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WEB-BASED PLATFORM TO COLLECT, SHARE AND MANAGE TECHNICAL DATA OF HISTORICAL SYSTEMIC ARCHITECTURES: THE TELEGRAPHIC TOWERS ALONG THE MADRID-VALENCIA PATH

PLATAFORMA WEB PARA RECOPILAR, COMPARTIR Y GESTIONAR DATOS TÉCNICOS DE ARQUITECTURAS SISTÉMICAS HISTÓRICAS: LAS TORRES TELEGRÁFICAS DE LA LÍNEA MADRID-VALENCIA

Margherita Lasorella[a], Pasquale de-Dato[b], Elena Cantatore[a,*]

[a] Polytechnic University of Bari, Via Orabona 4, 70125 Bari, Italy. margherita.lasorella@poliba.it; elena.cantatore@poliba.it
[b] Universitat Politècnica de València, Camino de Vera, 46022 Valencia, Spain. pasdeda@cpa.upv.es

Highlights:

- A web-based platform is set up for sharing technical knowledge of systemic architectures of the historic Telegraphic Towers located along the Madrid-Valencia path.
- The platform takes advantage of point cloud models properly enriched with general, historical, and technical data in the RGB version, and with decay patterns in the mapped ones.
- The platform is linked to a relational database organised for managing technical data and choosing interventions according to main ontologies, normative and geophysical boundary conditions.

Abstract:

Considering the variety of architectural Cultural Heritage typologies, systemic architectures require specific attention in the recovery process. The dimensions of "extension" and "recurrence" at geographic and technological levels affect the complexity of their knowledge process; they require systematic ways for their categorisation and comprehension to guarantee correct diagnosis and suitable rehabilitation. Recent applications involving Internet of Things (IoT) for the built Cultural Heritage have demonstrated the potentialities of three-dimensional (3D) geographic information system (GIS) models and structured databases in supporting complex degrees of knowledge for technicians, as well as management for administrators. Starting from such experiences, the work presents the setting up of a web-based platform to support the knowledge and management of systemic architectures, considering the geographical distribution of fabrics, natural and anthropic boundary conditions, and technical and administrative details. The platform takes advantage of digital models, machine and deep learning procedures and relational databases, in a GIS-based environment, for the recognition and categorisation of prevalent physical and qualitative features of systemic architectures, the recognition and qualification of dominant and recurrent decays and the management of recovery activities in a semi-automatic way. Specifically, the main digital objects used for testing the applied techniques and setting up the platform are based on Red-Green-Blue (RGB) and mapped point clouds of the historical Telegraphic Towers located along the Madrid-Valencia path, resulting from the on-site investigations. Their choice is motivated by the high level of knowledge about the cases reached in the last years by the authors, allowing them to test rules within the decision support systems and innovative techniques for their decay mapping. As the experience has demonstrated, the systematisation of technical details and operative pipeline of methods and tools allow the normalisation and standardisation of the intervention selection process; this offers policymakers an innovative tool based on traditional procedures for conservation plans, coherent with a priority-based practice.

Keywords: technical knowledge; systemic architecture; digital model; web geographic information system (GIS); Spanish telegraphic tower; decision support system (DSS)

Resumen:

Entre la variedad arquitectónica del patrimonio cultural, las arquitecturas sistémicas necesitan una especial atención para su recuperación. Características como la "extensión" y "recurrencia" a nivel geográfico y tecnológico influyen en la complejidad de su comprensión; requieren métodos de categorización y conocimiento para un correcto diagnóstico de la degradación y una adecuada rehabilitación. Las recientes experiencias, que cuentan con el "internet de las cosas" (IoT) en el patrimonio cultural construido, han demostrado que los modelos de sistema de información geográfica (SIG) tridimensional (3D) y las bases de datos estructuradas tienen grandes potencialidades para apoyar a técnicos y administraciones en el conocimiento profundo. Considerado este punto de partida, el trabajo presenta la creación de una plataforma de apoyo al conocimiento y gestión de arquitecturas sistémicas, basada en la web, que tiene en cuenta la distribución geográfica, las condiciones del entorno natural y antrópico y los detalles técnicos y administrativos. La

*Corresponding author: Elena Cantatore, elena.cantatore@poliba.it

plataforma aprovecha modelos digitales, procedimientos de aprendizaje profundo y computacional, así como bases de datos relacionales en un entorno SIG; todo ello tiene como prioridades el reconocimiento y categorización de las características físicas y cualitativas más representativas de las arquitecturas sistémicas, sus degradaciones frecuentes y relevantes y la gestión de las intervenciones de recuperación de forma semiautomática. Los principales elementos digitales utilizados para testear las técnicas aplicadas y configurar la plataforma se basan en nubes de puntos RGB y mapeadas de las Torres de Telegrafía Óptica ubicadas entre Madrid y Valencia, resultado del profundo conocimiento de los autores por las investigaciones realizadas in situ. Esto permite probar diferentes criterios de soporte a la toma de decisiones y técnicas innovadoras para mapear las degradaciones. Se ha demostrado que la sistematización de los detalles técnicos y la concatenación operativa de los métodos y herramientas permiten la normalización y estandarización del proceso de selección de intervenciones; así, se ofrece a los responsables de las políticas patrimoniales una herramienta innovadora, basada en procedimientos tradicionales de conservación y coherente con una práctica basada en prioridades.

Palabras clave: conocimiento técnico; arquitectura sistémica; modelo digital; sistema de información geográfica (SIG) web; torre de telegrafía óptica; sistema de soporte a decisiones (DSS)

1. Introduction

The digitalisation of the construction sector in Europe has prompted scientists and administrators to address new challenges at both procedural and operative dimensions, aiming for a higher level of sustainability (Rosário & Dias, 2022). This process involves new and existing constructions, as well as historical fabrics and architectural Cultural Heritage. However, for the latter, the procedures must also support actions for conserving, protecting, and enhancing such architectures while considering preservation and specific risk exposures (Maietti et al., 2020). These goals should be achieved coherently with the traditional operative methods of supporting recovery process. The latter is typically structured in three main phases: i) technical knowledge, aiming to analyse geometric, historical, architectural, and material aspects, as well as the evolution of architectural-structural and functional transformations and the state of conservation; ii) pre-diagnosis, involving cataloguing and categorising all the information gathered in the previous phase to identify first hypotheses of diagnosis (i.e., phenomenological modelling supported by error or diagnostic trees, planning of the subsequent types of diagnostic analyses); and iii) diagnosis, where the collected information is processed and tested to identify the necessary recovery interventions, address deficiencies, and suggest new uses. Despite this structured approach, the operative process is significantly fragmented due to the variousness of information that needs to be collected (archival and direct surveys) and shared with various sector experts, including engineers, architects, restorers, historians, and archaeologists (Bruno et al., 2022).

Among the various types of Cultural Heritage, systemic architectural entities are distinctive due to their geographical distribution across the territory (Pintossi, Ikiz Kaya, & Pereira Roders, 2023; Pouso-Iglesias, Arcones-Pascual, Bellido-Blanco, & Valentín-Gamazo, 2023). Such fabrics are usually structured as networks of simple but systemic units featured by recurrent morphology and/or construction technologies and/or function (by way of example, defensive system –towers, castles...; rural systems –farms, farmhouses...; production systems –power plants, paper mills...). Consequently, the recovery process must address both micro (property/architectural artefact) and macro (urban entity/historical aggregate) scales, which increases the complexity of the entire recovery process and its management (Fatiguso, De Fino, Cantatore, & Caponio, 2017). Material and immaterial features, performance assessments, and conservation requirements must be recognised and evaluated for all these fabrics individually and then related to the system to identify recurring relationships and peculiarities (e.g., technological, and conservative) in line with their geographical distribution and extension. Additionally, natural and geophysical properties of the locations, such as seismic and flood risks, must be considered, with the possibility of extending or relating conservation actions to ensure the safety and security of these fabrics (Valagussa et al., 2021). This multi-scale analysis procedure underscores the need for a structured approach to organise all the required data to i) enable the unambiguous interpretation of data and properties, overcoming the plurality and diversity of technical expertise involved, ii) establish a proper structure for information relations based on the associated scale, and iii) facilitate management at the systemic scale (Bochenska et al., 2023; Carniello, Dos Santos, & Pimenta, 2022; Kioussi, Karoglou, Labropoulos, Bakolas, & Moropoulou, 2013; Noardo, 2018).

In that sense, the digital transition for systemic architectures plays a crucial role in the entire recovery process, moving beyond simple building modelling procedures towards specific approaches that support technicians and administrators in sharing technical knowledge and fostering collaborative and virtuous participation among all urban stakeholders (Aftabi & Bahramjerdi, 2023). Particularly for systemic architectures, new functional approaches are necessary to sustain the ongoing slow process of digitising the existing historical heritage in order to support i) the systematisation and standardisation of procedures, ii) the modelling of the architectural built heritage, and iii) the integration of traditional methodologies with innovative instruments (Banfi, Brumana, & Stanga, 2019; Currà, D'Amico, & Angelosanti, 2021; Benavides López, Martín Civantos, & Rouco Collazo, 2020; Pepe, Costantino, Crocetto, & Restuccia Garofalo, 2019).

Recent efforts in digitalising Cultural Heritage have resulted from the continuous upgrading of existing digital tools originally designed for other purposes (e.g., for the control of the industrial product and prototyping). The main results related to the resolution at the architectural scale of the ontological gap between lexicons for historical and modern constructions (Borin, Bernardello, & Grigoletto, 2020) and the geometric complexities (Grilli, Farella, Torresani, & Remondino, 2019). However, their digital representations –both at geometric and informative/semantic levels– constitute the first step in the whole process of their recovery, considering a specific chain of operative tools based on parametric 3D models also for conservation management (Lasorella & Cantatore, 2023; Saricaoglu & Saygi, 2022) properly enriched in their ontological dimension (e.g., MONDIS)

(Cacciotti et al., 2013). When the focus shifts to systemic architectures, scientific literature highlights the potentialities of Geographic Information System (GIS) as the baseline to solve topographical data. Even if it is traditionally used for 2D mapping, GIS tools have been recently improved to manage 3D information and explored for the assessment of detailed risk for large-scale territories (Sonnessa et al., 2023), even if it lacks semantics. In this context, this gap has been solved by introducing the CityGML ontology, properly declined for architectural Cultural Heritage, which has main geometric dialogues with the GIS environment. Among the others, GIS models allow the use, integration and management of point clouds, taking advantage of the Structure from Motion (SfM) photogrammetry techniques for single acquisitions, and Terrestrial Laser Scanning (TLS), Mobile Mapping System (MMS) and Airborne Laser Scanning (ALS) methods for digitalising large and continuous areas (Costantino, Pepe, & Restuccia, 2023; Peña-Villasenín, Gil-Docampo, & Ortiz-Sanz, 2019). Moreover, point clouds constitute the main basis of recent studies for analysing, cataloguing, and assessing the state of conservation of built Cultural Heritage. Starting from the standardised decay definitions, Machine and Deep Learning (M-DL) approaches have demonstrated the potentialities of artificial intelligence in segmenting, qualifying, and quantifying classes of decays in 3D and parametric models. Moreover, point clouds can be augmented by including information about location, extension and, when monitored, the progress of decays (Bruno, Galantucci, & Musicco, 2023; Matrone & Martini, 2021; Perumal & Venkatachalam, 2023).

Such evidence in literature has highlighted potentialities and opportunities of digital models and innovative tools, testing them for specific goals. On the contrary, all the experiences still focus on the automatic process for the resolution of specific matter on single fabrics or solving specific phases of the conservation process. Here, a peculiar opportunity can be read introducing informative systems supported by Decision Support Systems (DSSs). The use of structured technical knowledge by means of defined and proper ontologies for Cultural Heritage can solve the relations among observed data and properties, the diagnostic protocol, and the selection of suitable strategies of interventions. DSS can be introduced as resolutive structures of relationships among pathologies, environmental features and materials of fabrics, supporting technicians in a semi-guided procedure, supported by determined rules. Examples of such DSSs can be found in the energetic matter (Egusquiza, Brostrom, & Izkara, 2022) or the reuse of buildings on a large scale (Acampa, Battisti, & Grasso, 2023).

In light of this, the present work aims to define and structure a platform designed for cataloguing, archiving and managing a plurality of data and multidisciplinary information through digital systems based on texturized point clouds. In this platform, models and data are organised on the web and follow a multi-scale and innovative approach, coherently with the extension of systemic architectural heritage. In detail, the proposed platform enables to follow the phases of the cognitive process, where all the results of each phase are archived and systematised in a single web-based model and according to existing ontologies for Cultural Heritage and its conservation goal. The approach focuses attention on the role of the technical knowledge phase for the identification of recovery interventions, joining the traditional procedures towards a coherent integration and interoperability of data. In detail, the platform is designed and applied to the Optical Telegraphy Towers of the Madrid-Valencia line, chosen due to the current process of investigation which highlighted the complexity of their management. In fact, during the last years, the academic activities of Pasquale de-Dato, such as master's and PhD theses (Bas García, 2021; de-Dato & Hernández Navarro, 2016; Martino, Savini, Hernández Navarro, de-Dato, & Fatiguso, 2022), have contributed to a substantial campaign of point cloud and archival data acquisition, addressing geometric gaps for some of these towers. On the other hand, the recent experience of authors in managing complex databases and relations in relational ones offered the opportunity to integrate geometric details and related information, implementing results of previous works (Lasorella & Cantatore, 2023; Lasorella, Cantatore, & Fatiguso, 2021) to support the goal of this work. These activities and the provided experiences offer the opportunity to collaborate with local public bodies in supporting the conservation of such buildings. To this end, the platform has been structured to achieve two main objectives: i) cataloguing and disseminating technical knowledge among various experts involved in the conservation process, by means of a structured set of innovative digital tools, and ii) supporting technical experts in selecting intervention strategies through the development and integration of a technical DSS.

2. Method and tools for setting up the platform

As discussed in the previous section, scientific endeavours using innovative tools to manage transformation requirements for Cultural Heritage are still limited in controlling the entire recovery process. This is due to the inherent difficulties in managing, in a controlled way, the variousness of experts involved, and procedures and rules determined for the class of Cultural Heritage (e.g., single or systemic architectures). The opportunity presented by previous activities involving the collection of data on Optical Telegraphy Towers in Spain has motivated the scientific group to explore how such data can be effectively managed through a simple, coherent, and multi-user platform, starting from the novelty and potentialities of innovative tools for point clouds. This is a chance to test with the goal of supporting interrelation among academic activities and administrative procedures. Specifically, the platform aims to achieve four main objectives:

- Geolocate all the fabrics, to maintain the geographic information on the clouds and digitally trace the original connections among the entities. Geographic data also support the implementation of geophysical information about the place, enabling discussions of interventions with respect of local hazards.
- Catalogue all the technical information collected in a coherent and structured way to define a homogeneous dataset of preliminary information about single entities.
- Analyse the acquired models, guiding the technicians within structured and well-defined decay classes, aiming at their standardisation both at the identification and definition phases.
- Support a semi-guided procedure in selecting interventions by means of selected and suitable interventions, also in concordance with geophysical data.

To achieve these goals, the platform is built upon four digital techniques, properly combined with detailed requirements according to the available point clouds:

- GIS-based information systems, useful for georeferencing digital towers along the historical path. For this purpose, the QGIS v. 3.16 has been used for experimentation. Here, all the historical data about the fabrics are structured to allow the visualisation and fruition of iconographic drawings (when available), and geophysical information of the places, including natural hazards, geo-morphological information, and anthropic risks.
- Relational database (r-DB), structured according to existing ontologies and regulations in the field of architectural Cultural Heritage and, specifically, conservation, for archiving, systematisation, and querying of cognitive data. Specifically, the database is structured following i) the ontological definitions of components and elements of Cultural Heritage standardised according to the CIDOC Conceptual Reference Model (CIDOC-CRD) (Dörr, 2002); ii) the decay patterns for stone, adobe and bricks are identified and classified according to the international Glossary of the International Scientific Committee for Stone (ICOMOS-ISCS) (Vergès-Belmin, 2008); and iii) the relations about them and possible interventions as structured within the MONDIS ontology (Cacciotti et al., 2013). Specifically, interventions are defined as strategies for technicians, while the choice of technical solutions depends on the real tractability (e.g., type of solvent, brushing techniques, etc.). Relations among pathologies and causes are determined according to the wide campaign of analysis in the last years for the case studies and the group's detailed expertise, properly organised to establish the final structure of the DSS. For this purpose, the informative and relational database is structured on PostgreSQL, with the PostGIS extension, using the pgAdmin interface.
- Machine Learning algorithms are employed for the semi-automatic segmentation and classification of textured point clouds; this is functional to the results, promoting an automatic location of recurrent pathologies (biological colonisation, mould and crust).
- Web-based systems for the integration of digital information models and the sharing of technical knowledge among experts in the conservation sector. This is the core of the collaborative platform on a large scale, supporting variousness of expertise, enabling fast and easy visualisation, and facilitating the assessment of digitalised case studies.

The setup of the platform (Fig. 1) is structured in four main phases, mainly focused on the i) organisation of technical knowledge (collected data, image-based clouds, decay information…); ii) structure of the relational database; iii) implementation and enrichment of the GIS environment with all the digitalised towers; and iv) set up of the web-based platform for sharing and visualising results in terms of intervention and critical assessment.

The process relies on two fundamental types of point cloud, mainly involved in the development for cataloguing, organisation and managing collected data according to specific thematic levels of information, properly codified and introduced into the GIS environment:

- RGBCloud represents the digitalised fabric, resulting from the SfM photogrammetry in Agisoft Metashape v. 1.5.2. Photographs acquired in situ are elaborated to obtain point clouds and texturised models. The elaboration of the RGBCloud has resulted from a preliminary analysis of the fabrics (archival-documentary information and on-site inspections) useful for the definition of the type of survey (aerial and/or terrestrial) and the planning of the photogrammetric acquisition. Consequently, the images acquired on site were pre-processed, using photo editing software in order to decrease and/or eliminate the presence of noise resulting from the low environmental conditions during the frame acquisition (i.e., low light). Each digitalised architecture is imported into the GIS environment and codified with its ID in order to determine a unique code for its identification. The levels of details about historical data (photos, transformations, drawings), ownership (private/public), state of conservation (ruin, recovered…), technological information (material and construction techniques), and geophysical properties of the place (climate, anemometric details, natural hazards) are associated to each RGBCloud. This information is included in the GIS environment as sub-properties of the identified ID and properly coded, as outlined in Table 1.
- MAPCloud corresponds to the digitalised tower but is enhanced with decay mapping. It results from machine learning applications in the software CloudCompare of the related RGBCloud in its texturised version. In detail, the identification and classification of decay types are carried out by expert technicians who identify on portions of the textured model the RGB and HSV (Hue, Saturation, Value) values useful for the automatic segmentation of the point cloud (Colorimetric Segmenter plugin has been used, with filter RGB and HSV). In detail, a range of values corresponding to the RGB and HSV features has been identified for each decay on the RGBCloud. The identified maximum and minimum value triples were used as features, as well as input data for all other models during the mapping phase. In this way, points belonging to a specific range of RGB and HSV were associated with a decay theme. Consequently, the classified and segmented portion of the RGBCloud was associated with a single scalar colour between 1 (black) and 255 (white) corresponding to the degradation type (Convert to Scalar Field has been used in CloudCompare). Every mapped cloud is linked to the original ID and all the segmented decay information is properly classified and identified on the mapped cloud by means of specific hotspots. These are located in the mapped cloud, coded according to the set of decay types, and linked to the relational database (r-DB). Within the r-DB, the decay data are also linked to the ID of RGBCloud in order to enrich the relations and display subsequent results in terms of interventions. The structure of information related to the MAPCloud is outlined in Table 1, where the classes and information are detailed.

As far as the r-DB is concerned, it is linked to the GIS environment and establishes correlations for all the information according to detailed relations. Starting from the unique ID code assigned to each digitalised model, the database is structured following the interconnections (n to many) for all the data/properties organised in tables in the GIS environment. In particular:

- Direct relations are structured linking each ID with all the historical (HD) and general data (GD), previous interventions (Pi) and geophysical data (Gp), while one option for ownership (Ow) and State of Fabric (St).
- Direct links are built up between ID and mapped Decays (Dc).

The information about "Intervention" class can be filled in a semi-automatic way in the r-DB, thanks to the relations among decays, causes and interventions as defined in the MONDIS ontology. In detail, the r-DB (Fig. 2) is structured in the classes of information outlined in Table 1 –General, Technical, Geophysical, Diagnosis and Intervention Data–. Information is correlated through a relational system that allows the organisation of data according to a predefined decision support structure. Each section consists of defined data fields capable of hosting the specific information required for diagnosis validation. In fact, the diagnosis section comprises two subsections – Decays and Causes– depending on the technical and geophysical information. However, a detailed section of intervention is introduced, including the class and related intervention details. Specifically, the data systematised in the Technical Data section defines the identification of the z-th type of decays according to ICOMOS glossary. These data are correlated with the geophysical ones for the association of the m-th possible causes, to each of which, for every m-th cause, the w possible intervention strategies are linked and correlated. In detail, the rules of the r-DB are structured as follows:

- to each tower (Code) the specific section.
- to each section the n data.
- to each z-th decay (Dc) the possible m causes (Cs).
- to each m-th cause (Cs) the w suitable interventions (Itv).

Finally, the platform for web sharing and visualisation is established. The publishing of digitalised models and informative systems is achieved through a user-friendly web map using the QGIS plugin (qgis2web). Point clouds are converted for web uses (Potree Converter and Potree Viewer have been used for the purpose), and the associated information is structured within the r-DB using hypertextual links. Specifically, the web map, starting from a geographic system, allows the visualisation of both the clouds (RGB and MAP) guaranteeing the dual usability for all end-users. Moreover, the platform is designed to incorporate digital point clouds with specific hotspots. In fact, these are introduced in the RBGCloud to link all the general information organized in the GIS environment. In MapCloud, hotspots are added and located for each recognised decay. The use of these hotspots facilitates the referencing of structured data within the r-DB in the visualised clouds. It also enables the management of the same information on a webpage, thereby supporting the conservation process efficiently. The simultaneous visualisation of general data for each tower helps technicians in determining the suitable causes among the possible ones, as structured in the r-DB, and choosing the proper interventions, also considering the geophysical data of the place.

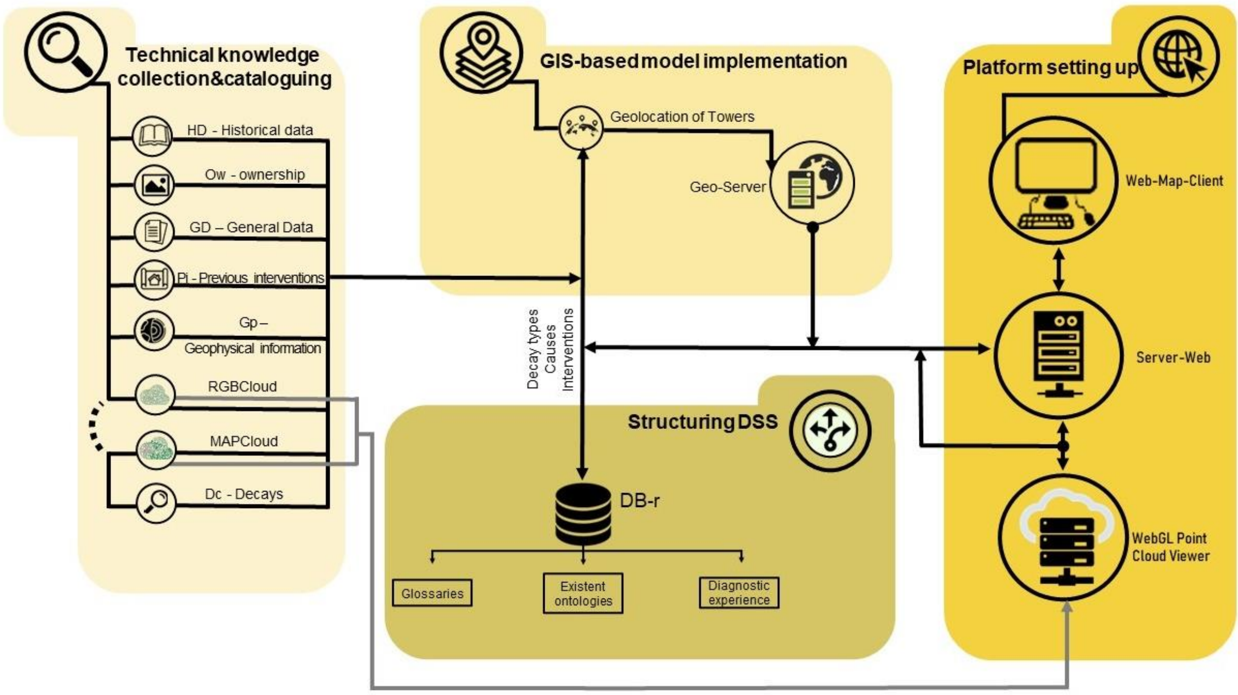

Figure 1: Flowchart of the process for the setting up of the platform.

Table 1. Structure of details related to RGBCloud and MAPCloud in terms of associated codes, possible implementation in the GIS environment, and datatype extension of external collected data.

Class of Information [Code]	*Information*	*GIS detail*	*External data type*
	RGBCloud		
ID [ID]	ID	Y	
General data [GD]	Toponym	Y	
	City	Y	
	Address	Y	
	Longitude	Y	
	Latitude	Y	
	Year of construction	Y	
	Use	Y	
	Ownership	Y	
Technical Data [TD]	State of fabric	Y	
	Constructive Type	Y	
	Historical data	Y	.doc/.docx; .pdf; .jpeg/.png
	Previous interventions	Y	.doc/.docx; .pdf; .jpeg/.png
Geophysical data [Gp]	Macro-scale	Y	
	Micro-scale	Y	
	MAPCloud		
Diagnosis Data [Dg]	Decay	Y	
	Cause	Y	
Suitable intervention [Itv]	Intervention	Y	

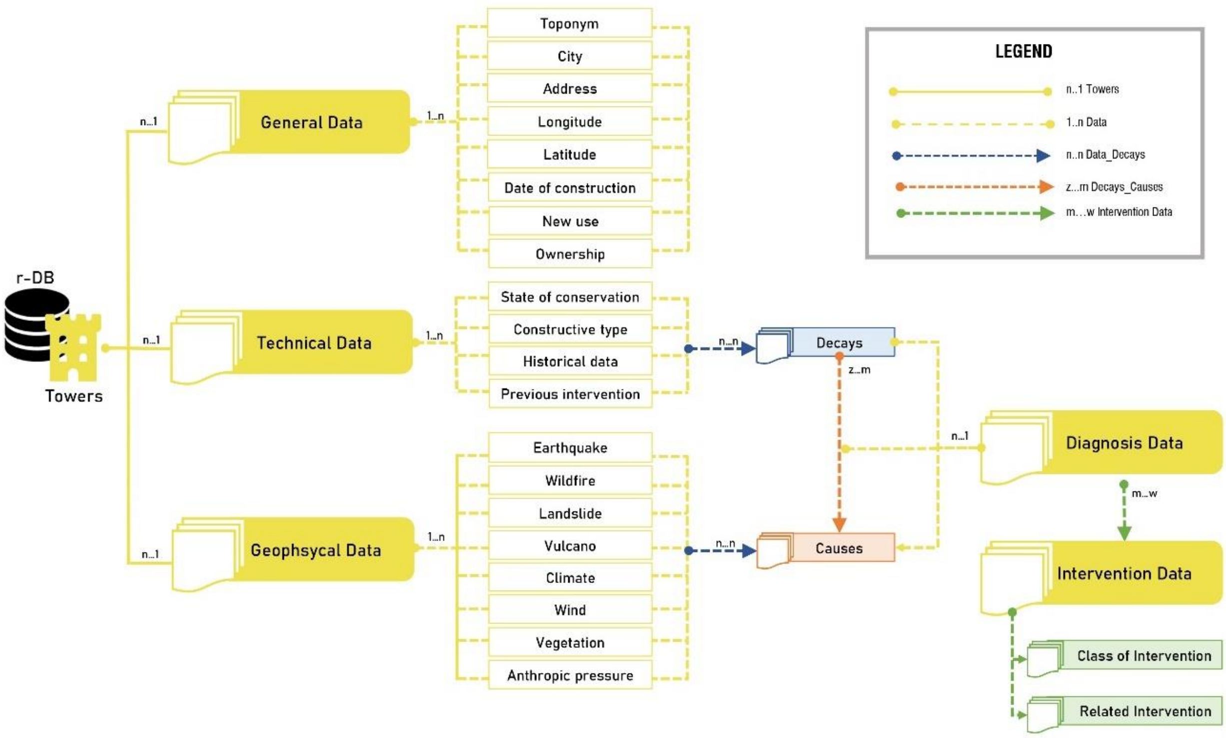

Figure 2: r-DB structure.

3. Case study and results

3.1. Architectonic and spatial details of the Telegraphic Towers

Optical Telegraphy in Spain not only represents one of the great but fleeting milestones of Spanish technology but also hides infinite connections with the history, society, and culture of 19th-century Spain, extending in some ways to current telecommunication technologies. The real technological revolution of telegraphic activities was the ability to transmit complex messages in real-time and over very long distances using technical instruments with hardly any interference. Since their inception during the French Revolution, optical or aerial communication systems have been continuously improved in line with technological evolution (Romeo López, 1980). The significant importance of these systems lay in the fact that the encrypted code was associated with a more complex message collected in a previously written phraseological dictionary (Olivé Roig, 2007). The message, which passed from one tower to another, was captured using spotting scopes with achromatic lenses that allowed the reduction of chromatic and spherical aberrations, enabling clear observation of the telegraph positions even over great distances.

In 1844, the Director General de Caminos, Canales y Puertos, as the Ministerio de Gobernación (Ministry of the Interiors), organised a contest to select the winning solution for execution. The selected proposal was of the Colonel of the General Staff José María Mathé Aragua, who oversaw all the phases and related operations, from personnel recruitment to directing all the construction activities and drafting the encrypted codes. The system consisted of a metal apparatus with a 3D structure of eight masts mounted on a type of tower-like structure. A metal cylinder slid vertically, marking twelve different positions, and laterally, a ball provided complementary service signals. Pulleys and a flywheel facilitated the movement of cylindrical indicator and ball.

The towers served as support for the devices, hosting the pulleys and flywheel, guarding manuals, and for the personnel employed. These buildings were usually located in the highest and most visible points of the territory but, at the same time, they were close to existing roads, highways, populated areas, and zones with less adverse weather conditions. In the provincial capitals, the apparatus was preferably added to the top of civil authorities' buildings. Coherently with the fortress features, the security of the tower was the main aim of the project. It had a raised entrance on the first floor, using retractable stairs stored in the building; the ground floor had loopholes for defending the tower, and the walls were thick to ensure good strength. Also, staff were soldiers, properly trained for telegraphy and known as "torreros" (de-Dato & Hernández Navarro, 2016).

The towers of some operating lines were abandoned for a few years due to their replacement by more modern electric lines. The complete abandonment of Optical Telegraphy in Spain was declared by Royal Decree in 1857. Until today, telegraph apparatus and all the militarily relevant elements were dismantled and consciously destroyed to prevent their use by enemies. However, due to the long process, most suffered high degrees of static problems and decay that have led many towers to a state of ruin or to disappear.

The choice of studying the Spanish Optical Telegraphy Lines is a consequence of the direct knowledge of the authors after their research and restoration interventions carried out in some of the towers that make it up. In addition, the number of towers, distributed in three executed lines[1], provides a wide casuistry for experimentation and the possibility of abstracting models related to the conditions of their current state. The field of experimentation has been limited to Line 2 - Madrid-Valencia, originally organised in thirty aligned towers built between 1848 and 1849. After their functional dismantling and the loss of some of them, today, the line counts nineteen towers still standing, allowing their study.

The telegraphic line is a systemic network of architectural units that maintains obvious conceptual, material, and constructive links even if not physically connected. All the towers, although with variants, are the result of a single project, properly replicated in selected sites distant no more than two and three leagues. The morphology of the tower shows the defensive military needs while the constructive and distributive aspects show extreme functionality. In the studied line, three groups of towers can be recognised, mainly organised by constructive aspects as follows (Fig. 3):

- The first consists of towers made entirely of stone with ashlars in the most sensitive constructive nodes (corners, cornices, jambs, and lintels) and masonry in the rest of the structural envelope (CT1); some bricks can be found as decorative elements (Fig. 3a).
- The second, more numerous, is constituted of towers built by masonry with elements of reinforcement of bricks, variously rigged according to the territorial constructive traditions, replacing the ashlars of the first group. All sources/researchers consider this variability as a consequence of the on-site availability of the used materials (CT2) (Fig. 3b).
- The tower Cerro del Vedado is an exception due to the use of bricks in the overall wall extension, while masonry at the ground floor (CT3). These features are not visible, due to the recent interventions of restoration.

The widespread geometry of the tower is quadrangular, with small variations, except for the Tower of Atalaya (in Villarejo de Salvanés) which has a trapezoidal plan to adapt the construction to the steep slope of the site. The other towers solve this problem with a stone-levelling plinth. The external walls have openings (windows and doors) organised on the first and second floors, in only two of the facades while, on the ground floor, they have loopholes on all four sides.

The building walls had up to three layers of lime plaster with different granulometry and resistance, offering a unitary aspect of all the towers despite the constructive differences. The original hypothesis related to the use of plaster for wall finishing is related to the necessity to improve the visibility of the towers concerning the landscape. This is confirmed also at the current state of conservations, recognising for unplastered walls the presence of whitewashing. Although the few remains of roof slabs reveal a flat one on the top floor, it is likely that the original one, as planned in the project, was a metal pavilion roof made of zinc or lead.

[1] The initial project foresaw more lines.

The current state of Line 2 presents two completely restored towers (Campillo in Arganda del Rey and Cerro del Vedado in Torrent), five completely in ruins or a situation of imminent collapse (Atalaya, Belinchón, Villares del Saz, Juan Bueno and Alto de la Portilla), and twelve with high or low state of conservation.

As far as the extrinsic features of the border conditions are concerned, the experience of the authors in studying the towers in Line 2 has also highlighted the strong interrelation between present decays and extrinsic environmental conditions, with specific details. According to the general notes in observing the architectural fabrics to assess their state of conservation, the geophysical data to be considered in the pre-diagnosis analysis of the telegraphic Towers are related to two levels of environmental factors that determine the variation of decay patterns.

At the macro-scale, the extension of line 2 intersects one climatological condition of possible ones in Spanish land, specifically the BSk (Cold semi-arid) climate type2 according to the Köppen-Geiger Classification. However, such data could be effective in comparing results with other lines that intersect four other climate types. While different natural hazardous exposures may be recognised in the territorial extension of the Line 2 checking the results in the service "thinkhazard.org"3 by the Global Facility for Disaster Reduction and Recovery (GFDRR). However, only natural and anthropic hazards that can have determined specific decay patterns are considered, while their relevance for static conditions4 is checked as adjunctive levels of information for the towers, according to the service for public administrators.

On the other hand, the micro-scale analysis includes the nearest boundary conditions related to the presence of vegetation, anemometric data, and anthropogenic pressure that have been revealed as the most effective in the pre-diagnosis phase. Specifically, the prevailing winds may compromise some facades, coherently with their orientation. Due to that, all the anemometric data were collected from the Global Wind Atlas5 and implemented in the database.

The presence of tall or low vegetation in the environment has also greatly influenced the decay pattern, as a consequence of hindered ventilation and limited direct solar irradiation, activating degradation phenomena (i.e., biological colonisation and mould). Specifically, four classes of vegetation can be recognised in real cases, reflecting specific strategies for the places (Monitored (M) or Design (DS) when the green barriers on the tower boundary are controlled by maintenance or are the process of a specific study), the complete absence (A) or infesting (I) when not controlled by authorities or owners.

Also, speculative anthropic pressure has been a crucial factor for the disappearance or complete transformation of some towers in urban contexts, with rural isolation being the main cause of exposure to vandalism and consequent anthropic degradation. Three levels of such pressure may be recognised: the high level (HP) has been reached when the anthropic pressure has transformed the original characters; a low level (LP) describes local modifications of some elements (holes, graffiti, etc.); in the other cases, anthropic pressure is absent (AP).

(a)

(b)

Figure 3: a) Tower of Quemada de Perales as CT1 type; b) Tower of Villares del Saz for the CT2 type.

[2] Updated data available at https://climateknowledgeportal.worldbank.org/country/spain

[3] https://thinkhazard.org/en/report/229-spain/VA

[4] Due to the position of the tower, located in hilly territories, flood and tsunami can be excluded, while earthquake, wildfire and landslide, volcano affect the static recovery of architectures and may be considered for adjunctive interventions.

[5] The Global Wind Atlas is a free, web-based application resulted from the partnership between the Department of Wind Energy at the Technical University of Denmark (DTU Wind Energy) and the World Bank Group (consisting of The World Bank and the International Finance Corporation, or IFC). https://globalwindatlas.info/en/

3.2. Results in platform setting up for the Telegraphic Towers

Starting from the extensive collection of data and information already provided for the Line 2 Madrid-Valencia and in accordance with the described methodology, all the towers have been coded in order to create a structured system of database for their identification and logical relations among them, geographic information and the required data and features. Specifically, the codification process uses the code "Line number + Name of starting and end line cities + _ + Tower number", allowing the integration of the traditional numbering of towers and lines, the geographical distribution of fabrics between the starting and end points, and supporting the potential implementation of similar data for the other lines. All the data are thus codified and organised into properties following the structure of Table 1 and briefly summarised in Tables 2 and 3 for all the Towers.

The towers have been acquired using terrestrial and aerial tools. The images were acquired using a Pentax K20D featured by a focal length of 35 mm and f/20. The aerial acquisition was acquired using the FIMI X8 SE drone, with its internal camera. The image acquisition, both terrestrial and aerial, had a circle clockwise trajectory starting from the main façade, with a constant step defined according to the size of the single tower. The images obtained were pre-processed to obtain frames with balanced histograms, without the presence of noise. Pre-processing of the frames was performed using the image balance tools (brightness, contrast, saturation) in Photoshop software v. 20.0.0. However, after defining the tonal values of the images, they were automatically processed in sequence using the same settings.

Then, images were imported into Metashape software for RGBCloud processing. For all the buildings with material and constructive consistency, the RGBCloud has been processed in CloudCompare software to generate the associated MAPCloud according to the outlined method. The implementation of details in the web platform allows for querying or visualising such properties on the entry map. Particularly, all the georeferenced towers have been categorised according to the state of conservation (Fig. 4), as prevalent information to select common ones. Due to the systematisation of information, all the towers can be queried, displaying the details as in Tables 2 and 3.

Technical and geophysical data are included in the details of the associated visible Cloud (RGBCloud) (Fig. 5a), which can be viewed through the link above the popup windows. External data files (historical data and previous interventions) are accessible by external webpages via weblinks, allowing the parallel viewing of all the technical data (Fig. 5c). Similarly, mapped clouds (MAPCloud) can be opened and viewed on the webpage. Here, all the decay patterns can be accessed and recognised thanks to the hotspots (Fig. 5b). As discussed in the method section, MAP and RBG clouds are accessed through the web-GIS pop windows and are related through the same ID code. Thus, their visualisation on the web page can be switched thanks to specific hotspots (Fig. 5b).

Table 2. Details of the acquired towers for ID codes and general data (GN).

ID	*General Data (GN)*							
CODE	*Toponym*	*City*	*Address*	*Longitude*	*Longitude*	*Date of construction*	*Ownership - public (Pb) / private (Pv)*	*New use*
L2MV-T04	Campillo	Arganda del Rey	diseminado Vereda Majaigual s/n	-3.4122	40.2858	1848/49	Pb	museum
L2MV-T05	Quemada de Perales	Perales de Tajuña	camino de la Matagacha s/n	-3.3398	40.2406	Oct.1850	Pv	-
L2MV-T08	Atalaya	Villarejo de Salvanés	c/ del Beato Nicanor, s/n	-3.2032	40.1396	1848/49	Pv	-
L2MV-T09	Belinchón	Belinchón	cam. de Vallejera s/n	-3.0680	40.0567	1848/49	Pb	-
L2MV-T14	Villares del Saz	Villares del Saz	cam. Viejo	-2.5234	39.8324	1848/49	Pb	-
L2MV-T16	Valverde	Valverde de Júcar	cam. del Honcenero	-2.2309	39.7095	1848/49	Pv	-
L2MV-T17	Atajollano	Olmedilla de Alarcón	cam. del Cerro del Telégrafo	-2.1168	39.6252	1848/49	Pv	dovecote
L2MV-T18	Juan Bueno	Motilla del Palancar	cam. de la Torre	-1.9559	39.5610	1848/49	Pv	-
L2MV-T19	Atalayón (Atallazón)	Iniesta	cam. del corral de Salinas	-1.8065	39.5358	1848/49	Pv	-
L2MV-T20	La Muchuela	Graja de Iniesta	cam. de la Paja	-1.6658	39.5114	1848/49	Pb	water tank
L2MV-T21	Altura de la Paradilla	Villargodo del Cabriel	ctra. de las Cabrillas	-1.4672	39.5227	1848/49	Pb	-
L2MV-T22	Cerro de la Vicuerca	Fuenterrobles	ctra. Las Cuevas-Fuenterrobles	-1.3329	39.5875	1848/49	Pb	-
L2MV-T23	Cerro de la Jedrea	Requena	cam. Molino Requejo	-1.1704	39.5348	1848/49	Pv	-
L2MV-T24	Cerro de la Atalaya	Requena	cam. fuente Baldomero	-1.0728	39.5010	1848/49	Pv	-
L2MV-T25	Puntal de la Agudilla	Requena	cam. de la Torre	-0.9682	39.4730	1848/49	Pv	-
L2MV-T26	Alto de la Portilla	Buñol	cam. Cabrera	-0.8166	39.4378	1848/49	Pv	-
L2MV-T27	Alto del Herrero	Godelleta	c/ los Sauces s/n	-0.7041	39.4332	1848/49	Pv	-
L2MV-T28	Cerro de la Muela	Chiva	via Camino s/n	-0.6236	39.4582	1848/49	Pv	warehouse / telecom installation
L2MV-T29	Cerro del Vedado	Torrent	av. San Lorenzo, 90	-0.4903	39.4239	1848/49	Pv	pub-restaurant

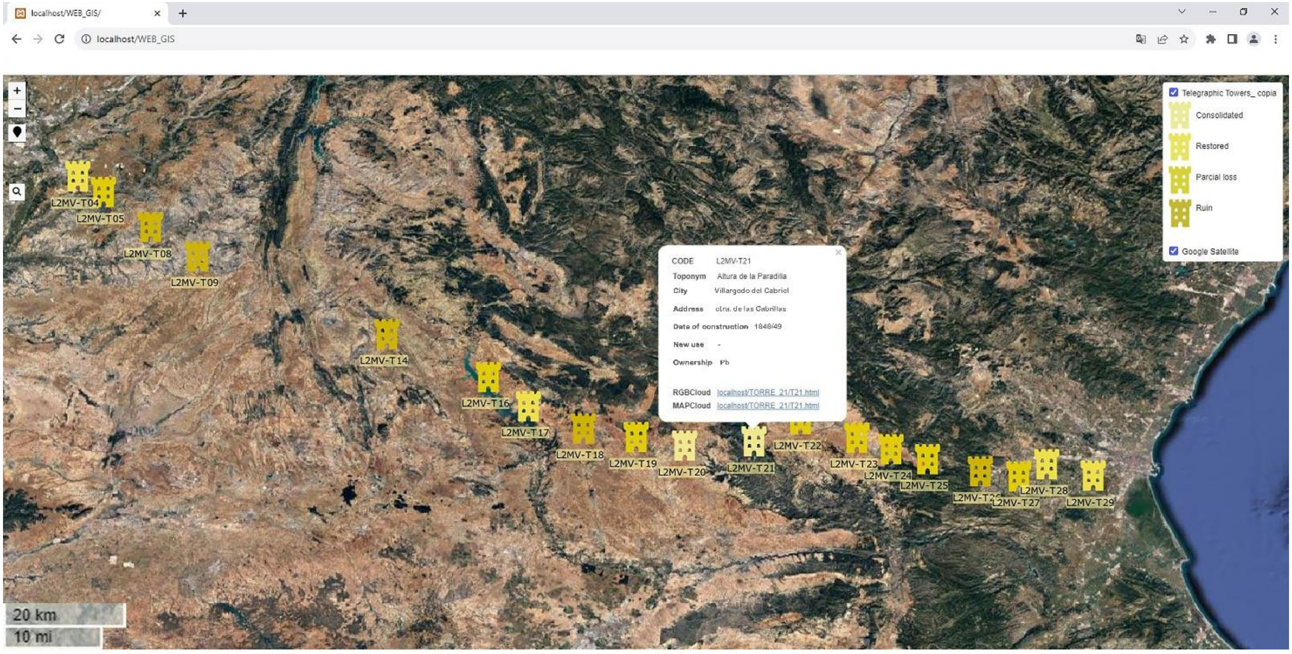

Figure 4: Entry web page of imported towers, detailed about their state of conservation (in the legend). The pop-up window allows the visualisation of details as implemented into the database.

Table 3. Details of the acquired towers for ID codes, state of the fabric, ownership, previous interventions, and geophysical data.

ID	*Technical Data*				*Geophysical data*								
					macro - scale					*micro - scale*			
					natural risk					*wind*			
CODE	*State of conservation (Re Restored; PL partially loss; Ru Ruin; Cd Consolidated)*	*Constructive Type*	*Historical documentation*	*Previous intervention*	*Earthquake (Very Low VL; Low L, Medium M)*	*Wildfire (H high)*	*Landslide (Medium M)*	*Vulcano*	*Climate*	*Speed [m/s²]*	*Direction*	*Vegetation - Monitored (M) / Infesting (I) / Design Strategy (DS) / absent (A)*	*Anthropic pressure - High (H) / Low (L)*
L2MV-T04	Re	CT2			VL	H	-	-	BSk	4.51	240°	DS	L
L2MV-T05	PL	CT1			VL	H	-	-	BSk	5.59	240°	M	L
L2MV-T08	Ru	CT2			VL	H	-	-	BSk	5.68	270°	I	L
L2MV-T09	Ru	CT1			L	H	-	-	BSk	5.92	270°	A	H
L2MV-T14	Ru	CT2			L	H	-	-	BSk	4.71	120°	M	L
L2MV-T16	PL	CT2			L	H	-	-	BSk	5.63	120°; 300°	M	L
L2MV-T17	Re	CT1			L	H	-	-	BSk	6.05	270°	M	H
L2MV-T18	Ru	CT2			L	H	-	-	BSk	6.12	270°	M	L
L2MV-T19	PL	CT2			L	H	-	-	BSk	6.19	270°	I	L
L2MV-T20	Cd	CT1			L	H	-	-	BSk	6.24	270°	A	H
L2MV-T21	Cd	CT1	X	X	M	H	M	-	BSk	5.54	270°; 300°	M	L
L2MV-T22	PL	CT1			M	H	M	-	BSk	5.86	270°; 300°	I	L
L2MV-T23	PL	CT2			M	H	M	-	BSk	6.05	270°	A	L
L2MV-T24	PL	CT1			M	H	M	-	BSk	6.05	270°	A	L
L2MV-T25	PL	CT2			M	H	M	-	BSk	6.05	270°	I	L
L2MV-T26	Ru	CT2			M	H	M	-	BSk	5.05	270°	I	L
L2MV-T27	PL	CT2			M	H	M	-	BSk	4.05	270°	I	L
L2MV-T28	Re	CT2			M	H	M	-	BSk	6.35	270°	DS	H
L2MV-T29	Re	CT3	X		M	H	M	-	BSk	4.52	270°	A	H

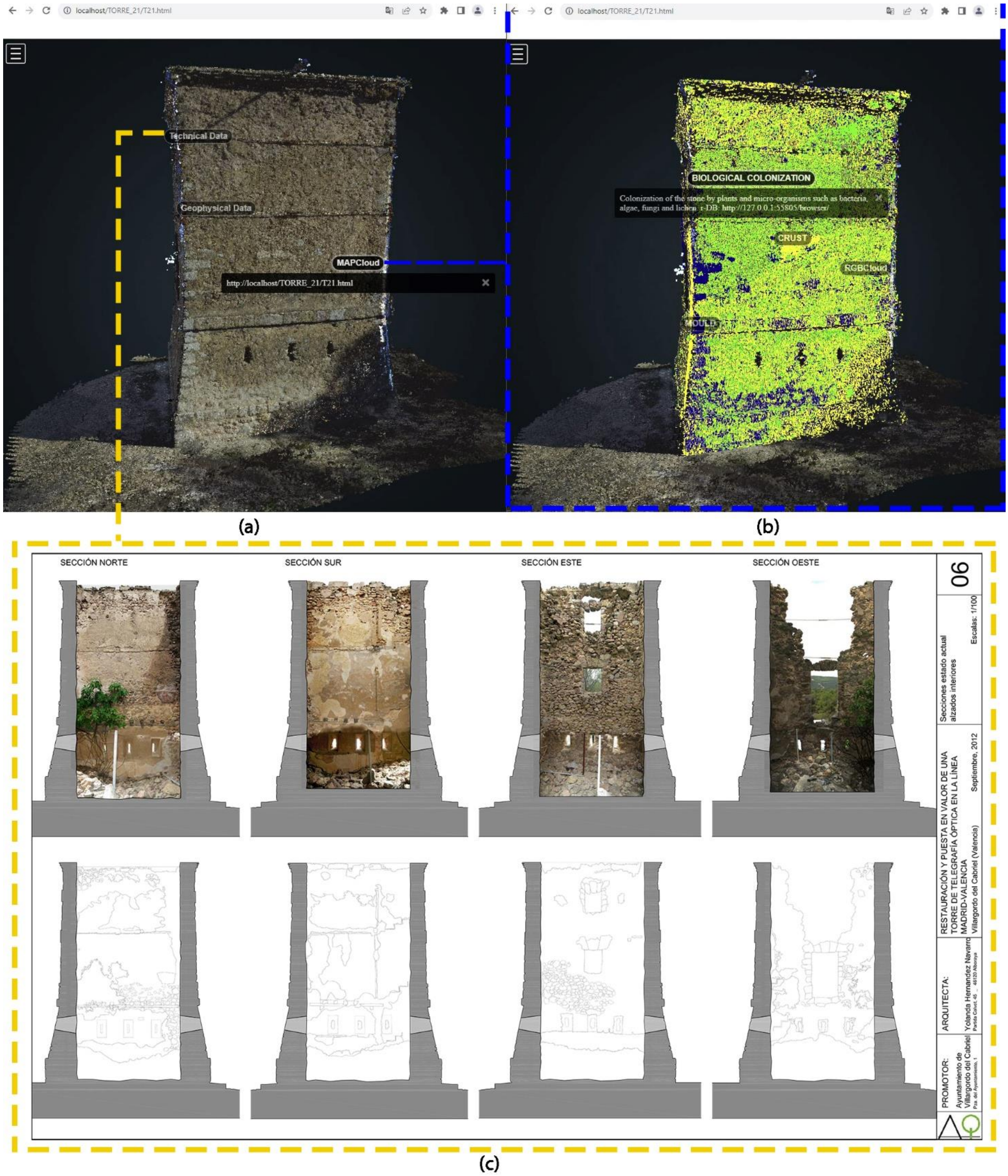

Figure 5: (a) Details of the RGBCloud visualisation, technical and geophysical data in the web-based viewer and (b) links to the MAPCloud of the L2MV-T21 (blue rectangle) and (c) external data referred to previous interventions collected for the same tower (yellow rectangle – A3 technical drawing of previous studies).

While all the towers have been integrated into the GIS environment, for the sake of brevity, the results of mapping and decay analysis are presented for two towers: L2MV-T21 and L2MV-T22. The main goal is to show the potentialities of the platform, the complexity of data to manage, and the consideration of decay and interventions coherently with technical data of towers and boundary conditions.

As summarised in Table 2, L2MV-T21 and L2MV-T22 share the main constructive characteristics. They have been built entirely of stone with masonry and lime mortar in the structural panels of the façade and with ashlars in the corners, cornices, jambs and lintels (CT1). Also, the upper cornices are of limestone slabs. Both are located at high elevations of the territory, allowing the extension of the distance between them (13 km) and with the previous and next towers (15 km) being the average distance of the line much lower. Specifically, the L2MV-T21 tower is in the Altura de la Paradilla in the town of Villargordo del Cabriel (Valencia) positioned at 924 m a.m.s.l.. The main façade (entrance) faces west. It is located in the Natural Park of the Hoces del Cabriel. This institution protects its territory and controls the vegetation constituted of scrub to the south and pine forests in the other orientations. The openings (door and windows) are located on the west and east façade of the two upper floors, allowing the optical connection with the previous and next towers; on the ground floor, three loopholes are on each façade.

From the documentation collected in the investigation, it is stated that in 2013 it was intervened with actions to consolidate the structural envelope that in some points had been reduced to half its thickness and the reconstruction by anastylosis of the window openings of the second floor. In the same intervention, the eroded joints were filled, especially on the upper floors, and the flat roof slab was built. In the intervention, the original pavement of the ground floor and the start of the spiral staircase were found. Exclusively lime mortars and stone elements recovered in situ by the collapse were used in the consolidation. The glulam beams were placed in their original position. It is still pending to finish the interventions of phases II and III, planned to eliminate materials unsuitable for previous interventions and reconstruct the intermediate floors, stairs and carpentry. The intervention is recognisable and allows it to be excluded from the analysis performed in this study.

The west facade, more exposed to the prevailing winds (Table 3), had almost completely lost the coating of the plasters to grow next to the tower before the intervention that accelerated the erosion and loss of the structural mortars, causing the partial collapse at the level of windows. Besides, the vegetation that, before the intervention, grew next to the tower aggravated the situation. Currently, the lime plasters are preserved on the northern façade, although the biological attack (biological crust and mould), and to a lesser extent on the south one.

The L2MV-T22 tower is located in the Cerro de la Vicuerca (or Bicuerca) in the mountain range of the same name on the border between Fuenterrobles and Utiel (Valencia) at a height of 1070 m a.m.s.l., being the highest in the province. Accessibility to the site through steep paths that run along the hillside is very complicated. The openings are located on the southwest and northeast façade of the two upper floors in the direction of the previous and next towers, preserving the three loopholes for each façade on the ground floor. The surrounding vegetation has been controlled with a felling of trees, but until recently, the tower was surrounded by pines and bushes that have accelerated the degradation phenomena, enhancing the pathologies related to low radiation exposure and dump or mould presence in most vertical surfaces.

The area is windy wildly from the west, where there has been a complete loss of the protective surfaces of the structural envelope. The northeast and southeast facades preserve the original plasters, although with partial detachments.

This tower has yet to be intervened; the only action has been installing an explanatory sign in the vicinity. The lack of roof and slabs also exposes the interior spaces where a fig tree has grown, further damaging its stability to degradation. For the same reason, it presents localised landslides and partial material losses. As described in the method, the RGBClouds of L2MV-T21 and L2MV-T22 are processed in order to recognise and locate the decay patterns. Figg. 6 and 7 depict the extension of biological colonisation and crust, which are most extended in the northern and western façades for L2MV-T21 and extremely spread in L2MV-T22 also on the southern walls. In both towers, it has been possible to distinguish and map the areas of the masonry affected by mould from the other types of biological colonisation degradation. Additionally, during the decay mapping process, mould was found along the mortar joints in the lower part of the walls and along the corners of tower L2MV-T21. In L2MV-T22, mould was found throughout the extension of the mortar joints of the tower. Regarding the causes of these decay patterns, the variation in the extent of mould along the facades of L2MV-T21 and L2MV-T22 is related to the different states of conservation of mortar joints. L2MV-T21 has been recently consolidated, while L2MV-T22 is featured by very porous mortars as a consequence of the overall lower state of conservation of its structure. On the other hand, the extensive biological colonisation and crusts along all the facades of L2MV-T22 are attributable to different micro-scale environmental conditions related to vegetation. In fact, infesting vegetation along the boundaries of L2MV-T22 determines high humidity levels on the vertical surfaces and reduces direct solar radiation, affecting the overall performances of the masonry on all cardinal exposures. In contrast, similar conditions only affect the northern and western facades of L2MV-T21.

For all the mapped decay patterns, specific hotspots have been added to the MAPCloud and linked to the associated tower ID in the r-DB. In this way, it is possible to use the MAPCloud model and display single types of decay patterns as point clouds, as have resulted from the semi-automatic mapping, classification and segmentation process of the RGBCloud.

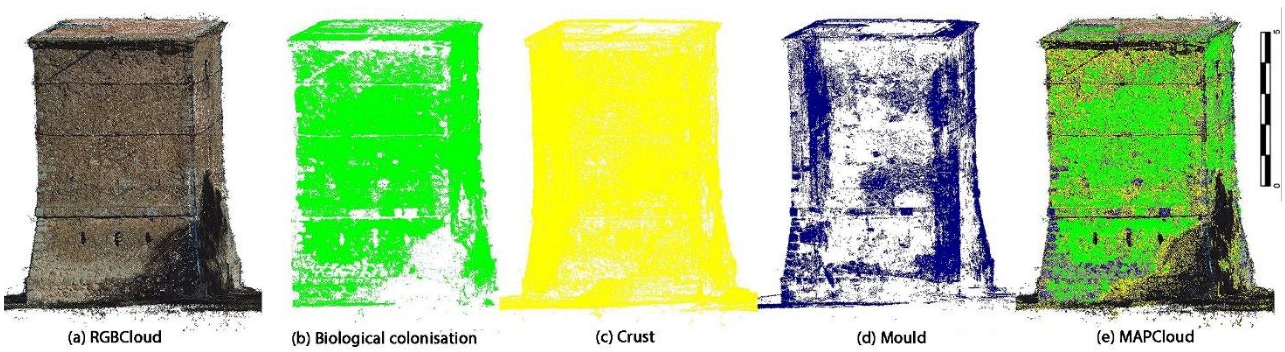

Figure 6: a) RGBCloud of the L2MV-T21; b) distribution of biological colonisation in green; c) distribution of the crust in yellow; d) distribution of mould in blue; and e) final MapCloud of the tower on the northern façade.

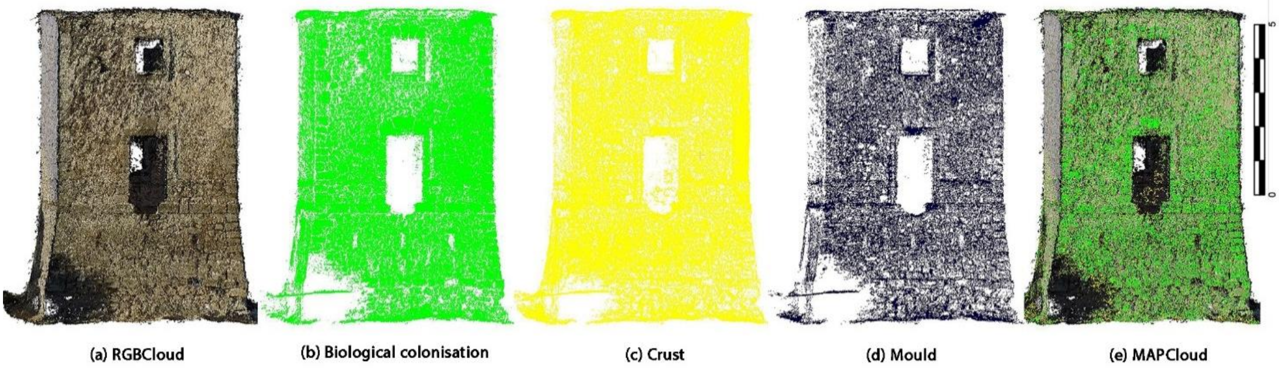

Figure 7: a) RGBCloud of the L2MV-T22; b) distribution of biological colonisation in green; c) distribution of the crust in yellow; d) distribution of mould in blue; and e) final MapCloud of the tower on the west façade.

As demonstrated, the knowledge about the extension, location and boundary conditions of these pathologies enables the interpretation of their causes and the selection of appropriate interventions. Specifically, according to the structured r-DB, the detailed decays are tested within the platform. Here, the structured relations allow users to select, among the available ones, the most suitable cause/s and validate it/them, checking all the information. Moreover, the availability of information about external conditions supports technicians in assessing and selecting suitable interventions among the possible ones, considering the relations superimposed within the r-DB about the interventions. Similar considerations apply to the presence of information about previous interventions, which can also support the interpretation of the decays. In detail, according to the structure of the database, for the diagnosis validation within the platform, the relations structured within the r-DB return the possible associated strategies in the specific intervention section for each macro-class. Therefore, in the intervention section, it is possible to select the required interventions available within the macro-class. As it is schematized in Fig. 8, while surface cleaning is a common intervention for both the discussed towers, the redesign and control of vegetation are additional and required interventions for the L2MV-T22 due to the infested trees along its boundaries.

4. Discussion

The use of digital models for the representation and assessment of real cases of architectural Cultural Heritage is currently a central point of discussion in the scientific and operative fields. However, this digitalisation process requires a structured system of rules in order to ensure a higher quality of the results. As is fully argued in the literature, this digitalisation process is not a simple pipeline of actions and chains of outputs/inputs among tools and software, but rather a structured set of actions which find fundaments in the traditional procedures as the basis of the operative chains. In that sense, the described method applied for the Spanish telegraphic towers has taken advantage of the photogrammetric techniques, geographic systems, relational databases, and machine learning techniques within a structured set of operative actions for the setup of a web-based platform for the collection and the management of technical knowledge of the selected architectures. Here, the operative pipeline aims at solving some widespread operative and theoretical necessities in the conservation process of systemic architectures (Argyridou et al., 2023; Maietti, 2022; Morandotti & Doria, 2023; Salerno, 2019; UNESCO (United Nations Educational, 2011):

- The standardisation of technical knowledge. The use of common rules in the acquisition procedures of point clouds, the cataloguing of decays (ICOMOS), and the systematisation of technical details according to coherent classes of details allow all the involved operatives to overcome subjective interpretation of the fabrics. This in in line with the necessity to read and classify the recurrent peculiarities on the basis of the values of "systemic" architectures.
- The normalisation in interpreting decays. The coherent structure of physical and material details is combined with the rigid structure of the glossary for decay identification (ICOMOS) and the automatic (but calibrated) procedures in the decay location (machine learning). In that sense, technicians involved in pathological identification could be supported in the interpretation phase. Moreover, these elements, integrated with the use of realistic digital models in point clouds, allow an extended overview of pathologies, also in not accessible parts of fabrics (e.g., ceilings).
- The normalisation in recognising causes. The full knowledge of intrinsic and extrinsic features of fabrics is the central node of the resolution of the diagnosis phase. The normalisation of decays and the comprehensive details about transformations and construction materials and techniques, besides external strengths (natural or anthropic), allow to equip technicians with a comprehensive toolkit for assessing the fabrics. As it is clear, the relational database has a key role in that sense and requires to be set up in a coherent way, taking advantage of the deep knowledge for the specific case study.
- The regulation of interventions. The identification of a set of suitable interventions for the resolution of the possible pathologies and the control of extrinsic factors which are involved in the cause-effect of the process, support technical and administrative decisions. On the other hand, the identification a priori of this system of interventions is also in line with the conservation prerogative for systemic buildings. Compatible and homogeneous transformations represent the common features of suitable interventions to consider for safeguarding, in a systemic way, landscape, technical and cultural significance of this class of architectures.

Figure 8: a) Selection of the L2MV-T22 tower in the web-based platform; b) visualisation of the RGBCloud model and details of the selected tower and implementation of the decay choice in the MAPCloud; c) selection of possible causes of biological colonisation within the r-DB properly checked with the collected data; and d) details about interventions compatible with the features of towers showing the possible (orange) and the selected (green) ones.

All these advantages have been systematised in the web-based platform which constitutes both the interface and the operative tool for the process, allowing the interdisciplinarity interchange of the required knowledge (i.e., physical properties, environmental conditions, determination of strategies) and the control of the phases in an overordered way (e.g., management of priorities of interventions). Moreover, due to this, the management of the overall extension of the case study in a single web platform enhances its potential to be extended as a service. The geographical basis and the geophysical information of the places already included in the models get ready to be extended with further technical, landscape or administrative details required for their reuse (e.g., touristic paths) or with physical damages caused by extreme or hazardous events towards service to improve resilience for the Madrid-Valencia path, supporting risk management and risk communication (UNISDR, 2015; Valdés, Amaratunga, & Haigh, 2013).

5. Conclusions

The present study shows the opportunities offered by innovative tools for collecting, managing, and sharing technical knowledge related to systemic architectures, organised within a collaborative platform. This was developed to manage and share data collected on the Telegraphic Towers – Line 2 Madrid Valencia - over the past few years by the Spanish research group. One of the critical challenges encountered during these activities was the need to establish a structured framework for each tower to create an organised database for their preservation based on a prioritisation approach. Additionally, the collected data represent a valuable resource, considering the historical significance of these towers and the lack of detailed information available over time. These data can be shared with public administrations for potential reuse and revitalisation of towers after their preservation, considering geographic distribution and various dimensions for their assessment, including construction and technical details, and geophysical and environmental conditions.

While the structured method for setting up the platform is based on different information tools, the approach aims to organise them into a coherent system of multi-tools for the analysis of the examined architectures using acquired point clouds. The 3D models resulting from digital photogrammetry techniques are enriched at the informative-semantic level by connecting them with technical cognitive information. This information is coherently archived and systematised within relational databases, aiming at structuring a technical decision-making system. Furthermore, these models are geolocated using spatial information systems and are employed for the analysis of the state of conservation through artificial intelligence algorithms, which are useful for the semi-automatic mapping of surface degradation. Specifically, the paper emphasises how digital models, properly georeferenced, related to informative systems and shared in web tools, can support all the technical users involved in the recovery process for their preservation. The use of an open-source but well-configured web platform allows public bodies and technicians to access informative data and select interventions for Cultural Heritage while having all the details available in a unique database. This approach is beneficial for all types of buildings, but it is particularly advantageous for extensive architectural complexes where cultural and historical relevance is a common thread. In fact, given the widespread challenges in managing systemic architectures, the use of a single digitalised environment helps overcome fragmented and non-uniform details, data and properties, often associated with the opportunity to be collected, the period of collection, the involvement of technicians in knowledge process, and their personal repositories. Moreover, the platform can serve as a database of all the projects to reuse single towers as sources of best practices, common practices, and lessons learned, providing all the data and details to monitor design activities and manage new ones.

Furthermore, the use of a web-based platform has demonstrated how controlled access, specifically through email authentication, can assist public bodies in sharing the contents while dominating the rules of final users and their permissions in modifying and implementing data. This is in line with the traditional way of managing administrative knowledge for real operative technicians. In the case study application, such opportunities have also been tested to promote the integration of historical information about Telegraphic towers during the time due to the scarceness of details as a consequence of their loss after their dismission.

Another significant benefit for systemic architectures is provided using digital models. Considering the lower level of attention that these towers receive at administrative and tourist scales, there is a risk of their physical and functional obsolescence, potentially leading to their complete loss. Digitalised architectural models can help preserve their cultural significance over time, ensuring their cultural preservation in the Spanish territory. Furthermore, the existence of digital models on a shared platform can support their ongoing response to changing relevance over time, managing the progression of decay patterns, and assessing them while external strengths, such as climate change effects, and anthropic pressure, alter their micro and macro environmental conditions.

All these issues contribute to extending the broader issue of the European digital transition for controlling and monitoring Cultural Heritage, encompassing both the “as built” and “reuse” dimensions. This approach allows for the asynchronous management of individual structures and their spatial variability, considering the inherent significance of systemic architectures, in alignment with traditional methods for their preservation and revitalisation.

Author Contributions

Conceptualisation: Elena Cantatore, Margherita Lasorella; Data Curation: Margherita Lasorella; Formal Analysis: Margherita Lasorella; Investigation: Margherita Lasorella, Pasquale de-Dato; Methodology: Elena Cantatore, Margherita Lasorella; Resources: Pasquale de-Dato; Software: Margherita Lasorella; Visualisation: Margherita Lasorella, Pasquale de-Dato; Supervision: Elena Cantatore; Writing – Original Draft Preparation: Elena Cantatore, Margherita Lasorella, Pasquale de-Dato; Writing – Review & Editing: Elena Cantatore.

References

Acampa, G., Battisti, F., & Grasso, M. (2023). Decision Support System for the Management of Interventions on Buildings in the Historic Centre of Florence: From Conservation to Regeneration. In International Conference on Computational Science and Its Applications (pp. 329–340). Springer. https://doi.org/10.1007/978-3-031-37126-4_22

Aftabi, P., & Bahramjerdi, S. F. N. (2023). Developing a decision-making framework within the management of historical cities: Towards integrated conservation and development of the Roudaki neighbourhood. *Land Use Policy, 129.* https://doi.org/10.1016/j.landusepol.2023.106653

Argyridou, E., Karaoli, A., Hadjiathanasiou, M., Karittevli, E., Panagi, I., Mateou, M., … Efstathiou, K. (2023). The first attempt for standardisation in 3D digitisation. The EU study on quality in 3D digitisation of tangible Cultural Heritage. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-M–2,* 103–109. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-103-2023

Banfi, F., Brumana, R., & Stanga, C. (2019). Extended reality and informative models for the architectural heritage: from *scan-to-BIM process to virtual and augmented reality. Virtual Archaeology Review, 10(21),* 14. https://doi.org/10.4995/var.2019.11923

Bas García, V. (2021). *La realidad digital al servicio del patrimonio arquitectónico. El caso de la torre telegráfica de Godelleta como experiencia interactiva* (Universitat Politècnica de València). Universitat Politècnica de València. Retrieved from http://hdl.handle.net/10251/180656

Bochenska, A., Kot, P., Muradov, M., Markiewicz, J., Zawieska, D., Hess, M., & Antoniou, A. (2023). Critical evaluation of Cultural Heritage architectural standard documentation methods across different European countries. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-M–2*(M-2–2023), 251–258. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-251-2023

Borin, P., Bernardello, R. A., & Grigoletto, A. (2020). Connecting Historical Information with BIM Ontologies. HBIM Methods for the Visualization of Harris Matrix for the Torrione in Carpi. In *Graphical Heritage: Volume 1-History and Heritage* (pp. 757–770). Springer. https://doi.org/10.1007/978-3-030-47979-4_65

Bruno, S., Galantucci, R. A., & Musicco, A. (2023). Decay detection in historic buildings through image-based deep learning. *VITRUVIO - International Journal of Architectural Technology and Sustainability, 8,* 6–17. https://doi.org/10.4995/vitruvio-ijats.2023.18662

Bruno, S., Scioti, A., Pierucci, A., Rubino, R., Di Noia, T., & Fatiguso, F. (2022). VERBUM – virtual enhanced reality for building modelling (virtual technical tour in digital twins for building conservation). *Journal of Information Technology in Construction, 27,* 20–47. https://doi.org/10.36680/j.itcon.2022.002

Cacciotti, R., Valach, J., Kuneš, P., Čerňanský, M., Blaško, M., & Křemen, P. (2013). Monument Damage Information System (MONDIS): an ontological approach to Cultural Heritage documentation. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, II-5/W1,* 55–60. https://doi.org/10.5194/isprsannals-II-5-W1-55-2013

Carniello, M. F., Dos Santos, M. J., & Pimenta, C. A. M. (2022). The territorial approach to development: a methodological perspective to the cultural dimension and its components. *Revista Brasileira de Gestao e Desenvolvimento Regional, 18*(1), 117–133. https://doi.org/10.54399/rbgdr.v18i1.6517

Costantino, D., Pepe, M., & Restuccia, A. G. (2023). Scan-to-HBIM for conservation and preservation of Cultural Heritage building: the case study of San Nicola in Montedoro church (Italy). *Applied Geomatics, 15*(3), 607–621. https://doi.org/10.1007/s12518-021-00359-2

Currà, E., D'Amico, A., & Angelosanti, M. (2021). Representation and knowledge of historic construction: HBIM for structural use in the case of Villa Palma-Guazzaroni in Terni. *Rivista Tema, 7*(1), 8–20. https://doi.org/10.30682/tema0701b

de-Dato, P., & Hernández Navarro, Y. (2016). De torre en torre: mensajes codificados en los cielos de la Meseta. *Oleana: Cuadernos de Cultura Comarcal,* (30), 159–175.

Dörr, M. (2002). The CIDOC CRM-an ontological approach to semantic interoperability of metadata, 2001. *AI Magazine, Special Issue on Ontologies.*

Egusquiza, A., Brostrom, T., & Izkara, J. L. (2022). Incremental decision making for historic urban areas' energy retrofitting: EFFESUS DSS. *Journal of Cultural Heritage, 54*, 68–78. https://doi.org/10.1016/j.culher.2022.01.011

Fatiguso, F., De Fino, M., Cantatore, E., & Caponio, V. (2017). Resilience of Historic Built Environments: Inherent Qualities and Potential Strategies. *Procedia Engineering, 180*, 1024–1033. https://doi.org/10.1016/j.proeng.2017.04.262

Grilli, E., Farella, E. M., Torresani, A., & Remondino, F. (2019). Geometric features analysis for the classification of Cultural Heritage point clouds. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W15*, 541–548. https://doi.org/10.5194/isprs-archives-XLII-2-W15-541-2019

Kioussi, A., Karoglou, M., Labropoulos, K., Bakolas, A., & Moropoulou, A. (2013). Integrated documentation protocols enabling decision making in Cultural Heritage protection. *Journal of Cultural Heritage, 14*(3), e141–e146. https://doi.org/10.1016/j.culher.2013.01.007

Lasorella, M., & Cantatore, E. (2023). 3D models CityGML-based combined with technical decision support system for the setting up of digital conservation plans of historic districts. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-M–2*(M-2–2023), 911–918. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-911-2023

Lasorella, M., Cantatore, E., & Fatiguso, F. (2021). Smart approaches to enhance technical knowledge of in/low-accessible heritage. *SCIRES-IT-SCIentific RESearch and Information Technology, 11*(2), 97–112. http://dx.doi.org/10.2423/i22394303v11n2p97

Benavides López, J. A., Martín Civantos, J. M., & Rouco Collazo, J. (2020). Architectural survey and archaeological analysis of the pinar castle as a starting point for its conservation. *Virtual Archaeology Review, 11*(22), 95–115. https://doi.org/10.4995/var.2020.12397

Maietti, F. (2022). Digital Documentation for Enhancement and Conservation of Minor or Inaccessible Heritage Sites. In *Cultural Leadership in Transition Tourism: Developing Innovative and Sustainable Models* (pp. 139–156). Springer. https://doi.org/10.1007/978-3-031-14121-8_8

Maietti, F., Di Giulio, R., Medici, M., Ferrari, F., Ziri, A. E., Turillazzi, B., & Bonsma, P. (2020). Documentation, Processing, and Representation of Architectural Heritage Through 3D Semantic Modelling. In *Impact of Industry 4.0 on Architecture and Cultural Heritage* (pp. 202–238). IGI Global. https://doi.org/10.4018/978-1-7998-1234-0.ch009

Martino, A., Savini, P., Hernández Navarro, Y., de-Dato, P., & Fatiguso, F. (2022). The historical telegraphic towers from Madrid to Valencia: from knowledge to preservation and enhancement. *Journal of Architectural Conservation, 28*(3), 243–260. https://doi.org/10.1080/13556207.2022.2061133

Matrone, F., & Martini, M. (2021). Transfer learning and performance enhancement techniques for deep semantic segmentation of built heritage point clouds. *Virtual Archaeology Review, 12*(25), 73. https://doi.org/10.4995/var.2021.15318

Morandotti, M., & Doria, E. (2023). Information system as tool for Cultural Heritage documentation and preservation. Protocol structuring and testing on a case study. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-M–2*, 1081–1088. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-1081-2023

Noardo, F. (2018). Architectural heritage semantic 3D documentation in multi-scale standard maps. *Journal of Cultural Heritage, 32*, 156–165. https://doi.org/10.1016/j.culher.2018.02.009

Olivé Roig, S. (2007). Distintas etapas de la telegrafía óptica en España. *Cuadernos de Historia Contemporánea*, 29, 29–34.

Peña-Villasenín, S., Gil-Docampo, M., & Ortiz-Sanz, J. (2019). Professional SfM and TLS vs a simple SfM photogrammetry for 3D modelling of rock art and radiance scaling shading in engraving detection. *Journal of Cultural Heritage, 37*, 238–246. https://doi.org/10.1016/j.culher.2018.10.009

Pepe, M., Costantino, D., Crocetto, N., & Restuccia Garofalo, A. (2019). 3D modeling of roman bridge by the integration of terrestrial and UAV photogrammetric survey for structural analysis purpose. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 42*(2/W17), 249–255. https://doi.org/10.5194/isprs-archives-XLII-2-W17-249-2019

Perumal, R., & Venkatachalam, S. B. (2023). Non Invasive Decay Analysis of Monument Using Deep Learning Techniques. *Traitement Du Signal, 40*(2), 639–646. https://doi.org/10.18280/ts.400222

Pintossi, N., Ikiz Kaya, D., & Pereira Roders, A. (2023). Cultural heritage adaptive reuse in Salerno: Challenges and solutions. *City, Culture and Society, 33*. https://doi.org/10.1016/j.ccs.2023.100505

Pouso-Iglesias, P. X., Arcones-Pascual, G., Bellido-Blanco, S., & Valentín-Gamazo, D. V. (2023). Abandoned rural pre-industrial Heritage: study of the Riamonte mill complex (Galicia, Spain). *Virtual Archaeology Review, 14*(28), 95–109. https://doi.org/10.4995/var.2023.18652

Romeo López, J. M. (1980). El telégrafo óptico: 1790-1850: estudio crítico comparativo de los diferentes sistemas de transmisión utilizados. *El Científico Español Ante Su Historia: La Ciencia En España Entre 1750-1850: I Congreso de La Sociedad Española de Historia de Las Ciencias*, 241–250. Diputación Provincial de Madrid.

Rosário, A., & Dias, J. (2022). Sustainability and the Digital Transition: A Literature Review. *Sustainability, 14*(7), 4072. https://doi.org/10.3390/su14074072

Salerno, R. (2019). Digital Technologies for "Minor" Cultural Landscapes Knowledge. In *Geospatial Intelligence* (pp. 1645–1670). IGI Global. https://doi.org/10.4018/978-1-5225-8054-6.ch073

Saricaoglu, T., & Saygi, G. (2022). Data-driven conservation actions of heritage places curated with HBIM. *Virtual Archaeology Review, 13*(27), 17–32. https://doi.org/10.4995/var.2022.17370

Sonnessa, A., di Lernia, A., Oscar Nitti, D., Nutricato, R., Tarantino, E., & Cotecchia, F. (2023). Integration of multi-sensor MTInSAR and ground-based geomatic data for the analysis of non-linear displacements affecting the urban area of Chieuti, Italy. *International Journal of Applied Earth Observation and Geoinformation, 117*, 103194. https://doi.org/10.1016/j.jag.2023.103194

UNESCO (United Nations Educational, S. and C. O. (2011). *Recommendation on the Historic Urban Landscape*. UNESCO World Heritage Centre Paris, France.

UNISDR. (2015). *Sendai framework for disaster risk reduction 2015-2030* (UNISDR United Nations International Strategy for Disaster Reduction, Ed.).

Valagussa, A., Frattini, P., Crosta, G., Spizzichino, D., Leoni, G., & Margottini, C. (2021). Multi-risk analysis on European cultural and natural UNESCO heritage sites. *Natural Hazards, 105*(3), 2659–2676. https://doi.org/10.1007/s11069-020-04417-7

Valdés, H. M., Amaratunga, D., & Haigh, R. (2013). Making Cities Resilient: from awareness to implementation. *International Journal of Disaster Resilience in the Built Environment, 4*(1), 5–8. https://doi.org/10.1108/17595901311299035

Vergès-Belmin, V. (Coord.) (2008). *Illustrated glossary on stone deterioration patterns*. ICOMOS International Scientific Committee for Stone (ISCS). https://www.icomos.org/public/publications/monuments_and_sites/15/pdf/Monuments_and_Sites_15_ISCS_Glossary_Stone.pdf