The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-9-2025
30th CIPA Symposium "Heritage Conservation from Bits:
From Digital Documentation to Data-driven Heritage Conservation", 25–29 August 2025, Seoul, Republic of Korea

Digital Documentation and Data Analysis for Safeguarding Heritage at Risk. Condition Assessment of Colonia Varese

Federica Maietti [1*], Martina Suppa [1], Gabriele Giau [1], Luca Rossato [1], Guido Galvani [2], Marcello Balzani [1]

[1] Dept. of Architecture, University of Ferrara, Italy – (mttfrc, sppmtn, giagr, rsslcu, bzm)@unife.it
[2] Dept. of Ancient Sciences, Sapienza University of Rome | School of Conservation and Restoration, DiSPeA, University of Urbino, Italy – guido.galvani@uniroma1.it

Keywords: Heritage at Risk, 3D Laser Scanning, Photogrammetry, Modernist Architecture, Digital Data Analysis.

Abstract

The 3D survey of the geometric-morphological features and analysis of the state of conservation of the former Colonia Varese in Milano Marittima, Ravenna, Italy, was developed in order to provide the Emilia-Romagna Region with a comprehensive and accurate knowledge base of one of the most significant examples of Italian rationalist architecture in the 1930s. In addition to being a unique opportunity to deepen the knowledge of this architecture strongly representative of its era, the research has been a testing ground for developing the use digital technologies for documentation of endangered heritage. The imposing size building is indeed heavily compromised by degradation and collapses over time. The integrated survey was developed under challenging conditions due to the architectural layout, landscape surroundings, state of abandonment, and risk conditions. The use of digital acquisition technologies has made it possible to overcome this issues, documenting the architectural complex and the surrounding area. The resulting 3D models and graphical representations enabled a morphological analysis, carried out in parallel with the historical-documentary research, showing an architectural layout still clearly legible, and assessing the structural damages, surfaces degradations, and changes over time. Current developments include the application of Artificial Intelligence algorithms for data segmentation and advanced features recognition.

1. Introduction

In the context of safeguarding heritage at risk, the application of digital technologies is increasingly essential, allowing for accurate, non-contact documentation, even in contexts where the state of conservation does not allow for safe working conditions inside structures (Balzani et al., 2023). This is the case of the former Colonia Varese (Fig. 1), a Modernist architecture on the coast in Milano Marittima, Ravenna, Italy, on which this research focuses. The integrated digital documentation was carried out in order to provide the Emilia-Romagna Region with a comprehensive and accurate knowledge base for starting evaluations and possible strategies to preserve the complex (Masciotta et al., 2021), which is in a state of neglect and advanced decay up to structural collapse in different areas.

Figure 1. View of the Colonia Varese and the surrounding pine forest from the seaside (photo by the authors).

Although the former Colonia is in a severe state of deterioration and strongly altered compared to its original appearances, it retains its evocative charm. Documentation is the first step in preserving this extremely significant and representative architecture, so that its historical, cultural and material memory can be transmitted (Trizio et al., 2019).

The research was an exceptional opportunity to delve deeper into some issues extremely crucial nowadays. The topic of heritage buildings in a state of abandonment represents a part of the broader issue of heritage at risk. The risks to which built heritage and cultural sites are exposed are of different kinds, and many recent events give evidence of the irreversible damage that human actions or calamitous events produce on cultural heritage. The fires of Notre-Dame in Paris (2019) (Roussel and De Luca, 2023; Gros et al., 2023) and the National Museum of Brazil in Rio de Janeiro (2018), the earthquakes in Northern Italy (2012), the recent floods in different parts of the world, and current armed conflicts are just a few examples of the growing level of attention that needs to be paid to safeguarding cultural heritage, cultural landscapes, and tangible and intangible assets in general. In addition to earthquakes and volcanic eruptions, floods and landslides, fires, hurricanes, air pollution, conflicts and terrorism, anthropic actions and lack of maintenance or state of abandonment are equally a very widespread risk to which the heritage is subject. Since 2018 in particular, on the occasion of the European Year of Cultural Heritage, heritage safeguarding and protection against risk has acquired particular relevance through studies aimed at developing tools for quantifying damage from extreme climate events, identifying vulnerability indicators, producing short and long-term scenarios and developing specific protection

strategies including the recovery of good practices from the past (Sesana et al., 2020).
The condition of abandoned buildings, such as the former Colonia Varese (Figg. 2,3), mixes different levels of criticality, adding the lack of conservative interventions to the impact that natural events and environmental conditions have on structures weakened by the lack of maintenance actions (Romão and Bertolin, 2024). In addition to being a unique opportunity to deepen the knowledge of Colonia Varese and increase interest and awareness towards this exceptional example of rationalist architecture, the research has been a testing ground for developing the use digital technologies for documentation of endangered heritage. The digital-based methodology, developed combining the most up-to-date survey tools and methods with traditional on-site inspections, provides an effective means for condition assessment.

Figure 2. Current conditions of the Colonia Varese reinforced concrete structure (photo by the authors).

Figure 3. View of a portion of Colonia Varese affected by collapses of horizontal structures (photo by the authors).

The research is the result of an interdisciplinary collaboration that brought together the team of experts and site managers from the Emilia-Romagna Region with researchers in the fields of integrated digital survey, diagnostics, representation and structural investigations from the University of Ferrara. Among the most relevant outcomes is the development of a documentation methodology adapted to the conditions of risk and partial inaccessibility that characterise the Colonia Varese, and the methodological integration that allowed the Emilia-Romagna Region to be provided with essential representations for the analysis of the metric-morphological, conservative and structural features, as a basis for possible future interventions.

1.1 Research context

The Colonia Varese was built between 1937 and 1938 on the initiative of the “Federazione dei Fasci” of the Province of Varese to provide children with a seaside colony on the Adriatic Sea. The building was designed by the architect Mario Loreti and opened in 1939 under the name “Colonia Costanzo Ciano”.
Mario Loreti (Rome, 1898) began working in the field of industrial design as a furniture designer. In 1928 he registered with the Order of Architects of Rome, listed as an engineer; probably he first attended the faculty of engineering, since the Higher School of Architecture for the professional training of architects was established only in 1919, becoming operational in 1920. He then began working in the studio of the architect Pietro Aschieri. In 1930 Loreti visited Germany and the austerity of new architectures of that period deeply impressed him. In 1932 he joined the National Fascist Party, and his career had a sharp increase. In 1929 he carried out the intervention in Piazza Bologna, starting to apply the new rationalist language in his design. In following interventions his style became even more dry, assuming the linear severity of 1930s constructions. An example is the Singer headquarters in Rome, where the preciousness of the materials balanced the project austerity. In the mid-1930s, thanks to his membership in the regime, Mario Loreti obtained some government commissions in Northern Italy, including the design of Piazza Monte Grappa and the Palazzo del Littorio in Varese. In 1936 he was involved in two important social projects of the Varese community: the maritime colony of Cervia and the sanatorium of Sondalo (Mazza, 2010). From the Colonia Varese project plan, it seems that Loreti wanted to give the plant the shape of an aircraft complete with wings, tail and fuselage (Fig. 4).

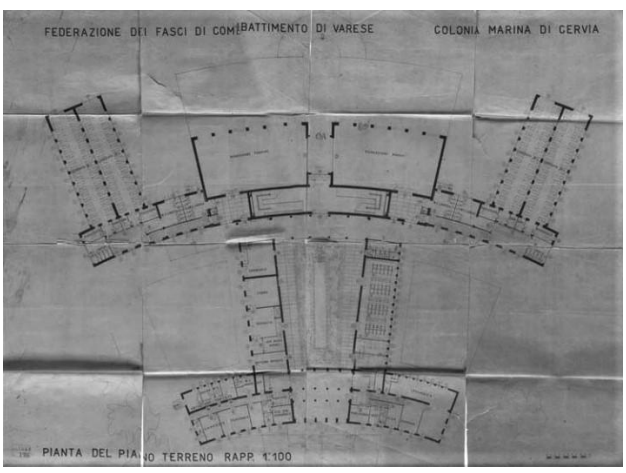

Figure 4. Colonia Varese project plan (Ravenna State Archives).

The colony was designed to accommodate approximately one thousand boys and girls. The central body was a monumental

grid of reinforced concrete supporting the ramps; on the sides are the two-storey service wings and, in connection with the central body, two five-storey wings in which the dormitories were located.
A large park led to the Colonia’s main entrance, located in the centre of a two-storey volume that formed its façade, protected by a canopy. A portico with eight circular reinforced concrete columns led to the trapezoid-shaped inner courtyard, bordered laterally by two-storey buildings and, towards the sea, by the complex of ramps that connected the dormitories.
The ramps, which are one of the Colonia’s most characteristic and peculiar architectural elements, originally provided access to the five dormitory floors via separate paths for boys and girls (Figg. 5, 6).

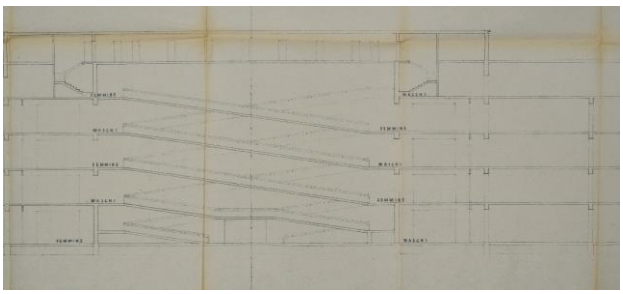

Figure 5. Project drawings of the ramps (Ravenna State Archives).

Figure 6. View of the ramp structure in a comparison between a period photo (Ravenna State Archives) and the current condition.

Inside the entrance body were offices and services to the east and west. The two bodies to the side of the courtyard housed, on the right, the showers on the ground floor and the staff refectories on the first floor; the one on the left housed the coal store, furnace, workshop and services on the ground floor, and the kitchen on the upper floor, connected to the store below via a freight elevator. The ground floor housed two large recreation rooms facing the sea and separated by gender, while the upper floor contained two other rooms of the same size that served as refectories (Figg. 7, 8).
From June 1940, for a whole year, the colony housed a group of children of Italians living in Tripoli who were forced to repatriate due to the war emergency. Closed after two years due to the outbreak of World War II, it was used as a prison and war hospital for German troops. The Colony was partially damaged during the conflict and in the immediate post-war period underwent some restoration work, including the reconstruction of the central ramps (Bartolomei and Morganti, 2022). Since 1950, the Colony has been abandoned and has not been used since then, causing progressive deterioration, but anyway protected and preserved for its construction features.
The structure, an icon of rational Italian architecture, is characterised by the rigidly symmetrical shape of the planimetric layout and a monumental declination of functional devices such as stairs, ramps, etc. (Mulazzani 2019).

Figure 7. The recently completed Colonia Varese still named after Costanzo Ciano (source cerviaemilanomarittima.org).

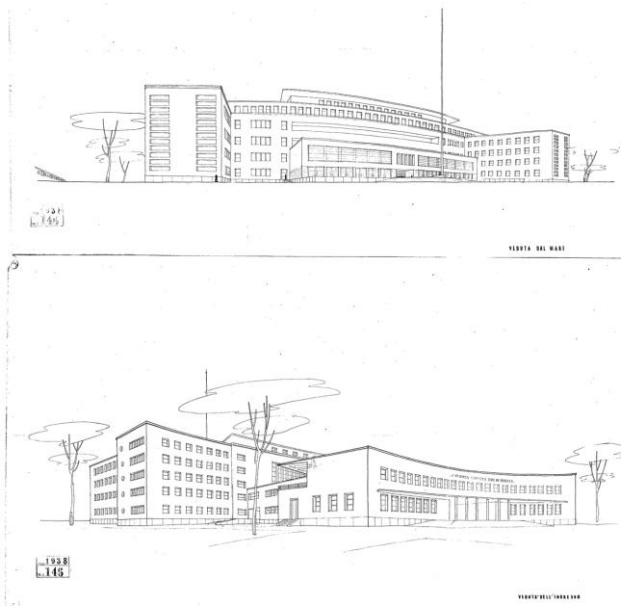

Figure 8. Project drawings. On the top, view from the sea, on the bottom, view from the entrance (Ravenna State Archives).

In addition to its imposing size (a total area of approximately 60,000 sqm, with a covered area of about 4,000 sqm), the result is a design of great formal impact despite its condition and the state of abandonment in which it has been left for years.
The complex was digitally surveyed integrating topographic methodology, 3D laser scanning and photomodelling procedures. The survey was strongly oriented towards a detailed analysis of the current conditions, carrying out a three-dimensional point cloud model for the analysis of geometric distortions for the purposes of a structural assessment.

Three- and two-dimensional elaborations were instead focused on the analysis of the crack framework and the overall surfaces state of conservation.

2. Research methodology

The survey of the former Colonia Varese was developed in a challenging contest and under challenging conditions. The main purpose was to provide the Emilia-Romagna regional bodies (Heritage, Logistics, Security and Procurement Sector, General Directorate of Resources, Europe, Innovation and Institutions) with an overall documentation performed by applying advanced instrumental techniques. In particular, the data capturing has been developed through the integration of topographic methodology, 3D laser scanner and photomodeling procedures. The purpose was the achievement of a three-dimensional point cloud model for the analysis of any geometric distortions for structural evaluations; a three-dimensional model obtained through the detailed survey of the external surfaces through photomodeling procedure; and the extractions of two-dimensional representations as a geometrically consistent and accurate support for the analysis of the crack pattern and of the overall state of conservation.
In a context like that of Colonia Varese, an essential part of the survey operations lies in the planning of the survey itself. Before starting the fieldwork, the documentation was organized in close collaboration with the Region in order to establish the methodologies to be applied, the critical issues, the scan-stations to be positioned to cover the building, the timing, and manage all the surrounding conditions.
In order to guarantee the required accuracy despite the obstacle of vegetation, the topographic survey was used to define a high-precision local coordinate system (Fig. 9), the boundaries of relevance and the support of sub-networks necessary for the detailed survey (Fig. 10).

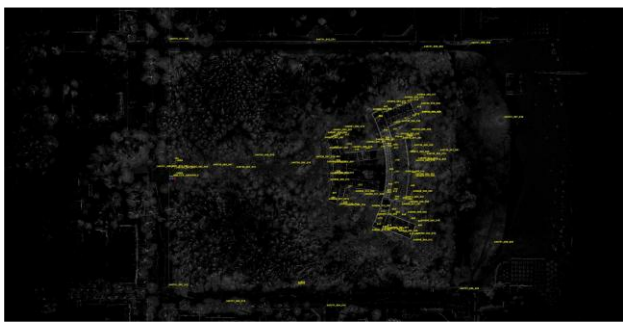

Figure 9. The topographic model (graphic elaboration by the authors).

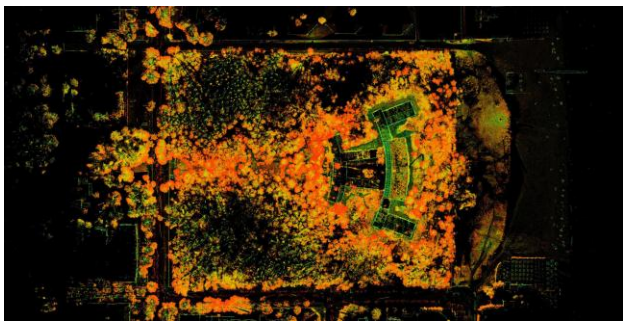

Figure 10. Plan view of the 3D laser scanner model (graphic elaboration by the authors).

The survey covered the entire complex and its immediate surroundings. The general state of abandonment, with sky-ground collapse of some portions in different areas of the building, did not allow in-depth internal analyses to be carried out, but only partial data to be acquired. On the other hand, the external surfaces and areas were surveyed through an acquisition campaign that, despite the dense vegetation all over around the building, involved the integration of several technologies in order to obtain a dense three-dimensional point cloud model in a coherent local coordinate system, as a data source for the two-dimensional extraction of information.
The diagnostic survey of the state of conservation of the surfaces and of the structural damage was carried out at the same time as the metric-morphologic data capturing and after having explored the main sources (in particular, the original project drawings, the period photos and all the available technical and bibliographic documentation). These sources have proven to be essential for decoding the state of conservation, which has been detected through visual investigations and direct analyses, onsite.

2.1 The 3D integrated documentation

The topographic survey was performed through a Leica tps1202 total station (32 polygon vertices, 86 collimated targets).
The 3D terrestrial time-of-flight laser scanner survey was adopted for the acquisition of the exterior of the main buildings composing the complex, for the definition of the geometries and for the general evaluations of the possible geometric distortions of the perimeter structures (Li et al., 2025), both vertical and horizontal, and for the creation of sections and DEM (Digital Elevation Model). The coordinates acquired by means of the Leica P50 3D laser scanner are 19,000,000, measured by 139 stations (scan positions) and applying 86 targets.
The terrestrial photographic campaign was supported by aerial survey through UAS. The tool applied is a drone weighing less than 250 grams (DJI MINI 2). 8,000 frames were acquired, 86 targets were aligned, and a main mesh 3D model and 4 detailed mesh 3D models were created.
This procedure allowed the acquisition of images aimed at achieving a point cloud model of metrically coherent detail obtained through photomodelling techniques of the main buildings and for the extraction of planimetric orthophotos of the entire area.
The sections were directly edited on the point cloud following a rigid scheme of coordinate systems and section planes (Fig. 11). This procedure also established the nomenclature through which the elevation-sections extracted from the 3D models were identified, to be used as a basis for the mapping of the state of conservation of the surfaces and for the representation of damages and deformations.

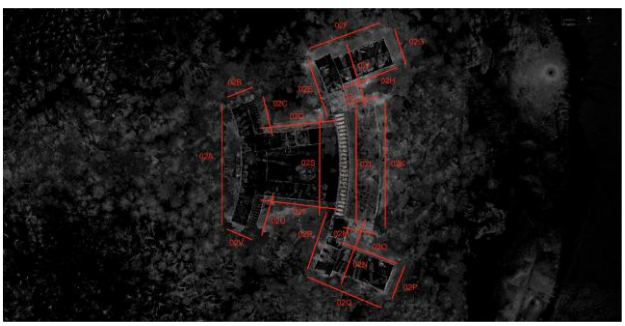

Figure 11. Vertical section extraction scheme (graphic elaboration by the authors).

The registration of the clouds by means of the coordinates derived from the topographical network contributed to the composition of three-dimensional point cloud models (Matrone 2018) (Fig. 12) from which the data necessary for the drafting of the CAD drawings were extracted.
The integration of the above mentioned tools and methodology allowed to partially overcome the site complexities.

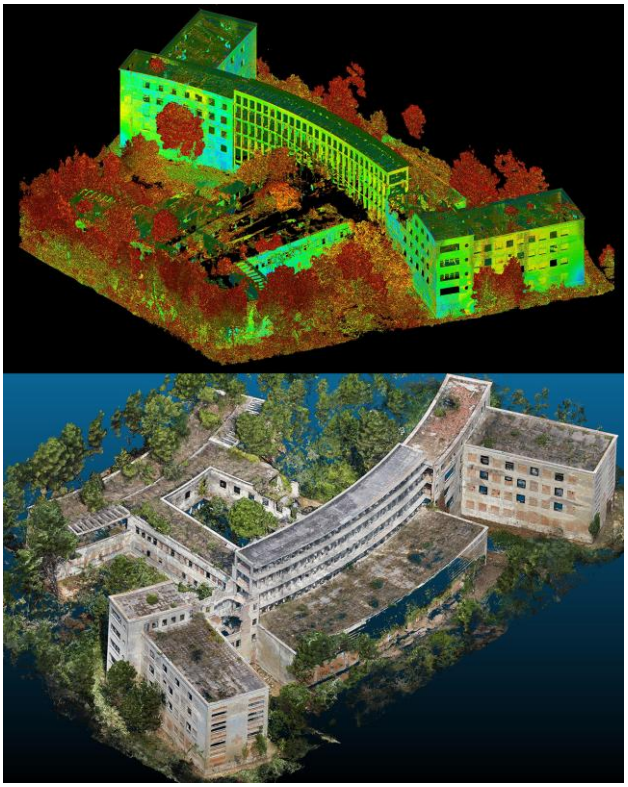

Figure 12. Views of the 3D point cloud and the model obtained through photomodelling (graphic elaboration by the authors).

3. Diagnostic survey and state of conservation mapping

The procedures for the diagnostic survey and assessment of the state of conservation were extensively based on data obtained from digital capturing, and through onsite inspections limited to areas where it was possible to carry out observations in complete safety (De Fino et al. 2023). After onsite investigations, the conditions of collapse (structural and superficial) were assessed through the analysis of 3D metric-morphological information.
The methodology adopted for the integrated diagnostic survey on surfaces followed a hierarchical progression from landscape context to construction details, included the assessment of preliminary research (indirect sources, previous studies, original drawings, technical information from surveys previously carried out, etc.) and on field analysis (geometries and shapes, materials and construction techniques, macroscopic morphologies of degradation).
The first step involved the macroscopic analysis of the materials and construction techniques. The following predominant classes were identified: reinforced concrete, concrete, brick (external infill walls, hollow bricks for filling the window holes, etc.), plaster, mortars.
A preliminary classification of the main decays affecting the external surfaces of the Colonia Varese was then drawn up by identifying a set of issues visible during the inspections. The degradations have been divided into the following categories:

- physical-chemical (environmental conditions),
- physical-mechanical,
- biological,
- anthropic,
- structural.

Then, taking the UNI 11182/2006 as a basic reference, a decay abacus was set up including the main deteriorations identified in relation to the materials. As far as concerns the structural analysis, a specific procedure was followed, developed by the research team responsible for the damage and deformation assessment.
Mapping of surface degradations was carried out by combining field observations (which produced a preliminary annotation on sketches of the elevations) with the identification of decays and degradation mechanisms on DEMs. The extractions of the elevations from the model obtained via digital photogrammetry were essential to outline the degraded areas with great precision, being the model metrically accurate and consistent with the integrated laser scanner and topographic survey.

Figure 13. Sample of degradation outlining on the surfaces of one of the elevations, using the DEM as a basis for mapping the conservation conditions in detail (graphic elaboration by the authors).

Then the degradation mapping has been represented on CAD drawings. The macro areas of degradation and conservation conditions were assigned to specific layers on the software (Fig. 14), with graphic patterns and related abacus.

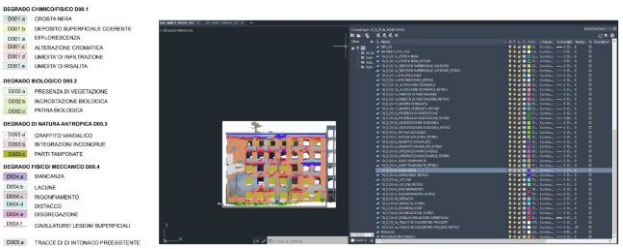

Figure 14. Sample of CAD mapping, where states of conservation are assigned to specific layers (graphic elaboration by the authors).

The degradation mapping was drawn up on the basis of the standard document UNI 11182:2006 - *Cultural heritage - Natural and artificial stone materials - Description of the form of alteration - Terms and definitions*. This standard, which provides a shared lexicon and nomenclature for the

identification of degradation, has been integrated with additional classes specifying different anthropic degradations and inconsistent/incompatible interventions.
The creation of vector files (Fig. 15) including the mapping of the state of conservation of the surfaces on an accurate geometrical basis is essential for the computation of conditions and possible interventions. Mapped areas are indeed manageable by levels and the extension of the surfaces affected by specific degradation is a measurable area, providing additional elements for the evaluations relating to possible future actions and strategies.

Figure 15. CAD mapping, with degradations represented in vector format for computational purposes (graphic elaboration by the authors).

4. Outcomes and further developments

The carried out integrated survey and analytical methodology for the assessment of the state of conservation, allowed to provide 3D data and extractions representing an extremely valuable source of knowledge of the Colonia Varese.
The laser scanner model has been delivered with two levels of point density (1 centimetre and 5 centimetre mesh), in addition to the photomodelling one and a comprehensive photographic documentation (general and thematic).
All the extracted elevations were processed as architectural drawings, as architectural representation with degradation mapping and as representation from photomodeling. Each elevation was then delivered as a layered vector drawing with architectural representation, degradation mapping and extracted elevation from photomodeling.
Structural survey and damage survey graphic representations were carried out for each floor of the structure and according to the subdivision into structural units, in addition to the survey of the deformation framework.
The source models (both the point cloud model and the digital photogrammetry model) were also the basis for carrying out some experiments in the classification of data related to surface features within the project AIM-eBIM - *Adapted Information Management for existing Buildings Information Modeling*. The project, funded by the Emilia-Romagna Region under the PR-FESR 2021-2027 programme, is focused on advancements in digital tools applied to existing and cultural heritage, encouraging the application of digital sources in a widespread, accessible, aware, and critical way. The scope of the project concerns the strengthening of research and innovations in applying advanced technologies, exploiting the advantages of digital data capturing, Building Information Modeling (BIM) and Artificial Intelligence (AI). The project addresses some open issues in heritage digitisation, including the need to highlight knowledge and survey as integral parts of the design process, to focus on the concept of quality of the restoration or redevelopment project, and to make digital data effectively accessible.
One of the key points is to move away from the current tendency to replace methodological processes with tools, which should be oriented towards achieving digital data quality, focusing on which methodological approaches should be adopted to make data and information dialogue, conveying conservation or intervention needs.
BIM and AI applications are at the forefront of this evolutionary scenario (Avena et al., 2024), where the connections between geometry, data, information classes, and significances require new forms of hierarchical discretisation and conceptualisation (Ceccarelli et al., 2023). Digital models can and must concretely enter into protection, conservation and valorisation actions, at a time when, despite an impressive digital evolution, 3D data are often unused in everyday intervention practices by professionals, site managers, heritage curators.
AIM-eBIM pursues the challenge to combine parametric modeling, source digital data management and AI applications. BIM for existing heritage is indeed an explored topic, but new processes need to be faced, such as the optimization of digital survey data, data thematization and segmentation (Lanzara et al., 2022), simulations on BIM models with thematic data integration, and new tools for sharing adaptively populated digital models.
Within the scope of the project, the implementation of informative data to be associated with BIM is based on thematic criteria, applied to previously acquired case studies/datasets and new digital surveys (Giau and Maietti, 2024).
The Colonia Varese dataset is one of the thematic test under development to process data concerning surface features, as it is particularly significant in terms of mapping and interpretation requirements (Maietti, 2023). Tests on Colonia Varese dataset (Fig. 16) are aimed to segment and classify point clouds of external surfaces according to materials and construction techniques, assessing the incidence of different features in the classification. The process involves the definition of an abacus of classes to be segmented, supervised Machnine Learning procedures, and critical analysis of results.

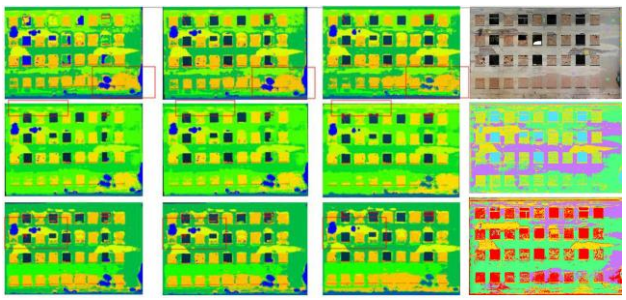

Figure 16. Comparison between different methods of material classification starting from the point cloud and, on the right, segmentation from images (graphic elaboration by the authors).

The dataset related to Colonia Varese is the 3D point cloud, in which each point is described by features, including spatial coordinates, RGB values and different geometric features. For training the model, a subset of the original dataset was used, enriched by the additional variable related to materials, which specifies the class of material associated to each point.
The dataset includes 8 classes of materials, representing the different structural components of the building. The different processes tested starting from the manual annotation of parts of the model up to the automatic classification of the features, demonstrate how the AI model is able to accurately segment the different surfaces of the building, replicating and systematizing the information provided by human annotation. The analysis of the state of conservation requires a more structured approach

than the classification of materials, due to the overlapping of different types of degradation. Unlike segmentation, which allowed the use of a univocal annotation, the simultaneous presence of multiple forms of degradation requires a more articulated methodology, able to distinguish and managing the interactions between the different decays.
A second phase focused on image segmentation, an approach that allows analysing and classifying architectural surfaces directly from visual data, allowing for faster analysis and a better ability to distinguish specific elements. Unlike point cloud-based segmentation, which provides a detailed three-dimensional representation, image analysis uses colour information to improve the recognition of materials and degradation conditions.
Additional experimentations on algorithmic training and predictions are ongoing, toward a management of source information (Aricò et al., 2024) "adapted" to existing heritage conservation in BIM environment. Strong efforts are focused in analysing data capturing requirements and criteria for thematic population in a more efficient and targeted way.

5. Conclusion

The research is a significant example of the application of integrated digital technologies in a complex context, both from a dimensional-morphological and environmental point of view, and due to the risk condition in which it currently is. The applied digital-based methodology, in combination with traditional historical research and on-site inspections, provides an effective means for diagnostic investigation and conservation condition assessment (Balzani et al., 2017).
One of the most relevant aspects of the applied workflow concerned the design of the survey process and the integrated documentation, developing a procedure strongly aimed at the characteristics of the site and adapted to the conditions of risk or inaccessibility. In this context, the mapping of the state of conservation on digital sources allowed to exploit a geometrically and metrically accurate and at the same time highly detailed basis in terms of visual appearance, in order to explore the conservation conditions even in totally inaccessible areas, and therefore impossible to be analysed through direct survey or "contact" diagnostic investigations.
Moreover, the integrated digital survey of the former Colonia Varese made it possible to explore the material evidence of an evocative, significant architecture, strongly representative of the period in which it was built. Through the consultation of archive sources, and in particular the period photographs and project drawings conserved at the Ravenna State Archives, according to the necessary references, framework and knowledge base.
In addition to the graphic documents, the research produced a summary report of the state of conservation that was possible to evaluate, considering that further diagnostic investigations and specialistic analyses at a structural level would be necessary to have a detailed picture.
Anyway, it is possible to state that the general state of conservation of the building suffers in particular from the damage to the structures, which show a widespread and, in some areas, severe level of damage, with large portions collapsed, both in terms of horizontal and vertical structures, making not only the degradation of the surfaces subordinate to this condition, but also making the superficial state of conservation strongly correlated to the structural damage.
The survey representation, consisting of about a hundred of technical documents delivered to the Emilia-Romagna Region (topographic and architectural survey, surface and structural deterioration identification) provides an interesting analysis and, above all, the metric-morphological basis on which to ground future investigations and interventions. The overall digital documentation of the former Colonia Varese was indeed drawn up in order to provide the Emilia-Romagna Region with a database to be used to start evaluations and possible strategies to safeguard this context. Important assessments are indeed underway regarding future actions. Whatever direction will be taken, the documentation carried out will be of essential relevance. Possible future developments are the accomplishment of the survey including missing internal spaces (following the safety of the areas most at risk of collapse) and the planning of a set of instrumental specialist diagnostic investigations. Further possible research scenarios concern the integration of data in shared platforms, in which the geometric data can be integrated with further information levels (Chiabrando et al., 2018). The development and application of Artificial Intelligence algorithms in integrated diagnostic evaluation, is an additional ongoing advancements aimed at further deepening the informative potential of digital datasets, extracting thematic data that can support additional analyses.

Acknowledgements

The "Survey of the geometric-morphological features and analysis of the degradation and state of conservation of the former Colonia Varese in Milano Marittima" was funded by the Emilia-Romagna Region, Heritage, Logistics, Security and Procurement Sector, General Directorate of Resources, Europe, Innovation and Institutions.
Responsible Manager: Elettra Malossi. Sole Project Manager: Elisa Tommasini. Working Group: Annalisa Loccioni, Irene Cavallari.
The survey and analyses were carried out by the Department of Architecture of the University of Ferrara, DIAPReM Centre. Scientific Managers: Marcello Balzani, Luca Rossato, Guido Galvani.
Responsible for the three-dimensional survey: Guido Galvani. Responsible for the diagnostic analyses: Federica Maietti. Responsible for the structural analyses: Andrea Giannantoni. Responsible for the graphic representation: Fabiana Raco. Working group: Martina Suppa (diagnostic analysis and representations), Gabriele Giau (three-dimensional survey support), Fabio Planu (CAD extraction support), Agnese Chianella, Luisa Pandolfi, Gabriele Giannantoni (structural analysis support).

The AIM-eBIM project is funded by the Emilia-Romagna Region under the FESR 2021-2027, Regional Programme - European Regional Development Fund, Action 1.1.2, Call for Strategic Industrial Research Projects addressing the Priority Areas of the Smart Specialisation Strategy, by D.G.R. n. 2097/2022 and D.G.R. N. 111/2023. CUP F97G22000480003.

The research on data segmentation process is also part of the IDAUP-International Doctorate in Architecture & Urban Planning, XXXVIII cycle, position financed by PNRR D.M. 351/2022 (Cultural Heritage-M4C1 I. 4.1) developed by Gabriele Giau in cooperation with the Cultural Heritage Department of the Emilia-Romagna Region as regional Host Institution.

Although the paper was written in close collaboration between the authors, the authorship of the paragraphs is as follows:
FM is author of chapters 1 and 2.
LR is author of chapters 1.1.
Chapter 3 has been written jointly by FM and MS.
Chapter 4 has been written jointly by FM and GG1.
Chapter 5 has been written jointly by FM and LR.

GG2 is the author of chapter 2.1 and he provided the 3D survey and the database from which graphic representations from the point cloud were extracted.
MB supervised the research.
Conceptualization: FM, LR, MS. Methodology: FM, LR, MS, GG2, GG1. 3D survey: GG2. 3D data processing: GG2, GG1, MS. Decay mapping: FM, MS.

References

Aricò, M., Ferro, C., La Guardia, M., Lo Brutto, M., Taranto, G., Ventimiglia, G.M, 2024. Scan-to-BIM Process and Architectural Conservation: Towards an Effective Tool for the Thematic Mapping of Decay and Alteration Phenomena. *Heritage*, 7(11), 6257–6281.

Avena, M., Patrucco, G., Remondino, F., Spanò, A., 2024. A Scalable Approach for Automating Scan-to-BIM Processes in the Heritage Field. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVIII-2/W4-2024, 25–31.

Balzani, M., Maietti, F., Montuori, M., Raco, F. (Eds.), 2023: *Built Heritage in post-Disaster Scenarios. Improving Resilience and Awareness Towards Preservation, Risk Mitigation and Governance Strategies*. CRC Press, London.

Balzani, M., Maietti, F., Kühl, B.M., 2017. Point cloud analysis for conservation and enhancement of modernist architecture. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/ W3, 71–77.

Bartolomei, C., Morganti, C., 2022. UAV-Based Srvey: The Case of Colonia Varese in Milano Marittima. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* XLVIII-2/W1-2022, 15–22.

Ceccarelli, L., Bevilacqua, M. G., Caroti, G., Castiglia, R. B., Croce, V., 2023. Semantic segmentation through Artificial Intelligence from raw point clouds to H-BIM representation. *Disegnarecon*, 16(30), 17-1.

Chiabrando, F., Colucci, E., Lingua, A., Matrone, F., Noardo, F., Antonia, A., 2018. A European Interoperable Database (EID) to Increase Resilience of Cultural Heritage. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-3/W4, 151–158.

De Fino, M., Galantucci, R. A., Fatiguso, F., 2023. Condition Assessment of Heritage Buildings via Photogrammetry: A Scoping Review from the Perspective of Decision Makers. *Heritage*, 6(11), 7031–7066.

Giau, G., Maietti, F., 2024: Comparative Analyses Between Sensors and Digital Data for the Characterization of Historical Surfaces. In Giordano, A., Russo, M., Spallone, R. (Eds.) *Advances in Representation. Digital Innovations in Architecture, Engineering and Construction*, Springer, Cham, 707–725.

Gros, A., Guillem, A., De Luca, L., Baillieul, É., Duvocelle, B., Malavergne, O., Leroux, L., Zimmer, T., 2023. Faceting the post-disaster built heritage reconstruction process within the digital twin framework for Notre-Dame de Paris. *Scientific Reports*, 13(1), 5981.

Lanzara, E., Scandurra, S., Pulcrano, M., Acquaviva, S., Gallo, M., Palomba, D., Di Luggo, A., 2022: VPL for HBIM: Algorithmic Generative Processes for the Thematic Mapping of Information Models. In Ródenas-López, M.A., Calvo-López, J., Salcedo-Galera, M. (Eds.), *Architectural Graphics. Volume 1 - Graphics for Analysis*, Springer, Cham, 453–463.

Li, F., Achille, C., Vassena, G.P.M., Fassi, F., 2025. The Application of Three Dimensional Digital Technologies in Historic Gardens and Related Cultural Heritage: A Scoping Review. *Heritage*, 8(2), 46.

Maietti, F., 2023: *Superfici di Rilievo. Metodologie integrate per la conoscenza e la conservazione del patrimonio architettonico: documentazione, diagnostica e rappresentazione*, Maggioli Editore, Rimini.

Masciotta, M.G., Morais, M.J., Ramos, L.F., Oliveira, D.V., Sanchez-Aparicio, L.J., González-Aguilera, D., 2021. A digital-based integrated methodology for the preventive conservation of cultural heritage: the experience of HeritageCare project. *International Journal of Architectural Heritage*, 15(6), 844–863.

Mazza, A., 2010. Misura, cornice, torsione. La modernità di Mario Loreti. In Docci, M., Turco, M.G. (Eds.), *L’Architettura dell’“Altra Modernità”, Atti del XXVI Congresso di Storia dell’Architettura*, Gangemi Editore, Roma, 400–413.

Mulazzani, M., 2019. Holiday colonies for Italian youth during Fascism. *Docomomo Journal*, 60, 16–23.

Romão, X., Bertolin, C., 2024. Risk protection for cultural heritage and historic centres: Current knowledge and further research needs. *International Journal of Disaster Risk Reduction*, 67, 102652, 1-5.

Roussel, R., De Luca, L., 2023. An Approach to Build a Complete Digital Report of the Notre Dame Cathedral after fhe Fire, Using the Aioli Platform. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVIII-M-2-2023, 1359–1365.

Salonia, P., 2023. Cultural Heritage and Risk: Let's Give Intelligence to our Technologies. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* XLVIII-M-2-2023, 1387–1394.

Sesana E., Gagno A.S., Bonazza A., Hughes J.J., 2020. An integrated approach for assessing the vulnerability of World Heritage Sites to climate change impacts. *Journal of Cultural Heritage*, 41, 211–224.

Trizio, I., Brusaporci, S., Luigini, A., Ruggieri, A., Basso, A., Maiezza, P., Tata, A., Giannangeli, A., 2019. Experiencing the Inaccessible. A Framework for Virtual Interpretation and Visualization of Remote, Risky or Restricted Access Heritage Places, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/W15, 1171–1178.