rest of the surface.

To further our analysis, we ask the platform to identify only the portion of wallpaper present in the image and describe its condition.

Having provided the information to the AI, the mapping of the area where the wallpaper is present is correctly performed.

Continuing our analysis of the wall surfaces, we now ask the AI platform to describe the possible causes of the wallpaper detachment in the following image.



A portion of the detachment of the wallpaper layer
own source from on-site inspection

ArchGPT - Main causes of surface detachment:

I. ***Incompatibility between layers****: underlying breathable lime-based plaster and wallpaper applied with organic adhesives, which over time have created a barrier to the breathability of the plaster, retaining moisture and promoting detachment. The large hanging flap is in fact typical of a loss of adhesion of the most recent layer.*

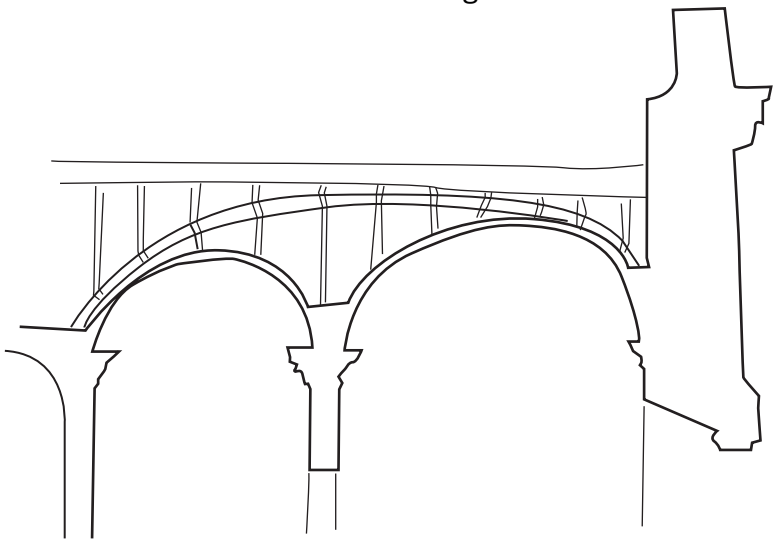
II. ***Rising damp or condensation****: since the damage is concentrated mainly in the lower-middle section, it can be inferred that there is possibly capillary rising damp, with consequent condensation, amplified by the impermeability of the wallpaper.*

III. ***Differences in mechanical behaviour between layers:*** *plaster generally has good elasticity and is prone to slow expansion; wallpaper adhesive, on the other hand, reacts quickly to changes in temperature and humidity. This causes internal tension and detachment of the paper, with probable removal of part of the underlying decoration*.

From this initial analysis, we note that the use of the AI platform is more accurate and effective when we ask it to identify and describe only one degradation phenomenon at a time. The initial generic mapping of the degradation did not produce an optimal result in terms of quality, while the mapping of the wallpaper area alone was well done.

To investigate this aspect further and verify its reliability, we change the object of analysis and consider the portion of the ceiling in room 106. As we know from the documentation on the history of the Villa, most of the rooms on the first floor were decorated with so-called 'false vaults' or 'camorcanna' vaults. These have a wooden structure that serves an aesthetic rather than a structural function, as they were added after the original construction (probably at the same time as the work on the room divisions).

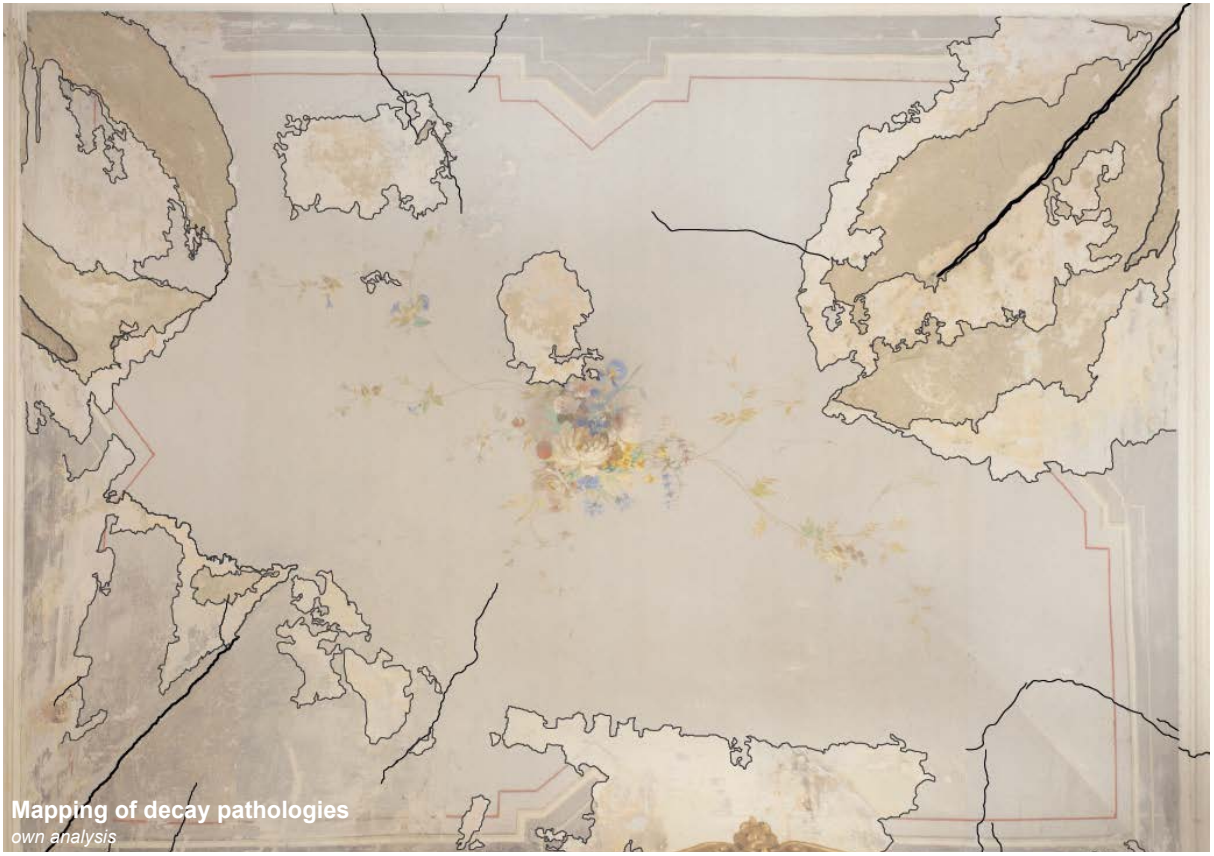
Specifically, these vaults are constructed with a thin wooden shell, supported by buttresses that connect it to the main beams. Looking at the structure of the vault from the attic, we can see that room 106 was initially covered by a single false vault. Later, when a partition wall was added to divide the room into two smaller ones, the false vault was further divided into two: one covering room 106B and the other covering 106A. The sketch helps us to better understand this structural change.



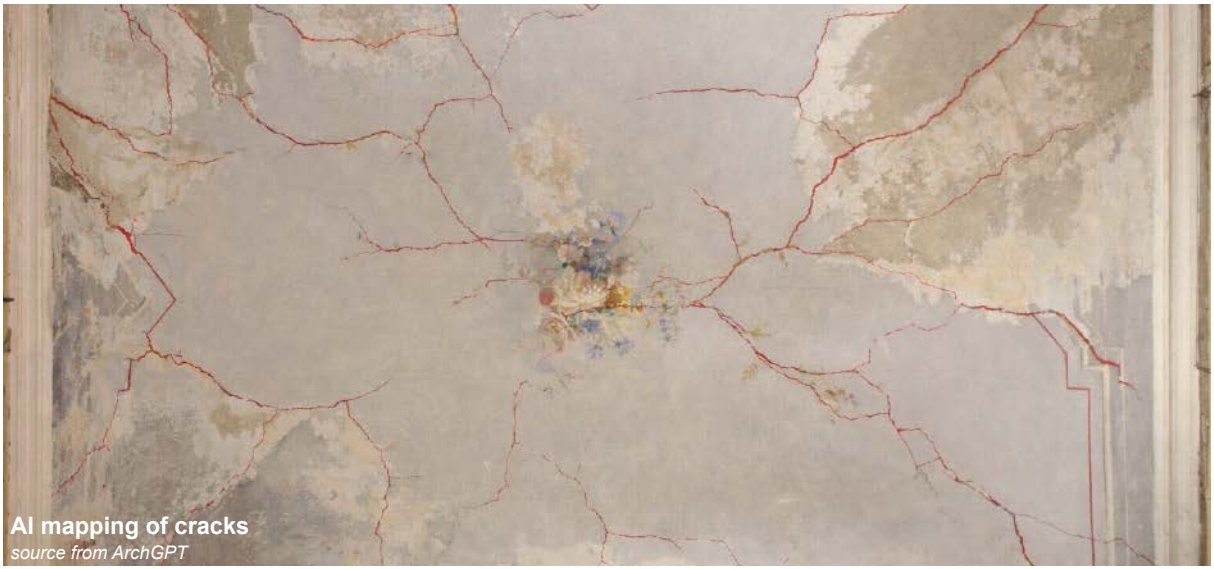
Sketch of the ceiling structure with the false vaults in room 106
own source

Let us now analyse the state of deterioration of the ceiling surface in room 106A:

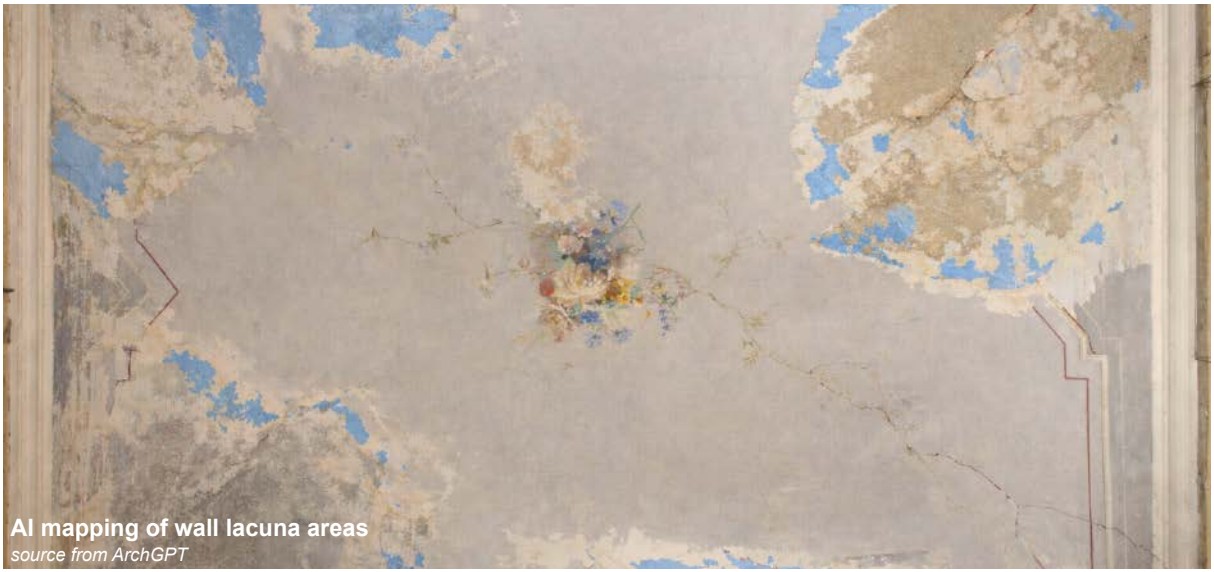
I. **Passing cracks:** along the lines of intersection of the faces of both vaults, especially in the north-west and south-east corners
II. **Superficial cracks:** spread across the entire surface of the vault, they do not appear to pose an immediate threat
III. **Plaster lacuna**: located in the south-east and south-west corners of the vaults, covering approximately 20% of the surface



Mapping of decay pathologies
own analysis



AI mapping of cracks
source from ArchGPT



AI mapping of wall lacuna areas
source from ArchGPT

To demonstrate that the AI platform reacts better when the analysis request focuses on a single type of deterioration, we ask it to map the image of the ceiling in two steps, separating the phenomenon of cracks from that of plaster lacuna.

As can be seen from the two maps, the AI platform was able to correctly recognise the different areas of deterioration, even though it received a large portion of the surface area. Compared to the mapping we carried out previously, we can say that its use in this case is an excellent support for the diagnosis of deterioration pathologies. In conclusion, our analysis leads to the following statements:

I. If we ask the AI to analyse the deterioration of a surface in general terms, the graphic output is fragmented and incomplete.
II. If we ask the AI to analyse only one type of deterioration at a time, the graphic output is significantly better.
III. AI seems to be a valuable aid, particularly in investigating the possible causes of deterioration, suggesting scenarios to be verified based on the building under analysis.

Considering this reflection, it is important to emphasise the current limitations encountered, especially from a graphical point of view, due in part to the fact that artificial intelligence performs the analysis solely on the 2D image it receives. For this reason, AI can't recognise every type of deterioration. Human observation, therefore, remains necessary and decisive, and cannot be replaced by such instrumentation.

3.4 Analysis of surface stratigraphy: an example of the application of AI in the study of materials

To continue our investigation into the application of AI platforms in the analysis of the surfaces in room 106, we turn our attention to the stratigraphy of the walls previously analysed. The nineteenth-century paint layer, visible due to the detachment of the wallpaper, is one of the elements that allows us to identify the layers of the surfaces and hypothesize their history. Specifically, the paint layer features a horizontal band at medium-low height, characterised by a neo-Greek style decoration.

By comparing the evolution of room 106 with the rest of the building, we can hypothesize that the neo-Greek decorative layer is contemporary with the decorations of the same style in the so-called Etruscan Room, located exactly below room 106. We can therefore date these decorations to around the mid-19th century. As we know, at the beginning of the 20th century, a layer of wallpaper was applied without taking precautions to isolate the neo-Greek decorative layer and preserve it over time. The paper was, in fact, glued directly onto it.

In the area adjacent to the ceiling, a fragmented glimpse of a winged lion is also visible. This fragment could be attributed to the same historical period as the lower layer of ceiling paintings, but we cannot be certain of this.





Details of the mural decoration
own source from on-site inspection



The module of the neo-Greek decoration
own source



A fragment of a winged lion
own source

In general, the relatively good state of preservation of the lower and upper decorations suggests two possible explanations:

I. There is only one neo-Greek decorative layer, which was applied to the entire wall, with most of the decoration subsequently removed before the wallpaper was applied.
II. The two decorations belong to two different historical periods and were created using different techniques.

In-depth studies would therefore be necessary to determine their dating.

The decorative stratigraphy described allows us to better understand the degradation phenomena present on the surfaces. In particular, we can say that the gaps in the paint layer can be attributed to the unprotected gluing of the wallpaper onto the decorative layer. On the other hand, linen nets were used along the edges of the walls to better glue the wallpaper; this made it possible to partially isolate the underlying layer, preserving it better over time.

Evidently, the owner's intention was to remove the previous neo-Greek decorations, which were considered out of fashion at the time. The upper register has been almost completely lost: it was probably covered with a layer of yellow wall paint, leaving only the lower frame. The causes of the pigment detachment are mostly related, although they could be attributed to the poor state of conservation and lack of maintenance of the room.



Analysed stratigraphic portion
own source from on-site inspection

Considering our study of the stratigraphy of the walls, we ask ArchGPT to examine a portion of the wall to identify the possible causes of the detachment analysed.

ArchGPT - Stratigraphy lecture:

I. ***Wall support*** *(structural layer): probably solid or mixed brickwork (typical of the building's era), not visible in the image but deducible from the construction context.*
II. ***Rough coat*** *(base plaster): air lime mortar + silica sand to level the wall support.*
III. ***Finishing plaster*** *(finishing layer): finer aerial lime, smooth surface suitable for pictorial decoration.*
IV. ***Nineteenth-century paint layer*** *(original decoration): probably tempera paint, with linear decoration and ornamental motifs. This is the primary layer exposed to erosion.*
V. ***20th-century wallpaper layer****: vegetable paper attached with animal/flour glue using a textile mesh (gauze) fixed with small nails, still visible today.*

The textile mesh is a significant element in the stratigraphy of the wall, as its possible function could have been:

I. *Reinforcing the wallpaper above*
II. *An attempt to consolidate a subsequent intervention*
III. *Support for a new finish (light plaster or stucco)*

In addition, the oxidation of the nails probably caused: rust stains, micro-fractures and localised detachments.

Architectural considerations:

This portion of the wall reveals a complex stratigraphy with a change between the 19th and 20th centuries, perhaps due to the transformation of the surrounding environment (aesthetic update). The decorative change, therefore, altered the original breathable system, generating hygrometric interference between incompatible materials.

The stratigraphic description carried out by the AI is consistent with our study of the surfaces. Knowing the history of the building, we can say that, in this case, the intelligent platform was able to identify the main layers and materials present in the image, recognising the historical periods and hypothesising the possible technical functions of the textile network. Among these, 'wallpaper reinforcement' is indeed the function for which it was intended. The conclusions are also consistent with the information we have gathered.



AI mapping of the stratigraphic portion
source from ArchGPT

We now ask the AI to create a graphic map, separating the 19th-century decorative layer from the visible portion of the textile mesh.

The image produced is partially correct, as the AI platform was able to identify the layer of the textile mesh in the foreground. On the contrary, we note a difficulty in highlighting the underlying decorative layer, which is incorrectly mapped. As in the analysis of degradation pathologies, even in that of materials, the AI platform proves to be less effective if our request involves mapping multiple phenomena and materials simultaneously. Its use is more interesting in hypothesising the stratigraphy and history of the surface.

These considerations should be understood in relation to an initial analysis approach and the chosen AI platform (ArchGPT 5.2). In the coming years, we will likely see further performance improvements in these intelligent platforms, which will produce more accurate and reliable results in the field of restoration. In the diagnosis of interior surfaces, our analysis of degradation phenomena and materials has allowed us to better understand the strengths and weaknesses of AI to date.

Having studied the potential and limitations of artificial intelligence in relation to a practical approach, we can conclude our research by exploring these topics in greater depth, placing ourselves within the international architectural restoration landscape.



The ceiling vault, where a large lacuna can be seen



A portion of the ancient wooden floor
own source from on-site inspection



The peeling of the surface under the window, caused by damp



The detachment of the wallpaper and the underneath layer of neo-Greek paint

PROMPT CHAPTER 4:
Considerations on the potential and limitations of artificial intelligence

Our investigation into the application of artificial intelligence in the field of interior surface restoration has given us an overview of its possible uses within the process. As we have seen since the first chapter, experimentation in the phases of surveying and reproduction, analysis and diagnostics, design and execution of the intervention, as well as scheduled maintenance and documentation, reveals a strong desire on the part of the industry community to update and improve the current methodology. In particular, the case study of the RePAIR project and the in-depth analysis of the application of AI platforms in the analysis of the interior surfaces of Villa Sottocasa have provided us with specific and practical examples of experimentation.

Considering prospects, this experimental trend could lead to an internal revolution, becoming the fuel for a regularisation of the conservation system. Let us imagine having the full support of AI in the restoration process: the detection of inaccessible parts and the automatic transfer of data via machine learning and deep learning to generate a 3D model that is constantly updated with the real building; the analysis of surfaces, their stratigraphy and any degradation requiring intervention; the organisation of work and simultaneous management on site; and, finally, the monitoring of assets and digital archiving.

AI is therefore a powerful tool for data acquisition, processing and analysis, prediction and monitoring. To conclude the research for this thesis and make an accurate assessment of the current conditions characterising the use of artificial intelligence in restoration, it is necessary to consider its current potential and limitations.



AI illustrative sketch of a bas-relief surface
source from ideogram.ai

4.1 Potential and opportunities for AI application

As our investigation has shown, the world of restoration is a complex process aimed primarily at preserving the physical and cultural integrity of assets, as well as their durability and transmission over time. In this context, artificial intelligence offers advanced and innovative support at various stages, from detection to analysis, from monitoring to post-intervention documentation and divulgation. Let us therefore analyse the strengths of its application, bearing in mind that our research context is constantly evolving.

In the initial survey phase, which is generally time-consuming, AI significantly speeds up the process and improves the accuracy of surveys thanks to the use of tools such as drones and other technological additions, which can facilitate the acquisition of data from hard-to-reach surfaces. The subsequent graphic reproduction of the object allows for the creation of a 3D model using H-BIM technology combined with machine learning in order to recreate the desired spatiality with its detailed elements. Furthermore, AI support not only reduces survey and reproduction times, but also operational risks, paving the way for a semi-automated workflow based on semantic segmentation of point clouds. These 3D models represent the starting point for all possible applications of artificial intelligence in the subsequent stages of the conservation process.

During surface analysis, we have seen how convolutional neural networks (CNNs) associated with AI allow for the automatic recognition and categorisation of decay, colour variations and micro-cracks not yet visible to the human eye through the fragmentation of images into pixels. Computer vision, combined with the Digital Twin Model, is another advanced application that AI offers in the form of timely inspection and monitoring for design purposes. Consider the work carried out to reconstruct the lost portion of Notre-Dame in Paris.

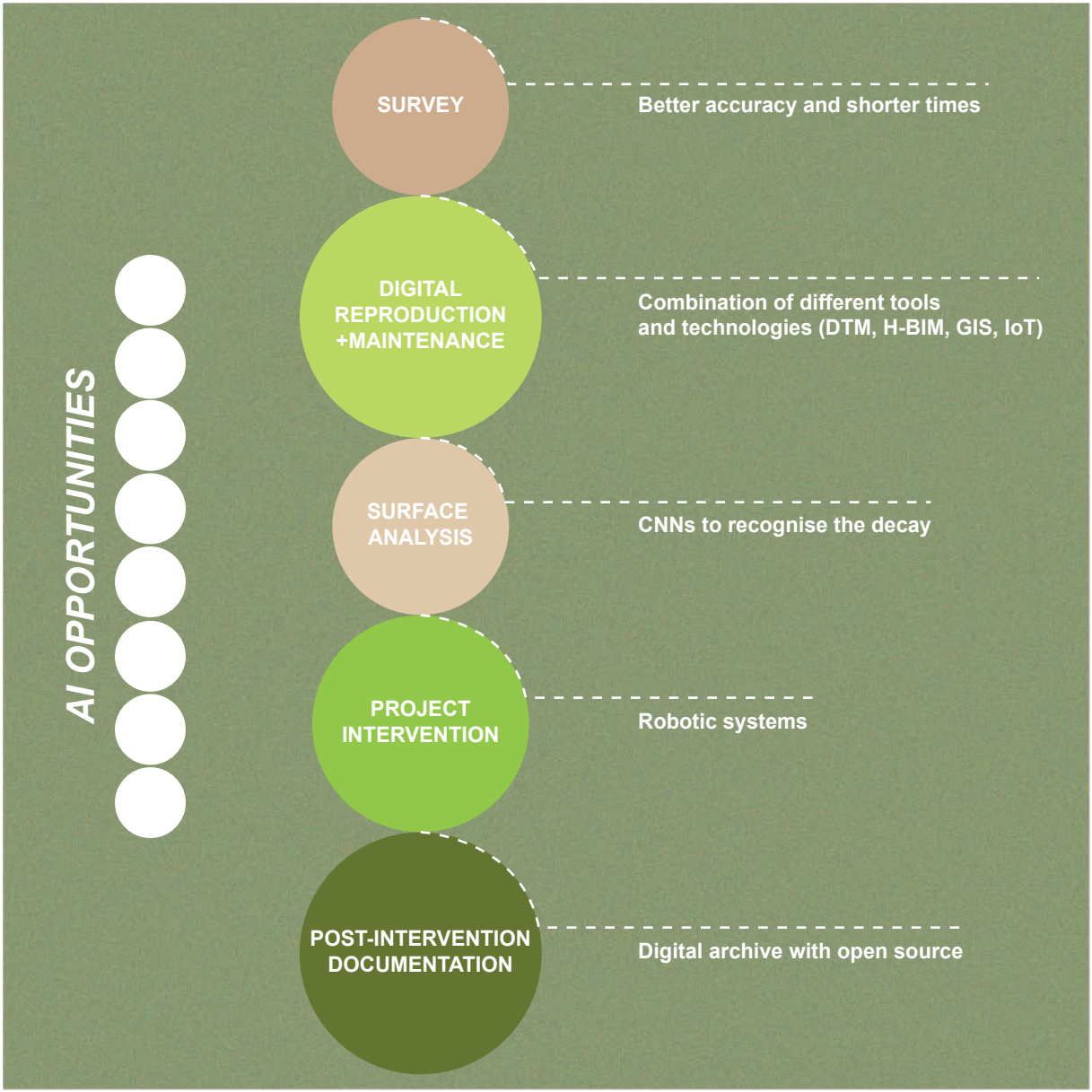
During the design and execution phase of the intervention, artificial intelligence can be integrated with robotic systems to operate directly on surfaces. The precision and reliability demonstrated in the RePAIR project in Pompeii position AI as a practical and ethical support that becomes an extension of human work. Furthermore, innovative experiments such as the use of polymer films in the field of art restoration open up new possible solutions in the restoration of interior architectural surfaces, through methodologies that are significantly reversible.

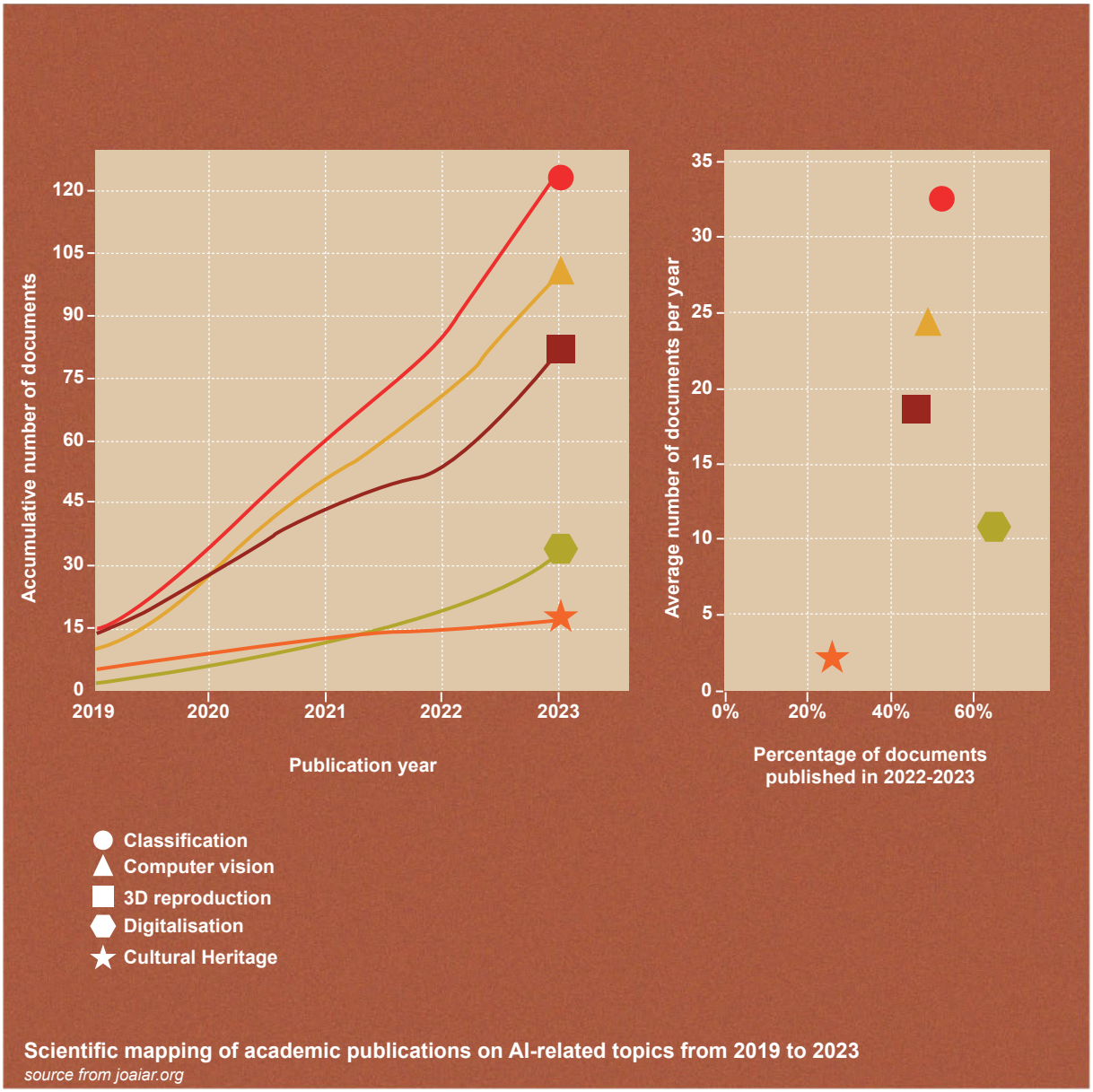
In the field of scheduled maintenance, AI allows predictive models to be obtained thanks to the integration of GIS systems and IoT sensors, which monitor the environmental and structural data of buildings in real time. Other advanced systems such as GeoAI perform the predictive function of possible damage to assets and demonstrate how technological development can effectively assist human work in the daily maintenance of cultural heritage.

In this regard, we can highlight the contribution of AI in raising awareness of the need to safeguard assets, as the possibility of a new operating methodology draws attention to the Italian restoration system, which in many cases is reactive rather than preventive. Interventions take place, that is, following an event that has profoundly marked and compromised one or more parts of an architectural asset. In this sense, intervening on an asset after an event means that the task of preserving the asset itself has been failed. We must also consider the negative consequences that reactive intervention entails. First and foremost is the loss of material of historical value, compounded by high project costs, greater consumption of materials and the possible replacement of original parts of the structure.

These aspects could be avoided if a policy of scheduled maintenance of cultural heritage were implemented, providing periodic checks that would certainly lead to lower costs and consumption of materials and resources, which are increasingly precious and rare. From this perspective, the use of innovative technologies associated with artificial intelligence offers an indisputable improvement in the management of the life cycle of assets, leading to greater collective awareness and, optimistically, to a culture of sustainable conservation.

In the post-intervention documentation phase, the advantages of artificial intelligence consist in systematically organising the digital archive and automatically updating it according to the data collected, overcoming the problem of fragmentation and accessibility of sources by operators.


AI OPPORTUNITIES
SURVEY
Better accuracy and shorter times
DIGITAL REPRODUCTION +MAINTENANCE
Combination of different tools and technologies (DTM, H-BIM, GIS, IoT)
SURFACE ANALYSIS
CNNs to recognise the decay
PROJECT INTERVENTION
Robotic systems
POST-INTERVENTION DOCUMENTATION
Digital archive with open source



Scientific mapping of academic publications on AI-related topics from 2019 to 2023

source from joaiar.org

Finally, AI takes on an interactive role in cultural divulgation through virtual reality, increasing its potential for immersive experience and creating appeal among the public. In this case, its application is to be understood in association with an educational and entertainment role.

In conclusion, the use of AI in the field of interior surface restoration offers a wide range of technological opportunities for operators in the sector and, in some cases, for the public. Among the main strengths that emerged from our research, we can therefore mention:

I. Increased performance effectiveness, precision, and sustainability of interventions
II. Reduction in time and possible human error.

(These considerations are referred in chapter one of this thesis.)

Finally, we can mention the scientific mapping published in the *Journal of Artificial Intelligence & Robotics*[37], which aims to track all academic publications on the topic of AI applications in restoration since 2019. The graph shows a rapid increase in such publications, indicating growing interest. In particular, the most frequently published topics are: classification techniques, computer vision, 3D reproduction and digitisation of cultural heritage.

[37] From web article https://joaiar.org/articles/AIR-1018.html

4.2 Current limitations and barriers to the dissemination of AI-related tools

Considering the above considerations, let us now reflect on the current limitations of using artificial intelligence in architectural restoration, as well as the barriers that hinder its possible evolution and experimentation.

First, the question of authenticity has always been a topic of discussion in the theoretical debate on the ethical question par excellence: *to preserve or to restore*? If we project this question into the field of our research, we must recognise the current risk that the use of AI may alter the original and authentic character of the reproduced asset. This risk is due to the difficulty in setting up the correct dataset, which must necessarily be specific to the historical period and style of the building under study, as an incorrect setting would mean a distortion in the 3D reconstruction. There is a risk of aesthetic distortion in relation to non-Western cultures, which are currently not very recognisable to machine learning and deep learning systems. A 2021 study by the MIT Media Lab[38] highlighted this problem in the museum and art world, as image recognition tools trained on European art collections were unable to correctly classify certain African and Asian artefacts.

[38] I. Marchese, *Preserving cultural heritage in the age of artificial intelligence: an overview of protection and militarisation,* The CoRSPU Magazine, 2025, pp.77

This is because artificial intelligence seems to be 'preset' on Eurocentric taxonomies. It would therefore be necessary to diversify datasets to include a broader spectrum of cultural expressions. The restoration community is showing increasing interest in this issue, as resolving this gap would significantly improve the performance and reliability of AI in the 3D reproduction phase.

An example of this interest can be found in Juan A. Barcelò's presentation[39] in the debate *AI-based Reconstruction of Prehistoric Remains* at the Digital Heritage International Congress in Siena in 2025, which highlighted the current difficulty in investigating the digital reproduction process due to the 'black box' nature of some AI algorithms. In contrast, the debate *Artificial Intelligence and Cultural Heritage in Practice: exploring approaches to operationalising values, law and responsible openness*[40] addressed the issue of ethics, legal compliance, and responsible openness in relation to the current regulatory and strategic uncertainty in the sector. Several interdisciplinary figures, such as lawyers, digital humanists, and cultural experts, participated in this discussion.

[39] Professor in the Department of Prehistory at the Autonomous University of Barcelona
[40] Presentation by A. Foka, A. M. Sichani, O. Murphy, P. Westenberger, DHIC 2025


AI LIMITATIONS
DATASET
Complexity in creating a correct data model
ETHICAL QUESTION
Current risk of altering the original character of the assets (especially non-Western cultures)
COPYRIGHT BARRIERS
Legal barriers due to nations' rights on the IA platforms
ECONOMIC BARRIERS
High costs of investment in hardware, equipment, highly skilled human resources

Secondly, we must consider that the use of innovative tools associated with restoration is currently hampered by significant economic and technological barriers, which make large-scale deployment difficult. In this regard, research carried out by the European Parliament highlights that the use of advanced resources in the museum and cultural heritage context requires considerable investment in digital infrastructure, equipment, and highly skilled human resources, which are difficult for small and medium-sized organisations to sustain.

In fact, it is necessary to have large amounts of high-quality data accompanied by accurate metadata. Their adoption is also currently hampered by certain legal copyright barriers in the countries that offer the necessary platforms, compounded by the limited funds available to institutions[41]. The result is a perception of high risk in investing in artificial intelligence systems and a lower propensity to fully experiment with them. It would therefore be necessary to create a targeted economic support policy, with funding to cover the costs of hardware, software, cloud, and personnel, and structured training programmes and the enhancement of data and tool sharing between institutions. In this way, the transition to a digitised process could be formalised, with concrete changes in the world of conservation, and the technological gap that makes the complete dissemination of AI systems impossible could be reduced[42].

[41] *Artificial Intelligence in the context of Cultural Heritage and Museums: complex challenges and new opportunities*, European Parliament document, 2023

[42] M. A. Azizan, N. Ishak, H. Desa*, Digital guardians: The Role of AI and Robotics in Protecting Construction Heritage*, International Conference on Artificial Life and Robotics, Japan 2025

4.2 Conclusions on the role of AI in the state of the art of interior surface restoration

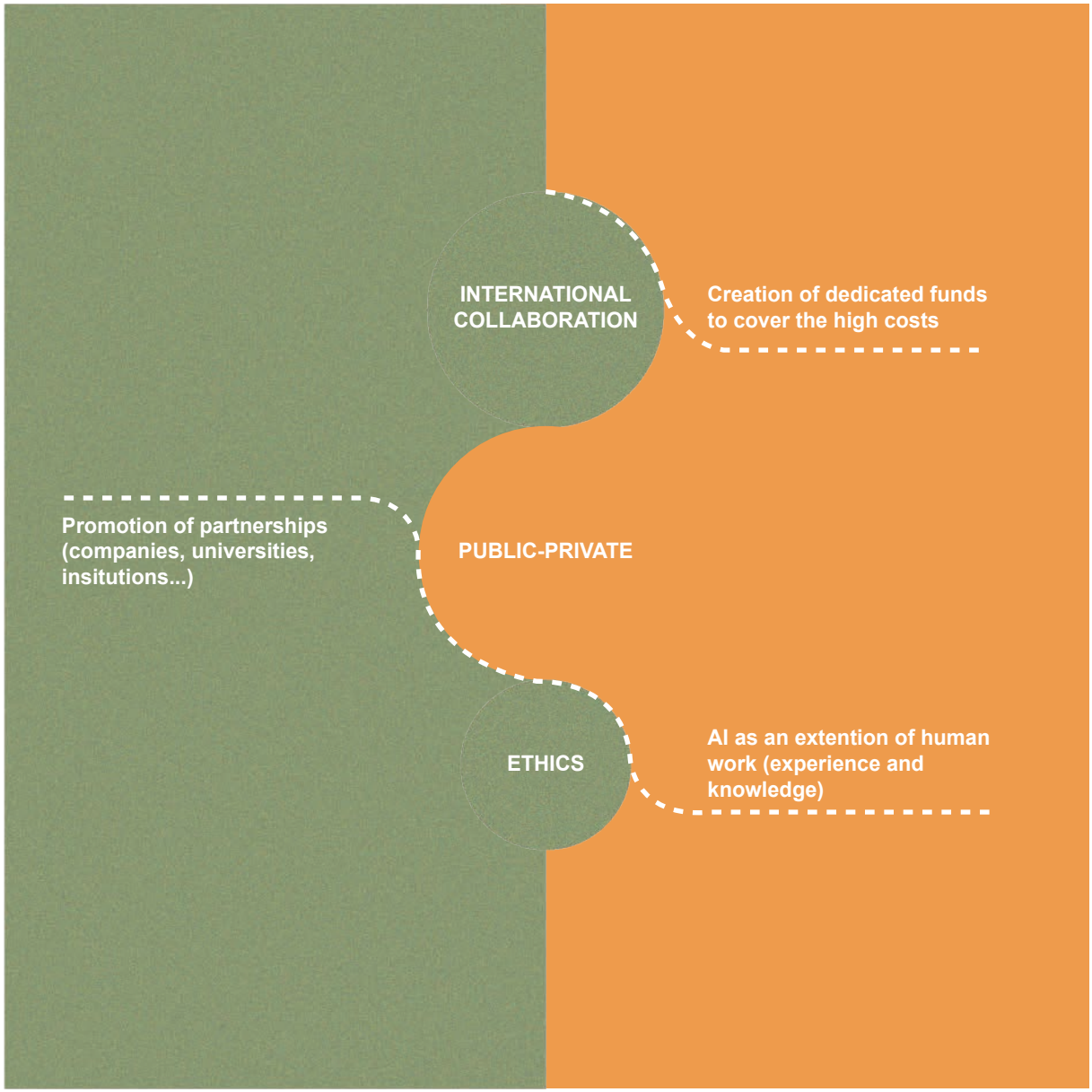
In this final chapter, we have reflected on the current potential and limitations of the use of Artificial Intelligence in the field of architectural restoration. In general, there has been considerable interest from the industry community, which in recent years has shown a progressive tendency to experiment with AI-related systems in the various stages of restoration, compatibly with the needs of the intervention and the availability of the institutions involved.

This tendency can certainly be attributed in part to the global digitalisation process, which is profoundly changing the way we think and apply our thoughts to every aspect of daily life. Whereas previously it was sufficient to use computers to perform certain practical tasks, today we are seeking solutions that automate complex and costly processes. Current economic and technological barriers are hindering this research. These represent the main obstacles to the development of innovative smart technology in restoration, as they determine the practical feasibility of the experiments described in the previous chapters.

If this problem were overcome, it would be possible to integrate new technologies into local contexts, which often lack adequate funding for restoration work. This would require collaboration between countries, ministries, and foundations to create dedicated funds to cover the high costs and calls for proposals specifically designed for small museums, cultural institutions, and archives. Furthermore, in order to support the development of dedicated AI platforms, it would be necessary to promote public-private partnerships between tech companies, institutions, and universities in order to create national or European platforms that allow access to computing, machine learning, and deep learning systems at low cost.

A second point to address in these conclusions on the state of the art with regard to our topic is that of ethics. As described in chapter two, the use of artificial intelligence should not be seen as a substitute for human work (and roles), but as advanced technological support capable of offering unprecedented performance. In architectural restoration, which has always been characterised by knowledge, interest in history, and the signs of ageing, it is important to maintain a *human-centred* approach, in which the machine becomes an amplification of human experience[43]. An ethical and responsible application, therefore, in which the value of architectural and artistic curation is not lost, but attention to detail and passion for the craft are remembered.

[43] S. Pansoni, S. Tiribelli, M. Paolanti, F. Di Stefano, E. Frontoni, E. S. Malinverni, B. Giovanola, *Artificial Intelligence and Cultural Heritage: design and assessment of an ethical framework*, The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVII, 2023


INTERNATIONAL COLLABORATION
Creation of dedicated funds to cover the high costs
Promotion of partnerships (companies, universities, insitutions...)
PUBLIC-PRIVATE
ETHICS
AI as an extention of human work (experience and knowledge)

Within the conservation process, the use of AI can play a key role for humans, as it allows for an amplified experience in the phases of learning about the building, its surfaces, stratifications, and materials, ultimately providing a complete picture of the object of study. Based on these considerations, artificial intelligence can therefore be considered a turning point for the current restoration system. In the not-too-distant future, it will probably be able to redefine international standards, generating a new codified system that involves the entire conservation process and focuses on scheduled maintenance.

In conclusion, we can affirm that, based on our research, the state of the art in restoration is currently a dynamic and constantly evolving field, characterised by considerable potential and actual significant economic limitations, but above all by an awareness of the need to maintain a balance between human sensitivity and advanced technology.

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