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THE DEVELOPMENT OF A 2D/3D BIM-GIS WEB PLATFORM FOR PLANNED MAINTENANCE OF BUILT AND CULTURAL HERITAGE: THE MAIN10ANCE PROJECT

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KEY WORDS: HBIM, GIS, planned maintenance, multiscale database, web app, cultural heritage

ABSTRACT:

The integration of Building Information Modeling (BIM), or Historic BIM (HBIM), and Geographic Information Systems (GIS) has assumed a crucial role not only in the management of smart cities or urban districts, as well as in the construction sector or infrastructures but also in the management, conservation and safeguarding of cultural heritage. This integration opens up new opportunities for decision-makers to assess the impact of interventions on heritage sites, evaluate preservation strategies, and facilitate informed decision-making processes. This contribution presents and describes the open-source web platform developed within the Interreg MAIN10ANCE project. The project aims to promote a common methodology for the cooperation and collaboration of the various stakeholders involved in the restoration, management and maintenance activities of built and cultural heritage sites. This objective has been pursued by creating a BIM-GIS database, focused on the definition of planned maintenance activities, whose data has been made available to professionals and management bodies by means of a shared web platform, usable directly in situ on a tablet or portable devices. The paper highlights the key components of the web platform, including the BIM, GIS, and artifact Viewers, the Planner, and the overall Dashboard. The platform's multiscale and multi-source approach makes it extensible to various cultural assets, whether environmental, architectural, or movable. By integrating historical and geometric information and planning maintenance activities, the web platform thus supports public administrations and professionals, amending existing state-of-the-art solutions.

1. INTRODUCTION

The built, architectural and cultural heritage is often characterized by a complex and stratified set of objects which characterize its historical and aesthetic value. Equally complex is the management of these elements which increasingly sees the use of IT systems to improve the organizational processes linked to the world of programmed conservation.
When conserving and safeguarding cultural heritage, one of the main objectives is to find solutions that reduce and minimize interventions on the heritage over time without compromising the function of the asset, value, and authenticity.
Planned maintenance is the most suitable element for this objective, guaranteeing the persistence of the asset through the careful and accurate planning of the interventions. It must therefore be articulated with different aims and purposes according to the object on which it is necessary to intervene (the environmental context, the building, or the movable heritage contained therein). It needs to consider a temporal cadence that can prevent the onset of pathologies or risks that could affect the condition of the asset in the long term.
Starting from these premises, the web platform created for the MAIN10ANCE project (https://main10ance.eu/) is a service whose ambition is to facilitate the collection, archiving and visualization of a series of information describing the asset and its conservation, past and future.
This ambition was carried forward with the pilot case of the *Sacri Monti* system, a UNESCO serial heritage since 2003, as an emblematic case of the widespread heritage and of this complexity in which the external environment, the architectural envelopes and their interiors characterize their inestimable value and which has allowed the creation of an information system that can then be scalable in other contexts. In fact, in such contexts, one is necessarily called upon to respond to problems of managing a particularly complex heritage, which is characterized by elements belonging to very different domains, ranging from the work of art to the architectural complex, also including the element landscaped. For this reason, a case study was chosen as an example of the design and implementation of the platform presented. In fact, it presents interesting levels of complexity, which allow articulated problems and questions to be addressed, as well as to anticipate critical issues and problems related to management.
In this framework, the present research wants to present a web platform ad-hoc developed to store and update maintenance data and spatial information (both 2D and 3D) related to cultural heritage complexes.
The present work shows the web app and demonstrator integrating GIS (Geographic Information System/Science) and BIM (Building Information Modelling) data with restoration and

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maintenance information. It illustrates the work developments described in (Bonfanti et al., 2021; Colucci et al., 2022).
The methodology focuses on the functionalities of the app showing its utility. This workflow could be easily replicable and sharable in other contexts and on other built heritage. The paper presents one of the outputs of the MAIN10ANCE project described in the next paragraph. Then, some standards and software adopted have been described. Section 2 focuses on the methodology and the web app creation, implementation and use. Then, results and discussion are presented.

1.1 The MAIN10ANCE project

The Interreg Italy-Switzerland MAIN10ANCE project (2019-2022) set out to define a model able to implement the planned conservation and maintenance plan of the *Sacri Monti* (Sacred Mountains) of Piedmont and Lombardy in Italy, which are UNESCO sites, and those of the canton of Ticino in Switzerland. This model can then be widely expanded and adapted to other cultural heritage sites and assets widespread on the territory.
Through the 3D integrated metric survey (Mobile Mapping Systems, Unmanned Aerial Vehicles, Terrestrial Laser Scanners, etc.), it was possible to obtain the digital replica of the chapels of various *Sacri Monti*, of their contents (statues, frescoes, paintings, furnishings, etc.) as well as of the surrounding environment. HBIM models and GIS data were defined, starting from these data, and then merged into a single specially designed multiscale database capable of containing technical-diagnostic reports of the restorers, maintainers, and artisans (Colucci et al., 2022). Everything was made accessible through a web platform (Figure 1) so that it could be easily consulted online by operators of all sectors.
In particular, this method makes it possible to separate every single element (e.g. from the roof covering or roof frame up to the trusses or the single statues or paintings) and assign codified information to each one. For example, on a statue, it is important to indicate both ordinary maintenance interventions (such as removing the dust once a year) with relative times and costs, and extraordinary (such as for treating the wooden parts). Once the data has been uploaded, it is possible to build the maintenance and conservation plan with a clear definition of both the planned interventions and their relative costs.
In this contribution, the functioning of this web app is, therefore, detailed; its advantages and new elements are highlighted in relation to the state-of-the-art, as well as describing the potentialities for its adoption on other cultural heritage sites.

1.2 State-of-the-art: standards and software

The MAIN10ANCE database has a primary objective of ensuring interoperability among various representation scales, models, and platforms. A significant survey was conducted to explore the integration of GIS and BIM domains and environments, examining different standards and data models in both domains. Firstly, CityGML (https://www.ogc.org/standard/citygml/) is probably the most internationally recognized standard data model for representing multi-scale 3D information for buildings and cities. Additionally, several extensions have been developed for different domains called Application Domain Extensions (ADE). On the other hand, INSPIRE (Interoperable Spatial Data Infrastructure in Europe, https://inspire.ec.europa.eu/inspire-directive/2) is the European directive (published in 2007 and mandatorily adopted by all European countries in 2020) aimed at creating an interoperable territorial data infrastructure in Europe. The standard aims to represent homogeneous cross-border.
Regarding architecture, engineering, construction, as well as resource and facility management, the Industry Foundation Classes (IFC, https://www.buildingsmart.org/standards/bsi-standards/industry-foundation-classes/) is the standard designed for Building Information Modeling (BIM). The IFC standard, certified by Building SMART, provides an object-based view of the model, including 3D and 2D geometries along with the relationships between objects. It aims to represent parametric information.
In the project and the present research, all the standards mentioned above have been adopted for database creation and developed as the basis for the web app.
n the framework of the state-of-the-art works on BIM-GIS integration, over the past decades, several studies, such as Osello & Rinaudio (2016), emphasize the need to bring together these

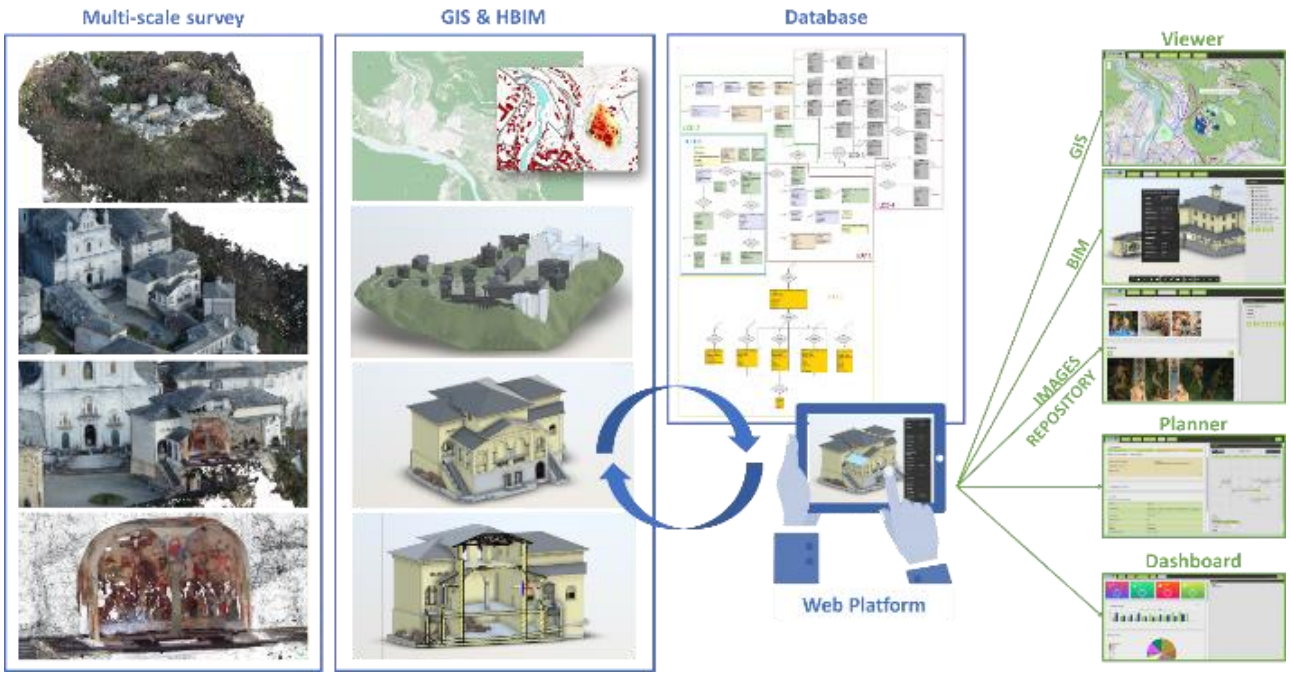


Figure 1. Overall workflow of the MAIN10ANCE project (blue) and the subdivision of the different functionalities of the web platform (green) to support the planning of the maintenance activities.

two different domains for various purposes and analyses.
The main objective is to communicate and share information at different scales of territorial representation, urban areas, and buildings, which underpin the development and transition of the architecture, engineering, and construction (AEC) industries in the digital era.
Their integration is not a new idea (El Meouche, et al., 2013; Del Giudice, et al., 2014; Fosu, et al., 2015; Amirebrahimi, et al., 2016) and has been the subject of international benchmarks like GeoBIM (Noardo, et al., 2019), where conversion procedures between IFC and CityGML have been studied. The potential applications for smart cities, sustainable environments, or the construction sector are just some of the multiple positive implications (Månsson, 2015; Wang et al., 2019; Song, et al., 2017). However, relying on a unified database conforming to standards that combines the informational layers of both environments represents a relatively new approach.
Studying the applications of BIM and GIS, one of the initial challenges to address is how to achieve technical integration. Although the main incompatibilities between BIM and GIS systems have been partially resolved, most interoperability issues arise when converting data between their standard data formats. Among the various BIM-GIS data format conversions, we can identify the first approach proposed a decade ago by the Open Geospatial Web Services (OGC) for CAD-GIS-BIM integration. It defined the requirements to link AEC data models and workflows with those of the geospatial community to make BIM objects available in standards such as CityGML. The development of CityGML aims to achieve a standardized definition of entities, attributes, and basic relationships in a 3D city model. Multiple geometries can be associated with the same object to achieve a time-based representation, different reconstruction hypotheses, or different levels of detail (LoD), as described in the following paragraph. On the other hand, the data schema architecture of IFC in the BIM domain is based on a higher level of detail and defines different conceptual layers, with each schema precisely assigned to a conceptual layer.
Likewise as presented in (Bruno et al., 2020) with the Chimera project, this web platform is LoD-based, integrates different kinds of data at various scales (images, shapefiles, BIM models and raster data such as digital elevation models – DEM), relies on a PostgreSQL database, and ensures the possibility to store historical and time-series data. However, it also encompasses the opportunity to:

- plan the interventions and maintenance activities through a specific Planner (section 2.2.2) that takes into account both their frequency and costs;
- visualize the trends of actions and the behaviours of the buildings and artifacts through a dashboard (section 2.2.3), where future sensor data could be managed too;
- work with a common language (glossary) and methodology (*risk phrases* – section 2.2.2), developed during the project, that enables the various restorers, artisans, professionals and management bodies to act in a univocal and coordinated way.

2. METHODOLOGY

2.1 The database and structure behind the web platform

The web platform described in the next section is based on a multiscale database structured according to a LoD subdivision (Colucci et al. 2022). It comprises the surrounding context data (LoD 0), the volumetric description of the buildings and units (LoD 1 and 2), the BIM modelling of the architectural heritage and outdoor environments (LoD 3), the images related to the indoor statues, artifacts, painting, frescoes, etc. (LoD 4), and, finally, the information and technical reports on the restoration activities, as well as those concerning the planned maintenance and risks (LoD 5).
Both commercial and open source software has been adopted. For the database creation PostgreSQL (https://www.postgresql.org/) has been used as open source object-relational database system together with PgAdmin interface. Then, thanks to the PostGIS (https://postgis.net/) spatial extension the 2D spatial data, at the territorial and framework scale have been added to the geo-database structure.
The BIM modelling has been carried out at different scales through Autodesk Revit, while for the web app, Autodesk Forge, a set of web service APIs to build cloud applications, is used as a container for the BIM models and for the libraries. Several libraries, both for frontend and backend, have been used for the application (visualization part) and to upload the BIM models, which get stored on the Autodesk Forge's own servers, in addition to the conversion of the models themselves into .svf file format, in order to be compatible with the 3D viewer on the browser. All the libraries are open source and have been installed through the *npm* (Node Package Manager) utility. *Supabase*, an open-source service for database storage, as well as for the images and documents contained in the application, has been chosen to contain the database itself.

2.2 The web platform

The platform provides various operational tools to support professionals to manage an asset's scheduled conservation plan in an optimized way, starting from ad hoc interfaces for multi-scale visualization: two-dimensional maps, three-dimensional models and images describe the asset from a geometric point of view and alphanumeric information which instead describe the personal data and the conservation-oriented activities necessary for the same. The interface (client side) thus allows interaction with the database (server side) in such a way as to be able to view, insert, modify and query a series of data in a structured and organized way so that they can be translated, at a later time, in useful information for understanding the progress of the Maintenace Plan and possibly optimizing the process.
To use the platform, the interested user does not need to install any software or license, in fact the use of the service and the source code are totally free to access. Furthermore, being web-based, the service can be used anywhere via a simple Internet connection via browser, accessed via any device, from a workstation to a tablet or mobile phone. This makes it possible to optimize the use of the data, even in the field, and with a real-time update, improving the collaboration of users, who can be multiple and different in terms of scope and objectives.
The prepared application is designed to be used by anyone, supporting different types of users with specific roles and tasks. The interface adapts to the needs of each user by providing them with the most appropriate tools. For this reason, the possibility of login has also been set up as well as different levels of authorization, each of which, depending on the role held, is provided with the possibility of viewing or not viewing certain information and of using or not using certain tools. In particular, three macro-categories of users have been envisaged.
The *tourist*, a user typically interested only in tourist aspects who are not required to register, is not allowed to view sensitive data characterizing conservation activities, but is allowed to use the property through viewers. This allows the service to be configured as a site promoter, with the exploration of maps, for a better understanding of the site, and the navigation of three-dimensional models, which can be functional for preliminary, supplementary or even alternative visits should the user need to be subject to a particular fragility.

The second type of user is that of the *operator*: it is the typical figure that brings together all the different professionals involved in conservation activities, such as maintainers and restorers, who can use the viewers but also information related to the activities on the asset. In fact, they can view the activities assigned to them, edit and enter new data relating to the activities performed. For this reason, they are registered users with this role, have access credentials and fall within a specific area of interest, i.e. a form that allows them to view and modify only the data relating to the asset or activity assigned to them. This also ensures the privacy, security and reliability of the data present and entered into the system.

Finally, the *manager* is the figure who administers, manages and controls all the data having the ability to access additional tools and features that allow you to intervene not only on the modification of individual data but also on the modification and optimization of the entire process of conservation, according to the return information visible in a dashboard which, through appropriate graphics, allows you to supervise the set of data relating to the assets under your responsibility. The platform is therefore designed to adapt to the needs of these different types of users, offering specific features and tools for each category.

The platform has been structured in such a way as to provide the flexibility given by being able to be used at any time: once digitized and inserted into the platform, the asset subject to programmed conservation can in fact find itself in an ideal t_0, for which all its elements are in a good state of conservation and it is therefore necessary to plan only the cyclical control and maintenance activities, i.e. those subject to specific frequencies and articulated on a regular basis over time; alternatively, the asset could find itself in difficult situations or in uneven conservation: in such cases it is possible to plan corrective, extraordinary maintenance and restoration activities, defined by the authors as "realignment activities", to restore that ideal t_0. These activities can also be programmed during construction in order to temporarily make an element flow outside the regular control and maintenance cycle and subsequently return it once the realignment activity has been completed.

For the use of the application, there are some necessary prerequisites for the correct execution of the entire process. They are diverse and include the filing and identification of significant components, the survey and creation of a support digital model and the accurate risk assessment of the asset and its elements. The process itself begins with the important phase of component identification and classification, a fundamental phase which determines all subsequent work phases. It is important to have created a BIM model associated with the data contained in the database, since the geometric interaction and the bidirectionality of the data between the real object and the database play a key role. Since the focus is on maintenance and preventive response to specific phenomena, it is essential to structure an assessment of the risks to which the managed assets are exposed. This allows you to optimize the planning of activities based on these risks, in order to ensure effective and targeted management. It is important to note that once the process has started, going back can be extremely costly, so the accuracy and completeness of the initial steps in the process are of vital importance.

The platform offers various tools to support users in the asset management process. Among these tools, there are three *Viewers*, a *Planner* and a *Dashboard* (Figure 2).



Figure 2. Upper panel of the platform with the five tools: three viewers, a planner and a dashboard.

2.2.1 The viewers

The three Viewers allow users to view data related to specific domains: GIS, BIM and artifacts and mobile works. These viewers are accessible to all users and provide an intuitive interface for exploring and analyzing data related to each domain.

In the GIS viewer (Figure 3), the various shapefiles and digital terrain models can be queried and visualized, such as the building footprints, the vegetation, contour lines, water bodies and rivers, road networks and so on. These elements permit conducting environmental analyses, and studying the context in which the heritage is located.

The BIM viewer (Figure 4a) grants a further level of detail with the possibility to query the geometries (Figure 4b), section the model (Figure 4c), measure them (Figure 4d), and cluster by architectural typology and category (Figure 4e).

It is thus possible to explore the dimensional and distributive characteristics of the building in detail. Interested users can take a virtual tour of the property, closely observing the elements and their peculiarities and questioning their properties. This approach also allows you to access and delve into environments that may not be easily accessible in a traditional visiting context. These tools are aimed at both tourists and operators, being in the latter case a sort of preliminary patrol which can be of great use in view of scheduled inspections.

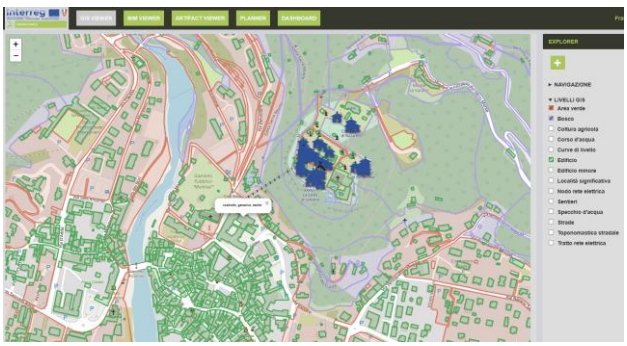
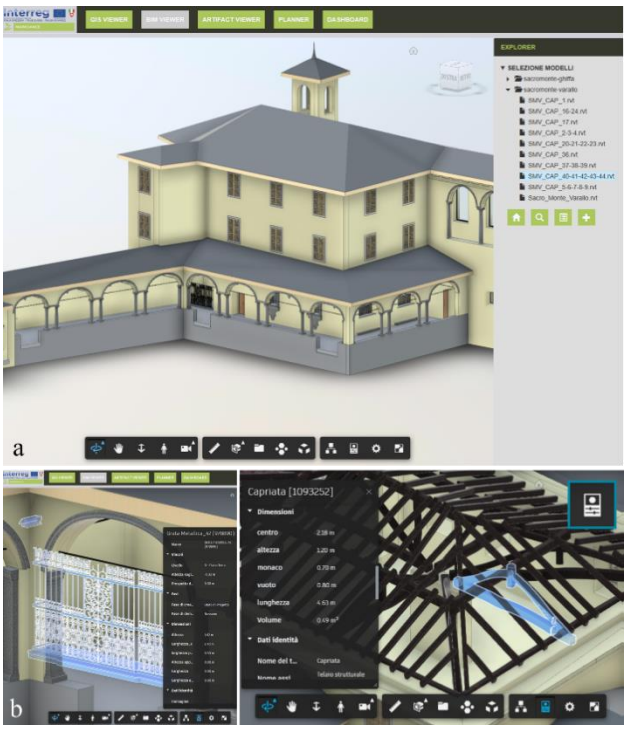


Figure 3. GIS viewer with the selection of some shapefile and query of one element.



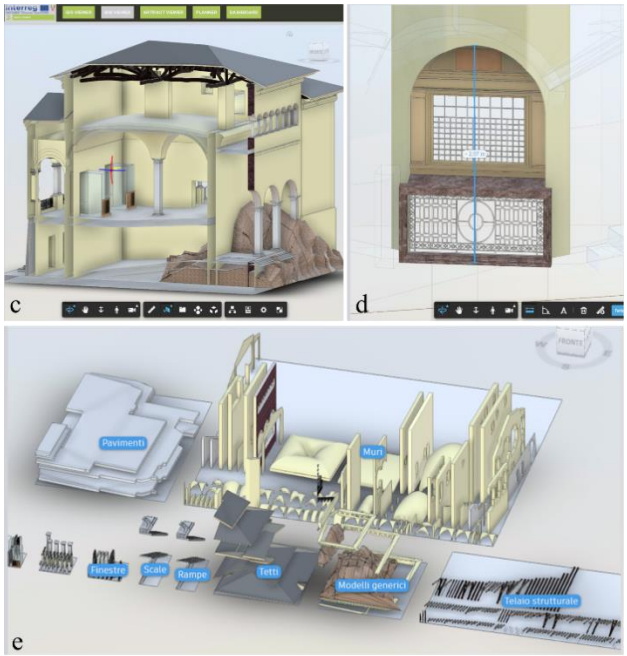


Figure 4. BIM viewer.

A registry form is then associated with each element of the HBIM models, containing further descriptive information (Figure 5).



Figure 5. Selection of a marble portal with a registry form for the insertion of further information.

Finally, the Artifact viewer contains the images, with possible related reports, of the indoor features of the chapels, such as statues (Figure 6), frescoes or paintings. The Gallery is organized as follows: *place* (selection of the whole historical complex), *building* (selection of a single building), and *category* divided into furniture, wall painting, decorative floor, picture or statue.

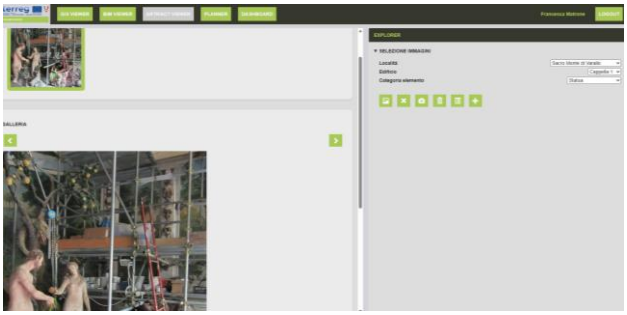


Figure 6. Artifact viewer with the selection of the statue category within Chapel 1 of the Sacro Monte di Varallo complex.

2.2.2 The Planner

The Planner, differently from the viewers, is an option available only to operators and managers. It allows to manage the planning and scheduling of activities. Thanks to a tabbed structure and a calendar of scheduled events, users can effectively manage heritage-related activities.

The LoD 2 of the entire selected complex is directly displayed within the Planner, and it is possible to enter data in five different sections: *planning*, *scheduling*, *ex-tempore* interventions, *execution* of activities and their *history* (Figure 7).

Planning and scheduling, although they look similar, are actually two consecutive phases. In detail:

- the *planning* section includes more general activities, in which the manager decides the interventions based on generic categories (soil, vegetation, roofs, walls, windows, floors, statues, etc.). Each of these categories is associated with different risk phrases, which can be selected and compiled individually, and describes the type of control or ordinary maintenance to be carried out.

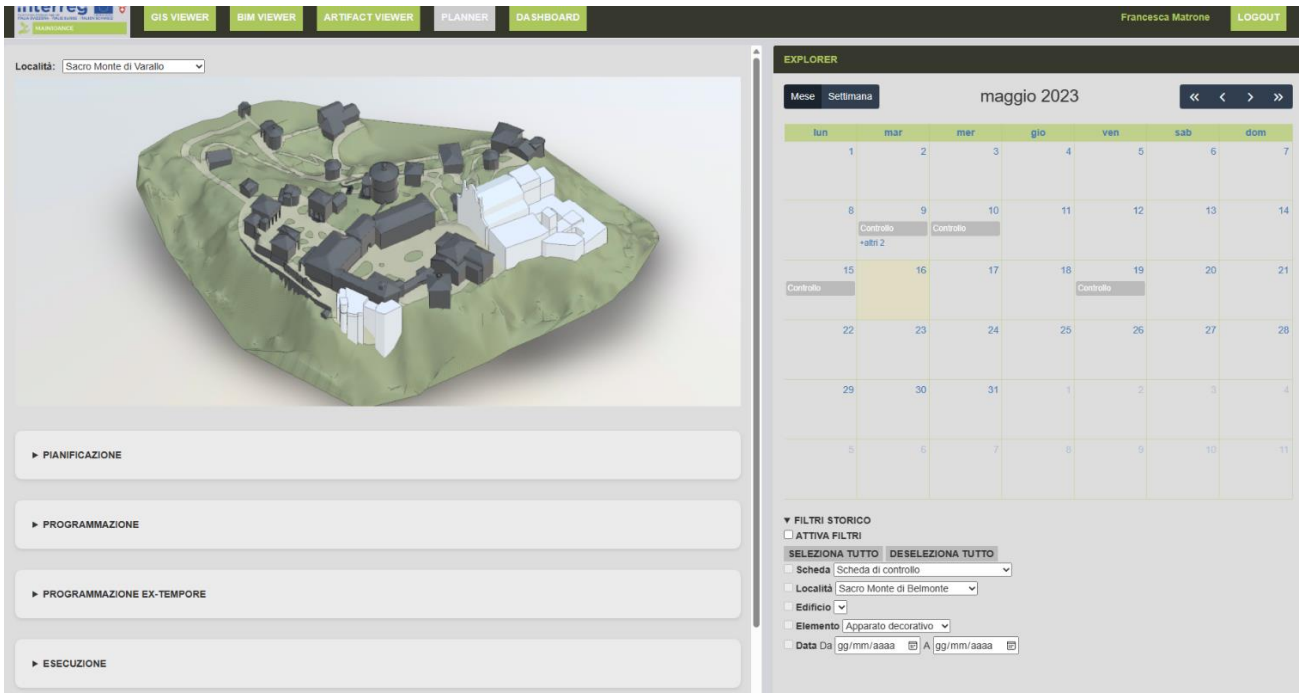


Figure 7. Planner panel with four of the five sections (left) and the calendar with the scheduled activities (right).

In addition, the frequency of interventions and the beginning of the activity planning cycle are also included. This panel, therefore, includes a set of activities to be performed with a certain regularity, e.g. periodic supervision;

- the *programming* section concerns individual activities, and specific events, not on generic categories and classes, but on each environmental, architectural or decorative element. Activities planned here are *cyclical*, which consist of regular control and maintenance, and *realignment* activities, namely interventions deriving from any problems encountered during the in situ checks;
- *ex-tempore* section allows the scheduling of extraordinary maintenance activities or immediate interventions caused by exceptional and unforeseen events or conditions;
- the *execution* section records the information regarding the interventions in progress, which will then flow, once completed, into the *history* section.

Data here filled in are automatically saved and stored in the database.

2.2.3 The Dashboard

Finally, the dashboard is reserved exclusively for the manager. It provides an overview of the state of the managed assets and the general trend of the activities. Through this dashboard, the manager can monitor crucial information in real-time, allowing for better supervision and management of assets. Overall, the designed tools offer users a multiplicity of specific tools for visualization, planning and monitoring of assets, allowing for more efficient and optimized management.



Figure 8. Overview of a part of the Dashboard.

On the other hand, in the case of use by the operator in charge of conservation activities, once they have logged in, they can access the advanced tools dedicated to maintenance activities.
The main access point is the Planner, which acts as a container for all the control and intervention sheets recorded up to that moment for the various elements of the asset. In addition, the Planner also lists activities planned for the future, providing a starting point for new registrations and activity documentation. The same interface is available for each card category, allowing users to consult all previously registered cards for a given item. These tabs are sorted by category and displayed chronologically, giving you a complete overview of past activity.
It is important to underline two key features of the platform: first, the calendar provides a temporal view of the distribution of activities, allowing users to plan and manage activities according to their chronological order; secondly, the geometric interaction and bidirectionality of the data play a fundamental role.
Users can easily navigate between model tabs and elements, allowing for a seamless flow of data and information between the two parties.
Collectively, these advanced tools provide authorized users with a complete and interactive overview of conservation activities, making it easy to plan, record and analyze them for both past and future ones.

3. DISCUSSIONS AND CONCLUSIONS

The web platform described is an output of the Interreg MAIN10ANCE project. It offers a number of benefits that make it a valuable and interoperable tool for several reasons.
First of all, it permits the management of multi-scale and multi-source data. Then, it optimizes control and maintenance activities, ensuring efficient and targeted supervision of the necessary operations. This entails a considerable advantage from an economic point of view, avoiding financial burdens and costly as well as invasive restoration operations.
Another relevant aspect is accessibility: being web-based and open source, it is easily accessible to everyone and does not involve licensing or subscription costs, making it an economic solution within the reach of anyone who wishes to use it. Furthermore, the interface is designed to be intuitive and easy to use, allowing users to interact easily and immediately with the elements of the models. A key element of the platform is the possibility of fostering collaboration between different professionals involved in the management of the property. As mentioned above, it makes it possible to manage information of a multi-scale and multidisciplinary nature, allowing experts from different areas to contribute their knowledge and share it directly in situ through a tablet or mobile devices (Figure 9).

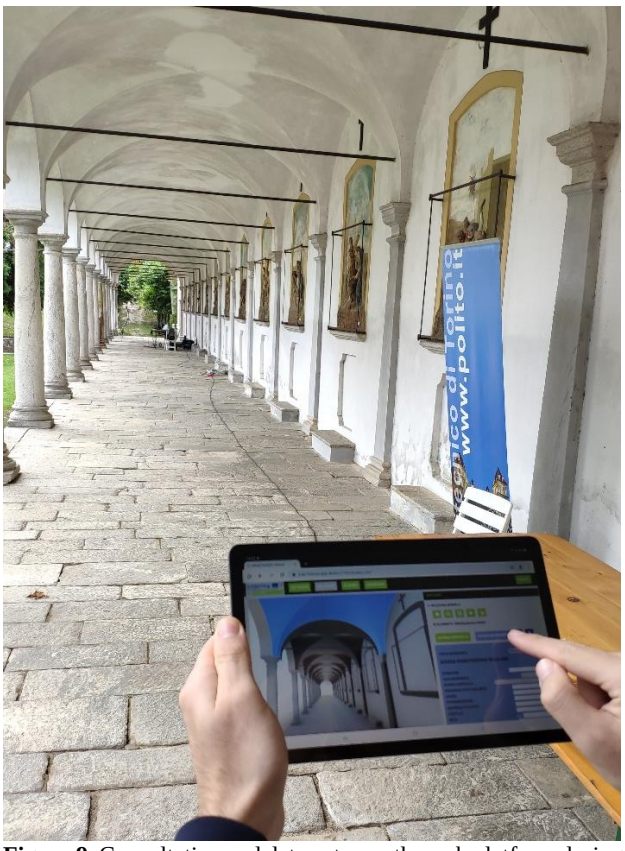


Figure 9. Consultation and data entry on the web platform during an inspection.

Finally, it also stands out for being participatory: to access it, you just need to register and enter your digital asset; this openness favors the participation of a wide range of interested users, helping to create a community of professionals who can share and mutually benefit from information and experiences.
In conclusion, it should be emphasized that the platform has been designed with an approach of continuous growth over time. A fundamental aspect is the active involvement of users, who provide valuable feedback which is used for the integration and constant improvement of the system. The opinions, requests and experiences of users are considered of great importance for the evolution of the application presented here. In summary, the platform is not just a finished product, but an ever-evolving process. This allows you to create a solution that is increasingly suited to the needs of users and to keep the platform up to date with the changes, challenges and emerging innovations in the field of asset management.
A future development of this work will be the inclusion of dynamic sensors data to enhance and boost the accuracy of the planned activities.

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