INTEGRATED DIGITAL PLATFORMS FOR THE DOCUMENTATION AND MANAGEMENT OF CULTURAL HERITAGE AT RISK

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ABSTRACT:

Research definition of strategies and instruments for the prevention, mitigation, and management of hazards resulting from natural or man-made catastrophes is increasingly experimenting with an integrated approach to the digital documentation and visualisation of the built and cultural heritage. In actuality, recent conflicts and events, as well as the rise in natural disasters in previously unaffected regions, demonstrate the growing interest of governments, public administrations and entities, as well as academics, in the development and preservation of the digital memory of man-made landscapes. However, the management of recent catastrophic events allowed for the development of techniques that today enable the transfer of tools and processes from emergency management to routine management.

Based on data from recent earthquakes in northern Italy, the current work describes some outcomes of the development of an integrated digital platform for seismic risk management that aims to integrate historical data from previous seismic events, data from existing databases, integrated digital surveys, carried out using integrated survey techniques, and semantically enhanced BIM-based models. The tool is being created as part of a transnational research cooperation initiative with thirteen partners from nations and regions along the Adriatic Sea. The program's overall goal is to improve cross-border emergency services while also raising their degree of safety and efficacy.

1. INTRODUCTION

In the contemporary debate concerning the management of the risk related to the effects of natural and anthropic events on the built heritage and, even more, on the cultural heritage, the awareness of the role and value that an organised, shared and accessible integrated digital knowledge plays in the processes of emergency management, securing and reconstruction defines new methods, tools and operational protocols that have direct consequences, finally, also on the processes of management and valorisation of the assets.

Calamities, natural or man-made, do not respect national borders and can have a transnational dimension. Natural hazardous and climate-related disasters disregard political borders, where additional barriers can complicate mitigation, response and recovery efforts (Booth, 2020).

The awareness mentioned above led States to first provide themselves with a framework of agreements and negotiations that is continuously being updated, and then to enhance it. The new Senday Framework for Disaster Risk Reduction 2015–2030, or SFDRR, is the product of strategic directives being shared globally with the following objectives: Reduce disaster damage to critical infrastructure and disruption of basic services; Increase the number of countries with national and local disaster risk reduction strategies; Enhance international cooperation to developing countries; Increase the availability of and access to multi-hazard early warning systems.

As highlighted by several research (Briceño 2015; Manyena 2016), the effectiveness of the SFDRR was questioned because of the limited impact and benefits provided by its implementation in different countries. The implementation does not address the root-cause of disaster which are highly connected with weak governance arrangements and non-risk informed development. Despite the development concept is present in the targets settled, the measurement is targeted to respond to disaster event instead of preventing the cause (Chmutina, 2021).

Equally significant for the definition of strategic guidelines and international cooperation on the issue of risks appears to be the Grand Bargain: Agenda for Humanity, to the implementation of which, in operational terms, the same barriers mentioned above contribute, according to various studies (Grand Bargain, 2022). The adoption of efficient risk management strategies is also challenged by the efficient implementation of energy policy (Valagussa, 2021).

Climate change is responsible of an increase in the frequency of hydrometeorological disasters such as decreased water availability, forest, and land fires. The natural disaster frequently occurring in the last years are the results of combination of complex issues caused by larger environmental, social and economic changes. Consequently, a resiliente approach is a global challenge faced by all with local, subnational, national, regional, and international dimension (Article 7, par.2) (UNFCCC, 2022), as further specified in the 2030 Agenda goals.

Space-based technologies, and satellite-based positioning technologies, such as meteorological and Earth observation satellites, communication satellites, as well as integrated digital survey technologies can be an essential tool as evidenced in past practice22 in order to facilitate the widespread and rapid use of terrestrial and satellite communication facilities to predict, monitor, and respond to major disaster through the world.

2. RELATED WORKS

Following the 2012 Emilia-Romagna earthquake, the TekneHub Laboratory and the DIAPReM Centre of the University of Ferrara set up a set of post-graduate training and research projects in partnership with the Agency for Reconstruction - 2012 Earthquake, Emilia-Romagna Region, in order to create a

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common framework for the development of protocols and integrated digital tools for the documentation of cultural heritage and built heritage damaged or at risk.

The interdisciplinary research group includes scholars and experts in a variety of fields related to cultural heritage, from the governance of complex events, to the protection and conservation of cultural heritage, and the application of integrated technologies for survey, digital documentation and project, and addresses strategic innovation objectives of the construction supply chain in the regional context: promotion of digitization of the value chain of intervention on existing built heritage by contributing to the adoption of tools to support decision-making and intervention processes, including through Big Data.

The actions implemented within the framework of common objectives are: doctoral projects focusing on specific types of cultural heritage damaged by the earthquake; research collaboration within the Interreg Italy-Croatia project “FIRESPILL, Fostering Improved Reaction Of Crossborder Emergency Services And Prevention Increasing Safety Level”, within which this work is partly developed; post-graduate training projects, in the form of international summer schools; After the Damages Academy, dedicated to built heritage at risk as a result of natural or man-made events; joint participation in international research/cooperation calls financed on a competitive basis. Overall, the initiatives are aimed at identifying solutions and best practices for enhancing cultural heritage resilience (United Nations, 2015).

3. DEVELOPED METHODOLOGY

Within the framework of the collaboration between the University of Ferrara, Department of Architecture, TekneHub Industrial Research Laboratory and the 2012 Earthquake Reconstruction Agency, case studies of digital documentation of cultural assets damaged by the 2012 Emilia-Romagna earthquake are implemented. The objective is the optimisation of a documentation protocol and the development of integrated digital information tools for a more effective risk management.

The Emilia-Romagna earthquakes, 20-29 May 2012, are the strongest earthquakes occurred in recent times. The earthquake that struck Abruzzo on April 6, 2009, was magnitude 6.3, and caused 308 casualties. Another major earthquake affected Emilia-Romagna, Italy, Lombardy, and Veneto on May 20 and 29, 2012 (magnitude 5.9), and killed 27 people. Earthquakes also have a major impact in economic and social terms. On May 20, 2012, at 4,03 PM, an earthquake of magnitude 5,9 with an epicenter in the town of Finale Emilia had affected a wide area causing damages in the provinces of Modena, Reggio Emilia, Bologna, Ferrara, Mantua, and Rovigo.

A second earthquake hit the same spot-on May 29 at 9.00 am with 5.8 magnitudes of intensity. Other shocks greater than magnitude five were recorded in the following hours of the same day.

There have been 27 victims, 400 injured, and more than 15.000 displaced in the two main events. Six relief camps were set up in the province of Modena, 2 in Mantua, one in the province of Ferrara, and one in Reggio Emilia. According to the seismic risk map, the site is in a low seismic risk areaThe emergency management was entrusted separately to the regions of Emilia Romagna and Lombardy, which used their personnel and volunteers from the two regions.

There was a great deal of work to assess the post-seismic fitness of the residential structures involved.

The earthquake, however, affected many production facilities, both industrial and agricultural, highlighting a legislative deficiency regarding the anti-seismicity of large, prefabricated structures.

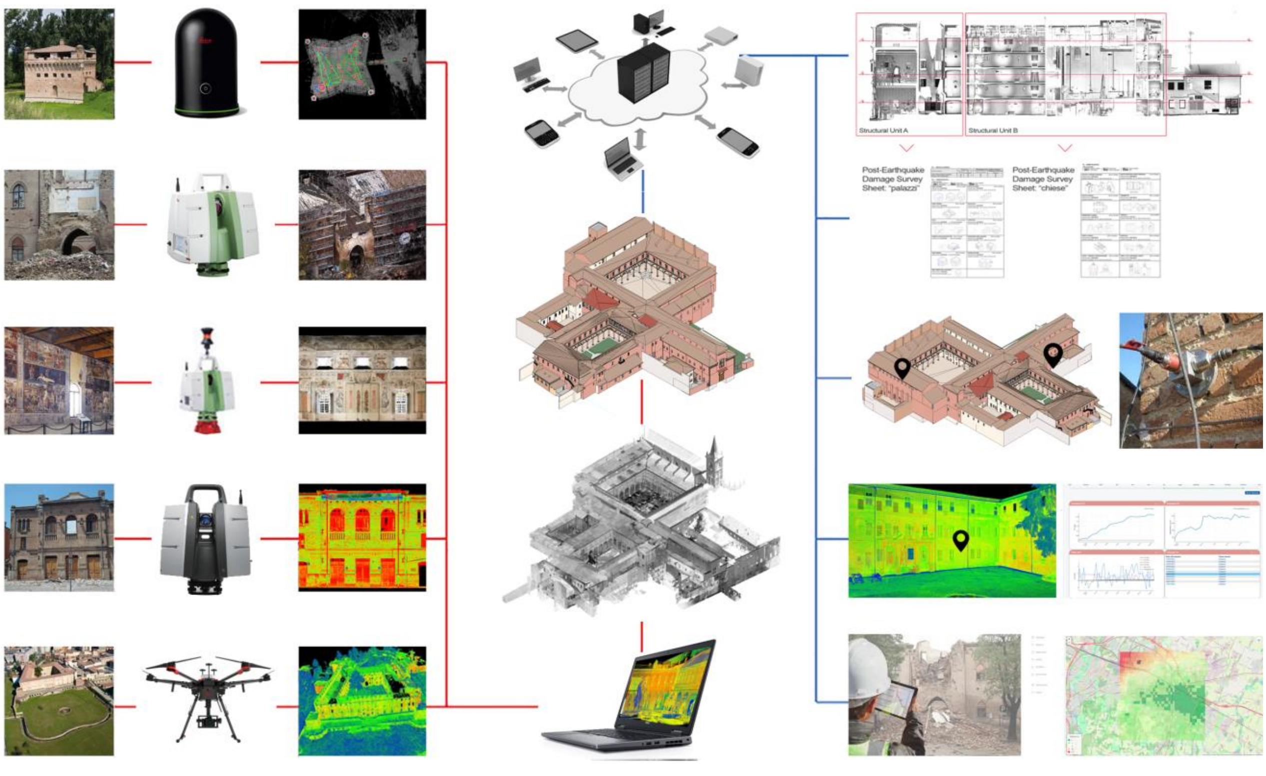

Figure 1. Integrated 3D seismic damage survey protocols.

The lack of availability of even a specific form for the analysis of the post-seismic agility of prefabricated structures has put the evaluation system in crisis and a particular improvisation of operations. The regulatory gap has been filled with a specific DM that should address the reconstruction.
More than 1,000 structures sustained serious damage, resulting in increased cost and time for managing the emergency, conducting damage assessments, and completing the ensuing phases of reconstruction.
The Emilia-Romagna Region established a temporary body, the Joint Commission, to support the joint approval of projects and reconstruction works by all the bodies responsible for governing the territory because of the risk of further escalation in terms of time and costs for the management of the post-emergency phases.
The Emilia-Romagna Region, the 2012 Earthquake Reconstruction Agency, the Architectural and Landscape Superintendence, and the Mayors of the municipalities in the crater region make up the Joint Commission.
Recent developments have enabled a thorough investigation of the efficacy and opportunities for implementation of the tools adopted to transfer the lessons learned into regular daily management.
This has been made possible by the innovative approach used for the integrated evaluation of projects and management of funding developed after Emilia-Romagna earthquake 2012.

3.1 Integrated digital platform for Cultural Heritage at risk

The geo-spatial management of public assets, in particular strategic buildings such as public offices and museums, can today rely on the application of BIM methods and technologies that can potentially integrate into a digital data model, digital twin, different sources of information related to factual, design and maintenance states of the building that change over time. However, the need to allow multi-scalar approaches and readings to the intervention project on the existing building, as well as the construction of alternative scenarios in order to evaluate the effectiveness of the planned actions, already highlights limits in the authoring environments related to the degree of customisation and information implementation, as well as the modelling of complex geometries, which push for the adoption and implementation of innovative digital environments.
However, it is the advent of integrated digital collaborative platforms (Psenner, 2021) that opens up the possibility of representing, conserving and diachronically comparing digital models that refer to different evolutionary phases of a building, the urban fabric (Centofanti, Brusaporci, 2013), a city and a landscape (Docci et altri, 2007).
Representation guides and orients, in this sense, through the processing of three-dimensional models, within complex data structures (Gaiani, 2011), and makes available new forms of representation, becoming an integral part of the information and communication process.
Consequently, cultural heritage and built heritage at risk due to natural or anthropogenic events become the context for experimenting with the development of an optimised protocol for 3D digital documentation, and not only of the intervention.
The methodology developed and illustrated in this paper defines the aims of the intervention to be of primary importance, together with the metric and morphological characteristics of the cultural heritage and existing built heritage under consideration. In fact, the cultural heritage and the built heritage present characteristics of uniqueness and complexity not only in relation to geometry and material characteristics.
The multiple sources of information, the plurality of investigations, the historical documentation and the representations necessary to support the intervention on built heritage require, on the one hand, that the information be accessible to more specialised users with diversified skills and, on the other, that synchronic readings of diachronic scenarios be allowed.

3.2 Toward a protocol for 3D documentation of Cultural Heritage

In Emilia-Romagna in May 2012, a seismic swarm caused serious damage to hundreds of cultural assets. Particular damage and recurrent collapse mechanisms occurred to churches, theaters, palaces, cemeteries, and fortified buildings. However, the damage survey phase that came after the emergency was handled immediately brought to light how inadequate the equipment used for the assessment (Chiabrando , 2017) were for such a vast number of destroyed buildings.
In fact, several inefficiencies at a procedural and interpretive level will be highlighted by the use of the codified damage and vulnerability assessment methods to the relief of the impacts of the 2016 Central Italy earthquake.
The events of May 2012 also brought to light flaws and inefficiencies, particularly about the evaluation of cultural heritage damage.
The methods that are still in use today can be divided into categories based on the subject (to date, only "Churches" and "Palaces" forms), assessment objective (damage, agibility, vulnerability), elements assessed (structural components, macro-elements, local collapse mechanisms), method of obtaining evaluation (score, outcome tree, etc.), assessment scale, (territorial, urban, compartment, individual building) (Vafadari, 2017). The same worksheets show variations in the method used to survey the constructed heritage for the two building types –churches and palaces– which are the only ones covered. On the one hand, factors including masonry quality, load-bearing vertical structures, and collapse mechanisms are evaluated. The latter one on the other.
Extending the method to the analysis of different building types, the experience of the 2012 earthquake shows that it was left up to the volunteer professionals employed in the survey operations to decide whether to use one or the other or, possibly, both forms for different portions of the same building.
The management of the disaster response, damage survey, and reconstruction process was primarily conducted with analogue tools, with the production of redundant data and poor integration and interoperability with already in use tools, in addition to the characteristics of the tools adopted described above.
Damage survey, management of survey teams, data collection, data modelling for the verification of the subsequent phases of work authorisation, granting of financing and site management are phases that are overall managed according to a traditional and poorly digitised approach.
The experience of the 2012 earthquake has therefore led to the identification, in the context of the relationship between the Emilia-Romagna Region, the Agency for Reconstruction, and the TekneHub laboratory, University of Ferrara, of strategic collaboration objectives such as: the development of pilot cases for updating damage survey forms; the development of integrated digital tools to support damage survey, in the emergency phase, and risk management in the ordinary phase.

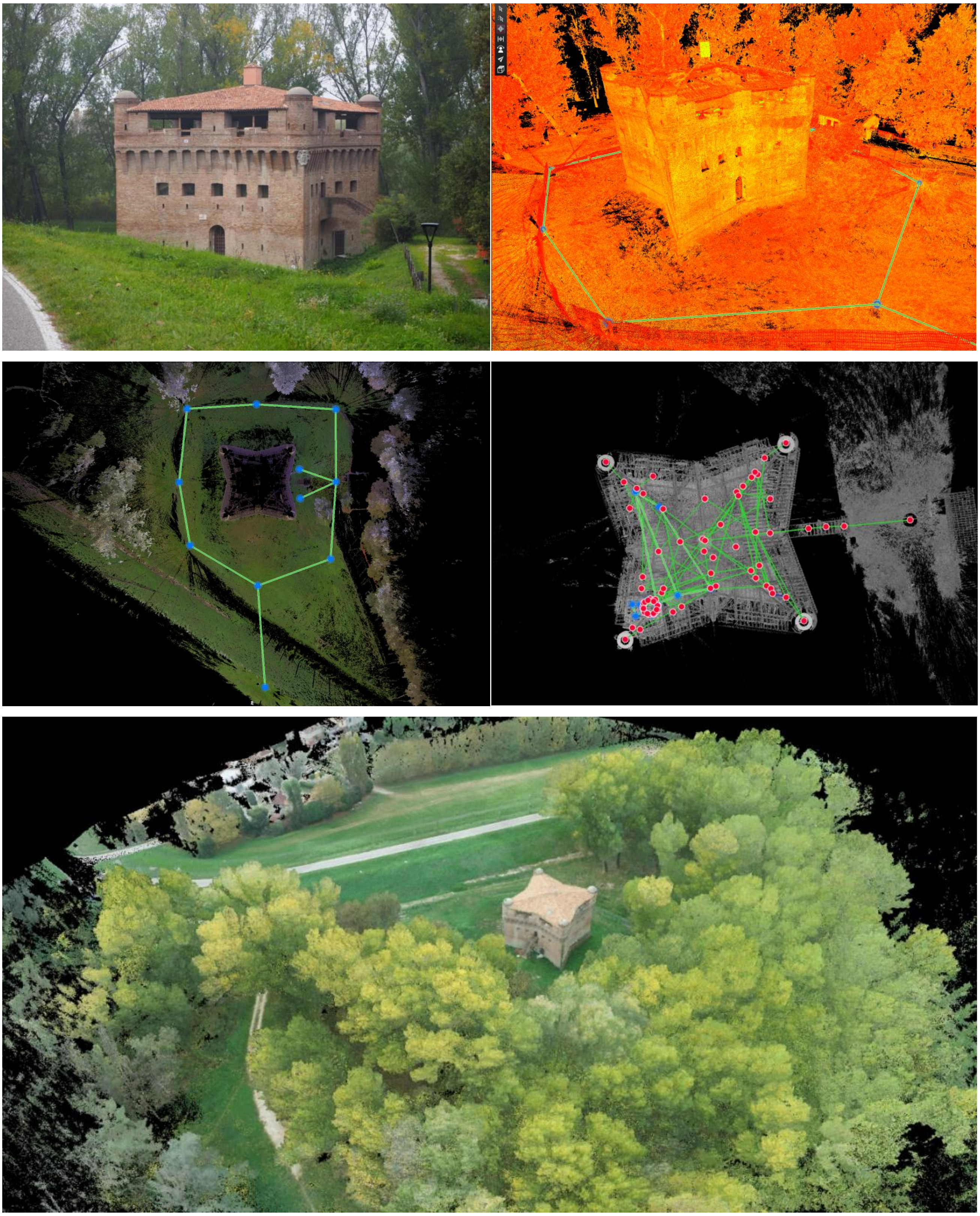

Figure 2. Integrated three-dimensional digital survey of earthquake-damaged cultural heritage. Rocca Possente, Stellata, Italy.

3.3 Integrated digital tools for damage assessment

Intervention on the built heritage requires the application of multi-scalar analyses.

Historical research, seismic history of the building, or of the urban fabric, on-site inspections and tests, assessment of intervention compatibility, investigations of materials and techniques, etc., are essential sources of information.

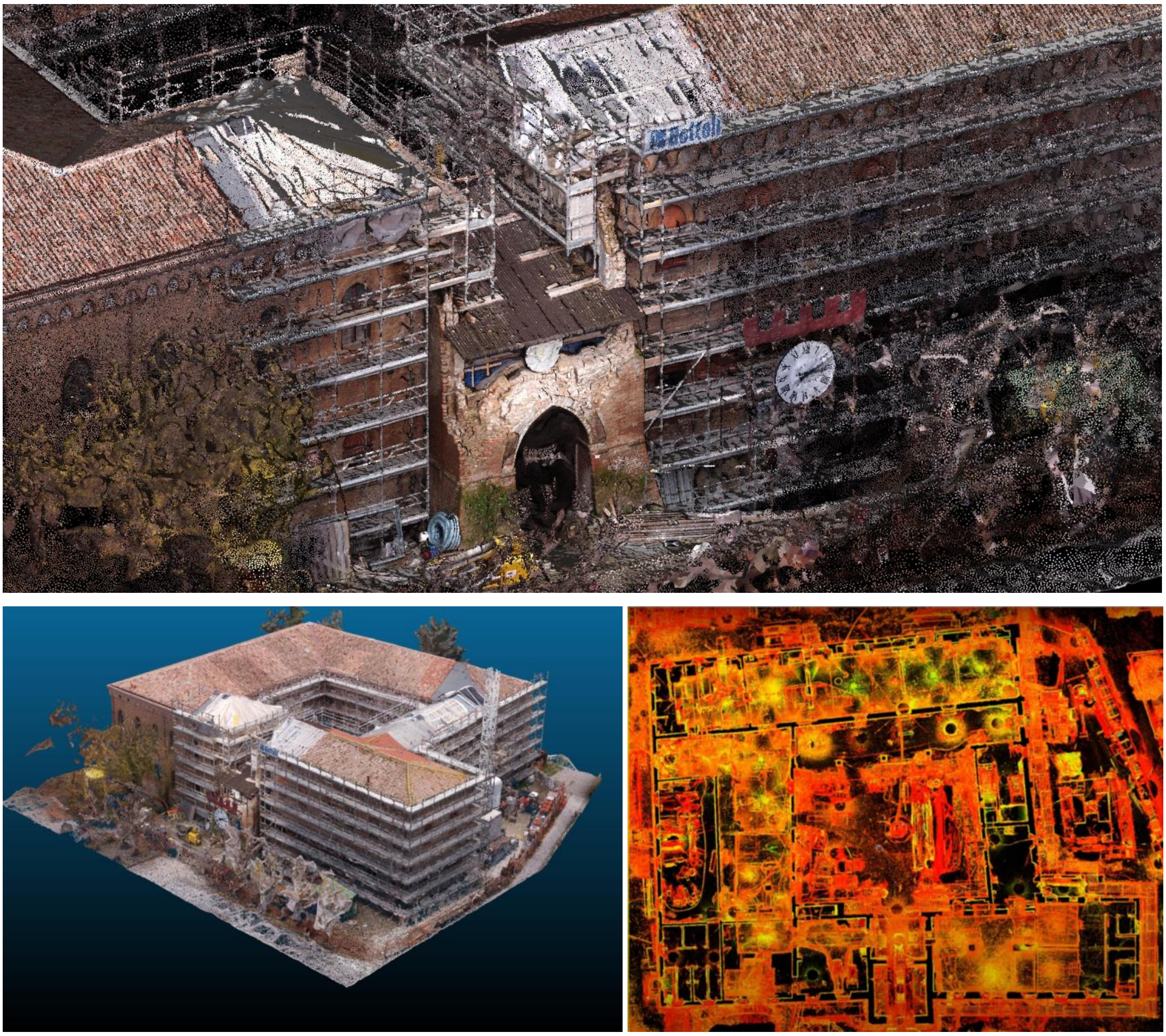

Figure 3. Integrated three-dimensional digital survey of earthquake-damaged cultural heritage. Palazzo Lambertini, Poggio Renatico, Italy.

The several scales of analysis associated to the intervention were established by the development of case studies of the heritage damaged by the 2012 earthquake with a view to the construction of a digital platform for damage survey and risk management.
On buildings such fortifications, palaces, and museums, integrated three-dimensional, topographical, terrestrial laser scanner, drone, and photogrammetric survey campaigns were carried out with reference to various states of art, some pre-intervention, others post-intervention.
As a result, the standard's information levels were implemented using the distinctive information sources of the Cultural Heritage being studied.
The basic functions of the tool were determined by the specified information demands, as well as the needs for accessibility and synchronic visualisation of diachronic representations of the state of art.
The implemented platform can support incoming (generic) traffic from any network (IoT and non IoT) and is able to collect, save and analyse the collected data. The integrated solution thus developed was divided into areas with different functionalities. The main functionality is the Dashboard Home: accesses, roles, authorisations; building master data; emergency management; survey/team assignment; survey execution; survey validation; survey status information modelling; intervention priority indexing.
Subsequent in-depth levels can be conducted at the territorial scale (from existing information sources made interoperable within the platform), at the building scale (digital identity card of the asset).
Each registry will consist of: Building Tab (i.e., Identifier and Master Data, Monitoring, Survey State, Diagnostics, Typological and Construction Characteristics, Structural Characteristics, Energy Characteristics); 2D Visualization; BIM Model for navigating the digital twin and accessing the source of the recorded data; The digital platform is implemented for the desktop version and prepared for the mobile version and integrates, starting from pilot case studies, functionalities related to the different phases of the life cycle of heritage subject to the risk of calamitous events such as digitisation and optimisation of the damage survey phase, following the occurrence of the event;

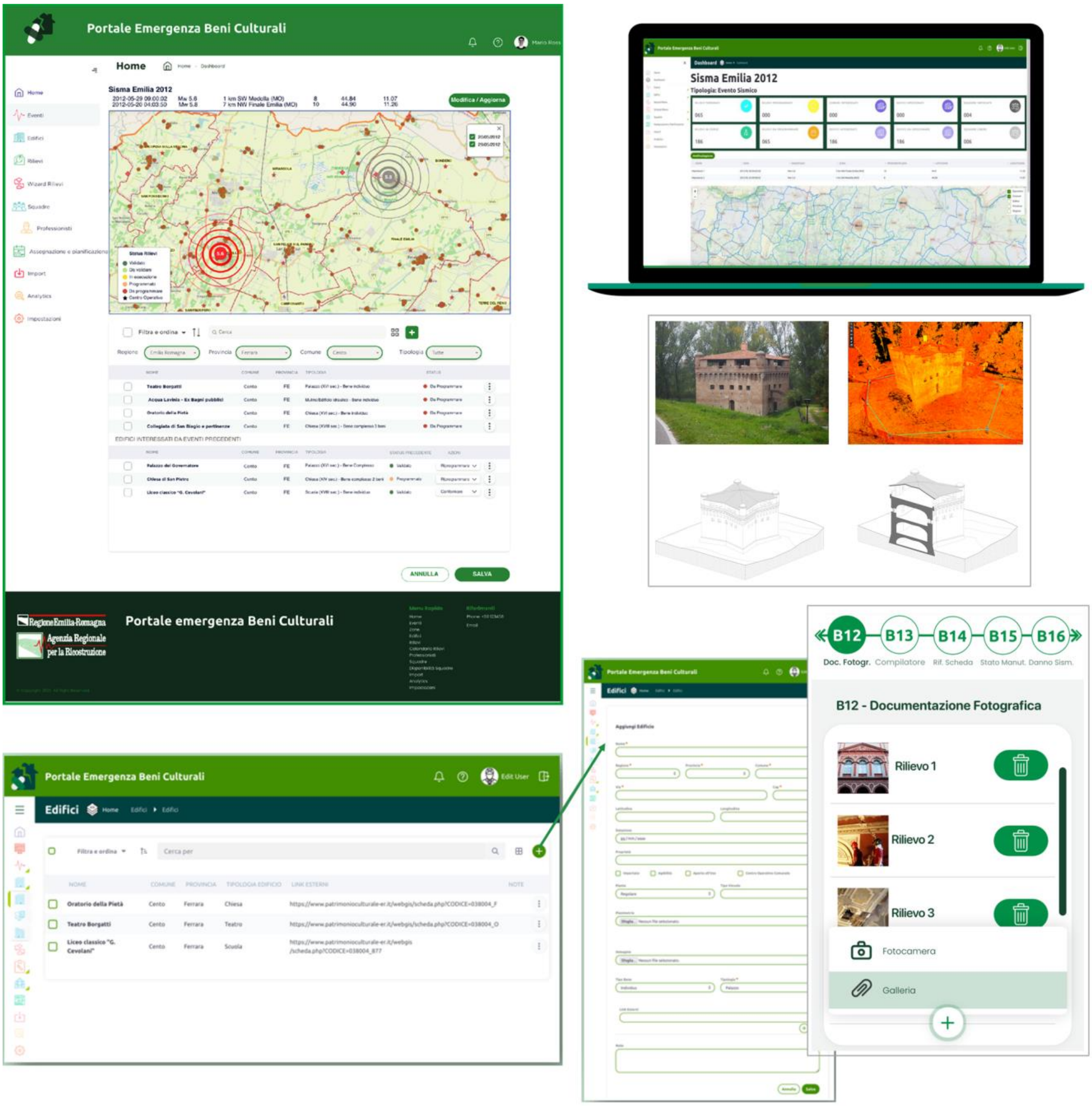

Figure 4. Integrated digital platform for damage assessment and risk management.

Management of the inspection, first aid and safety phases through the integration and harmonisation of existing databases; Visualisation in a BIM environment of data and information related to the actual state of the built heritage under consideration implementation of functionalities related to the monitoring, including continuous monitoring, of buildings in operational and post-intervention conditions in order to implement predictive models of data and scenarios in BIM based environments; dynamic integration of existing maps from different data sources, including satellite, in order to allow assessments and intervention priorities both at the scale of the individual building and of the territory. The result is a support tool for governance on the one hand and for the digitisation processes of the supply chain on the other, which also allows the involvement of a broad user base in data collection.
An information system such as the one described is intended to configure itself as the digital identity card of the building available for the development and modelling of both intervention priorities, at the territorial scale, and the effective planning and management of maintenance also from a predictive and big data management perspective.
In this sense, an essential prerequisite for the definition of the architecture and functionalities of the system is the need for continuous updating of data and their translation, based on a semantic approach, into accessible and usable information univocally associated with the different scales of analysis and interrogation foreseen.

3.4 Medium and long-term fallout

A recent research project by a group of professors and researchers from the University of Ferrara's DIAPReM Center and the TekneHub laboratory, who served as scientific managers and coordinators of the activities of integrated 3D

survey, scan-to-BIM modeling, and two-dimensional representation for over 600,000 square meters of state-owned buildings from 2019 to 2021, demonstrates the growing interest in the extensive use of the technologies described. even though such knowledge of the technologies is still relatively new.
However, knowledge related to their effective use is still inadequate.
The integrated digital three-dimensional survey data model is specifically not fully utilized as a direct source of information in the context as mentioned.
The paradigm shift that is occurring is obvious, supported in part by legal requirements but more so by public operators' desire to rely on digitisation and innovation processes.
Prior to defining a protocol for 3D surveys and digital documentation of cultural heritage at risk, it is important to consider the various situations in which the survey may be carried out, including damage surveys after catastrophic events and surveys of existing built heritage to determine the risk category.
The timing of a survey's execution and the calculation of the total data model is crucial for both contexts, but it is particularly important for damage surveys because it must enable prompt planning of rebuilding.
In addition, only a high-quality survey can provide multiscale readings that can be adopted over time for a survey of cultural heritage and constructed heritage in danger, such as the urban fabric of minor historic centers (Raco, 2019).

4. CONCLUSIONS

In order to develop and model intervention priorities at the territorial level and to effectively plan and manage maintenance from a predictive and big data management perspective, an information system like the one described is intended to configure itself as the digital identity card of the building.
Therefore, the requirement for continuous data updating and their translation, based on a semantic approach, into accessible and usable information univocally associated with the various scales of analysis and interrogation envisaged, is a prerequisite for the definition of the architecture and functionalities of the system.
The construction sector has found that information visualization is a crucial instrument for supporting the optimization of data-driven decision-making processes.
In this regard, even though HBIM tools on the one hand present intriguing opportunities for the integration of integrated digital information systems, the experience acquired suggests that certain limitations regarding the simplification and segmentation of the visualised information remain unresolved as a result of the limitations resulting from the calculation capabilities of integrated open standard visualisers when compared to native environments.
This latter challenge is still open with particular reference to the overall point cloud model generated by integrated digital three-dimensional survey. In fact, the processes of translation and subsequent representation, both two- and three-dimensional representation, show how the survey data is still poorly valued as a direct information source, with direct consequences on the increased probability of error in the interpretation and transmission of data from one information system to another.
Survey data that has been properly organized and divided and incorporated inside integrated digital platforms may favor and enable synchronic data interpretations of diachronic scenarios in order to improve risk management. However, there are still issues with the interoperability, accessibility, and efficient visualization of the integrated digital three-dimensional point cloud and HBIM semantically enriched models, as well as with the skills necessary to run complicated integrated digital platforms like those mentioned.

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