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SMART APPROACHES TO ENHANCE TECHNICAL KNOWLEDGE OF IN/LOW-ACCESSIBLE HERITAGE

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Abstract

For Cultural Heritage, the knowledge phase has a key role in the recovery process and it requires to be related to the in/low accessibility level of architecture. Even if, the "accessibility" usually relates the physical dimension of architecture to the end-users, inherent morphological and conservative features, as well as external stresses, may compromise the full knowledge of architecture by technicians involved in the recovery process. Due to that, the paper identifies a fast and smart approach for the remote fruition and knowledge of inaccessible and low accessible Heritage using Virtual Reality-based model. These are designed combining Virtual Tours, based on spherical images of the real environment, and relational database to support technicians in remote semi-guided analysis, diagnosis and assessment of the Heritage. Smartness and potentialities of the methodology are finally tested to the representative case of "Palazzo Carmelo" (Cerignola, Apulia Region, Italy).

Keywords

Virtual Reality, Cultural Heritage, Accessibility, Technical Knowledge, "Palazzo Carmelo"

1. *Introduction*

One of the main goals of a recovery project is to guarantee the full accessibility of architectures for end-users, providing useful interventions to delete all the physical barriers. However, before the design phase, the "accessibility" of architectures should be referred also to preliminary ones, such as those for their technical knowledge (Agostiniano, 2016). This earliest step represents a fundamental phase in the recovery process (Brandi, 1963) because of its relevance in observing the architecture and collecting and interpreting its characters in order to properly diagnose and identify the required interventions (Caprili & Puncello, 2019). It is not uncommon for technicians to be involved in the recovery process of low accessible or completely inaccessible architectures, also in the first activities. Here, the level of accessibility is related to all the starting users of the process, such as architects, engineers, diagnostic experts and restorers. However, the lack of accessibility can be related also to "inherent features of the building" or to external and unpredictable "stresses". The "inherent features of the building" refer to the objective characters of the architectures which decrease the whole level of fruition such as a) geographical characters of the site (Scianna & La Guardia, 2019), b) the morpho-typological features (Paladini, Dhanda, Reina Ortiz, Weigert, Nofal, Min, Gyi, Su, Van Balen, & Santana Quintero 2019) iii) the state of conservation of the buildings (Sánchez-Aparicio, Masciotta, García-Alvarez, Ramos, Oliveira, Martín-Jiménez, González-Aguilera & Monteiro, 2020) iv) the inherent environmental conditions (e.g. indoor ventilation and lighting) (Cantatore, Lasorella, & Fatiguso, 2020) and/or v) historical processes of transformations and interventions requiring several technical knowledge and skills (Messaoudi, Véron, Halin, & De Luca, 2018).

In addition to these, external natural or anthropic "stresses" may alter the accessibility of exposed places and buildings (Trizio, Savini, Giannangeli, Fiore, Marra, Fabbrocino, & Ruggieri, 2021) such as the pandemic emergency where the effects of lockdown and the temporal uncertainty of pandemic duration created stresses to the traditional recovery processes. The presence or the combination of these elements may lead technicians to determine a double level of building qualification: i) architectures with low accessibility, where fruition is allowed for a limited time and ii) inaccessible ones, when the access is completely denied (e.g., critical statical features). The combination of inherent criticalities for morphological and constitutive features of buildings and external forces emphasizes the necessity to change the paradigms for operative approaches. Here, the use of innovative operative codes is required in order to enhance and support the recovery process for critical architectures, involving both knowledge and design phases.

Specifically, the use of disruptive tools for the acquisition and digitalization of architectures represents the opportunity to solve these critical issues, combining methodological requirements and innovation potentialities (Banfi, 2020; Maiellaro, Varasano, & Capotorto, 2018).

Starting from these issues, the paper aims at determining a smart methodological approach to support the technical knowledge and the fruition of architectures featured by in/low accessibility by expert users, using Virtual Models and Virtual Reality tools.

2. *Digital Models and Virtual Reality to ensure an accessible technical knowledge*

The increasing trend in using and developing Information Communication Technologies (ICTs) over the last years promoted new openings also for the fruition and the analysis of cultural heritage. Previous experiences highlighted the potentialities of Digital Models (DMs), based on Virtual Reality (VR) experience, in providing documental supplies for touristic fruition (e.g. Virtual tours and digital reconstructions) (De Fino, Ceppi, & Fatiguso, 2020; Pybus, 2019), as well as in creating structured digital databases for the knowledge, the preservation and the management of the existent architectures (Cantatore et al., 2020; Ferrari & Medici, 2017; Harun & Mahadzir, 2021). Moreover, DMs also provide to enhance the diagnostic and recovery activities for Cultural Heritage in order to interact with the digitalised buildings for the fruition, the analysis and the management of related technical contents (Comes, Neamțu, Buna, Bodi, Popescu, Tompa, Ghinea, & Mateescu-Suciu, 2020; Di Giulio, 2021; Maiellaro et al., 2018). On the other hand, the use of Virtual Models (VMs), as specific structured DMs based on the Virtual Reality (VR) techniques, underlined the possibility to manage a variety of information between several actors involved in the recovery process of Cultural Heritage (Banfi, Brumana, & Stanga, 2019). In fact, VMs can be structured as digital databases where all the information can be related among them and the visualized scenes. At the basis of their structures, the VMs can be linked to information systems (hierarchical, network, relational and object-oriented databases systems) for the digital storage and management of data (Messaoudi et al., 2018; Stefani, Brunetaud, Janvier-Badosa, Beck, De Luca, & Al-Mukhtar, 2014; Vallet, De Luca, Feillou, Guillon, & Pierrot-Deseilligny, 2012), as well as to Decision Support Systems to relate technical information (organized as parameters) through multi-criteria relations and Artificial Intelligence algorithms (e.g. Machine learning). These became important in supporting technical users also during the diagnosis, solving semi-structured relations based on widespread ontologies, rules and regulations (Brunetaud, De Luca, Janvier-Badosa, Beck, & Al-Mukhtar, 2012; Cacciotti, 2015; Falcão, Machete, Castilho Gomes, & Gonçalves, 2021; Kioussi, Karoglou, Protopapadakis, Doulamis, Ksinopoulou, Bakolas, & Moropoulou, 2021). Moreover, focusing on the visible relevance of such digitalised environment, the use of VMs allows the re-creation of faithful and accurate virtual copies of real architectures to be fruited and analysed in remote view and with different immersive levels: full immersive or semi-immersive (Cipresso, Giglioli, Raya, & Riva, 2018).

This overcoming the in-situ surveys towards remote ones in the recovery process (Germak, Di Salvo, & Abbate, 2021). Due to such chances, the identification of new methods and operative approaches followed starting from VMs, trying to solve the interoperability of data and the exchange of knowledge between all the users involved in the recovery process, by means of a unique digital system (Rubio-Tamayo, Gertrudix Barrio, & García García, 2017). On the other hand, to understand how such goals have been reached as well as the relations between VMs and tools, research of recent scientific projects developed in Europe has been carried out. In particular, 7 projects involved in the analysis, diagnosis and preservation activities for Cultural Heritage have been selected, summarizing results in Tab. 1 (Al-Mukhtar, Chaaba, Atki, Mahjoubi, Deleplancque, Beck, Brunetaud, Janvier, Cherkaoui, Aalil, Badreddine, & Sakali, 2016; Bertacchi, Al Jawarneh, Apollonio, Bertacchi, Cancilla, Foschini, Grana, Martuscelli, & Montanari, 2018; De Fino, Scioti, Rubino, Pierucci, & Fatiguso, 2018; Di Giulio, Boeri, Longo, Gianfrate, Boulanger, & Mariotti, 2021; Fatiguso, Cantatore, Di Noia, Scioti, Bruno, & Pierucci, 2021; Janvier-Badosa, Beck, Brunetaud, & Al-Mukhtar, 2016; Ramos, Masciotta, Morais, Azenha, Ferreira, Pereira, & Lourenço, 2018).

Tab. 1: Summary of projects developed in Europe involved in the analysis, diagnosis and preservation activities for Cultural Heritage

Name Project (ref)	Years	Funding	Goal	Digital Model Types	Database Type	DSS	Users
SACRE (Janvier-Badosa et al., 2016)	2008-2012	Région Centre-Val de Loire (France)	Creation of a tool for the management of digital contents and monitoring stone alterations	3D Mesh texturized	Relational Database (MySQL)	Yes	Cultural Heritage Experts in preservation
Sistema senza contatto per la diagnostica con realtà aumentata di manufatti di rilevante interesse culturale e di difficile accessibilità (Mariella De Fino et al., 2018)	2014-2016	National fundings "MIUR Start UP" – Cultura ad Impatto Aumentato (Italy)	Elaboration of digital models for the remote technical knowledge	Virtual Tour and 3D Point Cloud	-	-	Diagnostic experts for the recovery of Cultural Heritage
VOLUBILIS (Al-Mukhtar et al., 2016)	2015-2018	Régional fundings - Centre-Val de Loire (France)	Development of a scientific and technical approach to map, manage and store data collected in recovery processes	3D Mesh VirtualModel 3D mesh texturized	Geo-Database	-	Archaeological Experts in preservation Tourists
INCEPTION (Di Giulio et al., 2021)	2015-2019	HORIZON 2020 program	Creation of an Open-standard semantic web platform to enhance knowledge, value and dissemination of European Architectures	HBIM and 3D Virtual Model	Relational and not-relational Databases (MS SQL No-SQL)	-	Researchers Practitioners Not expert users
SACHER (Bertacchi et al., 2018)	2016-2018	Regional fundings POR FESR 2014-2020 (Emilia - Italy)	Development of a smart Cloud Platform to manage the Life cycle of Tangible Cultural Heritage	3D Mesh texturized	RDBMS - Relational Database Management System (MySQL)		Cultural Heritage experts (various) Citizens Tourists
HeritageCARE (Ramos et al., 2018)	2016-2019	INTERREG SUDOE VB, SOE1/P5/P0258	Development of an immersive VR-tool for the monitoring and the preventive conservation of historic and Cultural Heritage	Virtual tour, 3D Point Clouds and HBIM	Geo-Database	-	Building owners Practitioners Administrative Universities
VERBUM (Fatiguso et al., 2021)	2018-2020	Regional Fundings POR Puglia FESR-FSE 2014-2020 (Puglia - Italy)	Development of a platform VR-Based for the technical knowledge of Cultural Heritage	Virtual Tour, 3D Point Clouds and HBIM	Not-relational Databases (NoSQL)	-	Practitioners Administrative Experts in Cultural Heritage for preservation

The critical analysis of these experiences highlights the increasing awareness about the potentialities of disruptive technologies mainly involved in i) creating methodologies for the acquisition of real architectures and the creation of digital models, ii) developing interoperable systems for the management of data and technical information, iii) creating digital storage based on structured ontologies and iv) allowing the participation of various users (expert, administrative and final) also in multi-spaces (combining in situ and remote, or fully remote fruitions) in the recovery process.

Moreover, the analysis highlights the potentialities in managing tools, external references (e.g., Databases) and the potentialities in disseminating and communicating contents among different users involved in the experiences.

Finally, the maturity of such tools and models, as well as methods, demonstrates the high functionality of such disruptive technologies also in solving the physical and procedural criticalities for architectures featured by low accessibility or full inaccessibility at the basis of the discussion, as introduced in the previous section. This, with the support of a detailed operative and methodological approach to be determined.

3. *Operative and methodological approach based on Virtual Model as a tool for the technical knowledge of low accessible and inaccessible architectures*

Consistently with the paper aim, the section introduces the innovative approach to support the technical knowledge of low accessible and inaccessible architectures; it results from the combination of the traditional process involved for Cultural Heritage recovery and the potentialities of disruptive VR-based digital tools. Specifically, Virtual Models are structured as Virtual Tours, based on spherical images, properly related among them and to specific levels of information, as already tested by the authors in Cantatore et al. 2020. These are useful for the creation of real-based digital copies about architectures and their technical enhancement according to the required level of knowledge involved in the recovery process. In addition to the previous results of the authors, the VMs are linked to a relational Database (r-DB) to store and codify the contents, according to the levels of information and a proper relational structure to support technical decisions of experts (DSS) in the diagnosis and intervention phases. Specifically, the methodology is structured in 5 phases (Fig. 1):

F1. Starting knowledge phase, mainly based on the collection of the data related to the architecture (knowledge_phase). Here, historical (previous projects, diagnostic and monitoring reports) and iconographic data (photographs, archivist data, historical documents) support the main catalogue of information for the analysis and technical interpretation of the built environment (e.g., morpho-constitutive state and evolution).

F2. Definition of the survey plan (pln_survey) refers to the pre-operative phase for the digitalization of architecture. Starting from the historical and archivist collected data, technical users should plan the photographic survey activities and procedures. Firstly, the expert can structure the image acquisition plan by means of the spherical head, defining their position and the total amount of photographs, according to the information about the morphological features of the buildings (number and prevalent dimensions of rooms, floor number, etc.). This activity is useful to ensure a proper overlap between spheres, as well as the widest acquisition level. In addition to the different levels of accessibility, it is possible to link two operative approaches for the shooting activities: using i) tripods for low accessible places or ii) robot or Unmanned Aerial Vehicles (UAVs) for inaccessible ones.

F3. Spherical image-based survey phase (shp_survey), as the operative step for the digital acquisition of architecture. The acquisition of spherical images (Sph_RGB) in the real environment is performed according to the planned activities and strategies in F2.

F4. Spherical image-based mapping phase (shp_mapping) represents the digital acquisition of the conservation state of buildings, according to the traditional creation of the “inspection charts” by technicians. Here, the state of decays (cracks, dampness and alterations) is still related to the technical expertise but supported by its deep and careful fruition of spherical acquired images. The mapping process takes advantage of raster (photo-editing) or vectorial image processing for the introduction of the related graphical marks into the spherical scenes enhanced with decay information (Sph_Map).

The operative process may vary considering the survey type: a) *in situ* using portable devices, i.e., tablets or b) remotely using on desk applications.

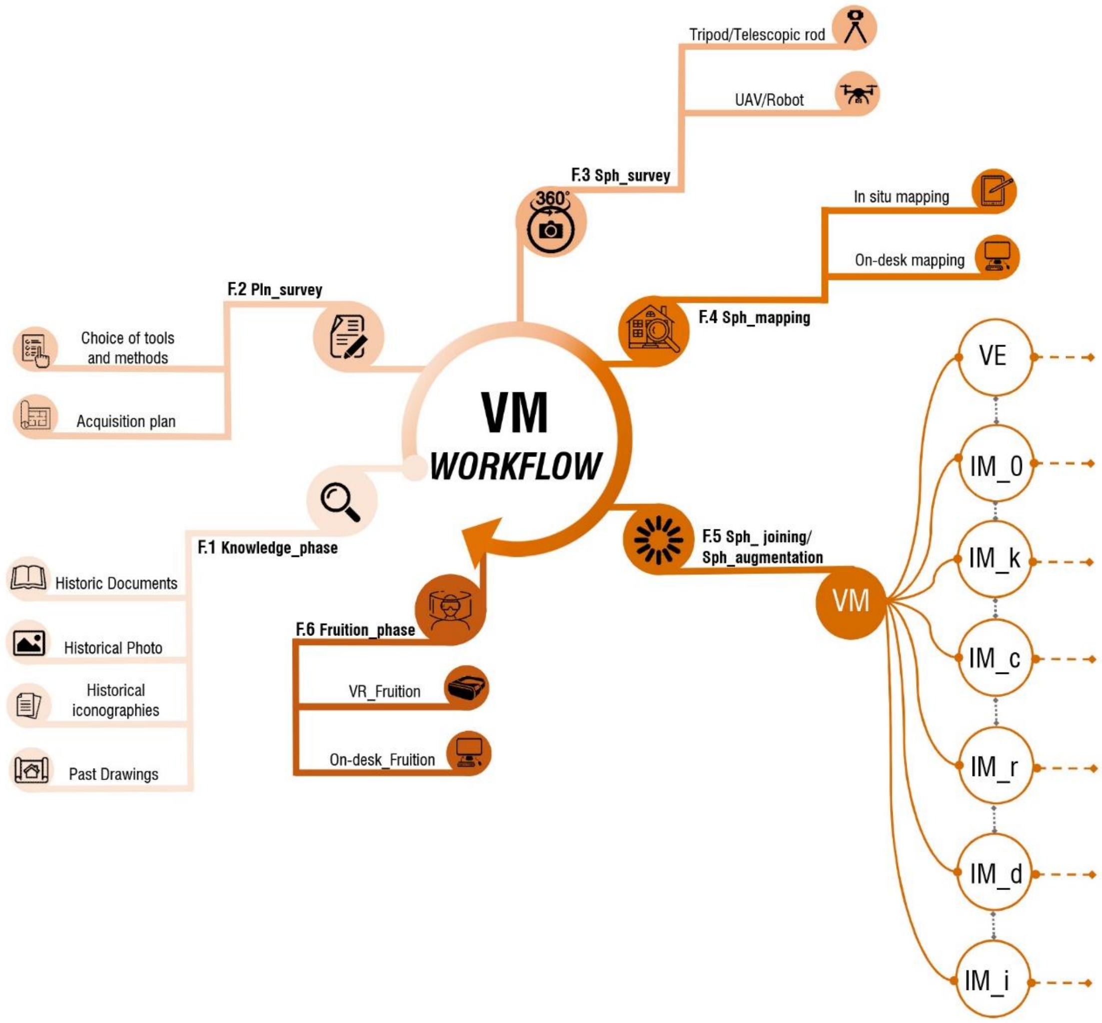

Fig. 1: Structure of the methodological approach detailed for contents and sub-elements of the discussion

F5. Creation of the Relational Virtual Model (VM-r) represents the technical digitalization step of architecture (Sph_joining/Sph_augmentation).

The VM-r is a unique digital model constituted in the Virtual Environment (VE) and enhanced with different level information layers (Fig. 2). In detail, VE is the digital and visible model of the architecture resulting from the structured organization of the collected spherical panoramas in F3 according to their distribution planning.

The combination of VE with each layer determines the creation of thematic VEs, called Information Models (IMs). These are structured according to the technical contents collected in previous phases (F1 – F4), properly referenced into the scenes, and related in the r-DB according to specific logic schemas/ontologies.

The r-DB is defined in order to organize and codify technical information in a semi-structured way, according to the glossary of material decays and ontologies for the representation of Cultural Heritage, as well as specific sector regulations and standards for causes and possible interventions (e.g., UNI NORMAL, EC regulations, http://www.ari-restauro.org/index.php/uni-normal/ (Vergès-Belmin, 2010). In the details of the IMs contents:

- IM_zero (*n* 0Shp_RGB) collects general and distinctive information of the whole architecture (building profile, localization, three-dimensional models, whole evolutive process). All the media are thus connected to the r-DB into the Sez_zero.
- IM_k (*n* kShp_RGB) gathers technical information collected during the preliminary phases. Differently from the previous one, this IM is enriched with detailed historical elements (photos, evolutive analysis technical details, historical projects and related details) by means of hotspots. These are specifically

located into the scene and, due to their potential variety, the IM_k is structured in order to guarantee multiple relations between the scene and the technical details (n_i kSph_RGB <--> { n_i media, n_j media, n_k media,…}). As in the previous phase, the information is catalogued in the Sez_knowledge) of the r-DB.

- IM_c is structured as the conservative models of the architecture, using the mapped spherical images generated in phase 4 (*n* Sph_Map). Moreover, the panoramas are structured according to three layers of details:
  - Layer_CrackPattern reporting the cracks and organized in *n* c_Map;
  - Layer_Decay where all the decays are stated within the *n* d_Map
  - Layer_HumidPattern, organized in *n* h_Map to show the Humidity decays.

  In order to guarantee the proper expert reading, i) each Sph_map should be linked to each Layer (Sph_map <--> c_Shp_Map <--> d_Shp_Map <--> h_Shp_Map) and enriched with the associated legend and ii) each layered graphical mark inserted in each sphere should be linked to the associated sez_ConservativeState of the r-DB.
- IM_r (*n* rShp_RGB) relates the VE with the results of the diagnostic reports. Here, the use of hotspots allows to locate the results, according to the real position, guaranteeing the variety of relations between single scenes and the *k* reports (k_i rSph_RGB <--> { k_j report , k_k report , k_l report , …}). As in previous IMs, the information is set in the Sez_diagnosticReport of the r-DB.
- IM_d (*n* dSph_Map) is the informatic model for the diagnosis. It is structured with the same visualizable information of IM_c but relates every graphical mark to possible diagnoses. This is possible thanks to the semi-structured architecture identified in the r-DB. In fact, all the data collected and reported into the IM_zero, IM_k, IM_c, IM_r are related into the r-DB with logical and topological relations of the decay, linking them to a set of intrinsic causes

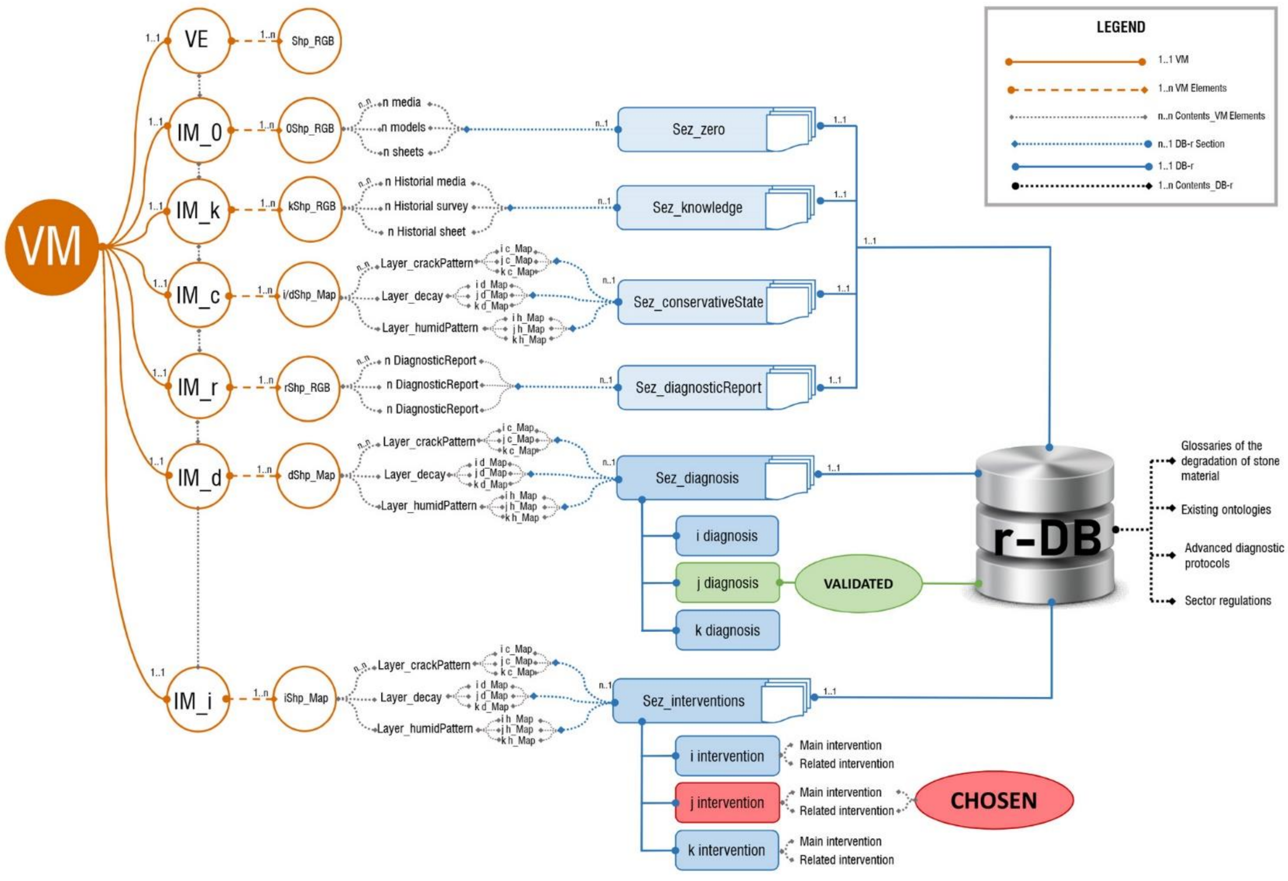

Fig. 2: Exploded view diagram of the VM contents and connection with the r-DB. Details of relations among contents in the IMs and relations of contents with the r-DB

and organized in the sez_diagnosis.
Actually, in this IM the expert user validates the diagnosis by means of its experience and technical knowledge although taking advantage of the minimum option set. Moreover, these activities are always supported by the fruition of the virtual environment, the correlated decay maps and thematic layers.

- IM_i (*n* iSph_Map) concerning the VM-r with the intervention thematic information. The Model uses the IM_c scenes but relates to each decay and humidity pattern a system of suitable interventions, derived from the relation into the sez_intervention of r-DB. As in the previous case, these are pre-selected into the database starting from the technical data imported, as well as to the confirmed diagnosis, but they are validated by the users. And this in order to take into account other external factors or elements (economic, aesthetic restrictions, etc.). Besides, the interventions are also related to main causes (principal phenomenon) and effects, according to the effective procedures in recovery.

All the IMs are structured using the same scenes and the same orientation, linking each of them to the equivalent in other IMs (n_i 0Shp_RGB <--> n_i kShp_RGB <--> n_i Shp_Map <--> n_i dShp_RGB etc). This allows to fully comprehend the VM and easily relate it between all the information and phases which are catalogued, selected and validated during the process.

F6. The fruition of the VM-r. The visualization of the digital model and user interaction is enabled by means of VR devices, guaranteeing a semi-immersive or immersive level of fruition for users.

Specifically, the creation of the VM allows technical experts to collect all the data (also re-elaborated) in order to have a full database of information to be reviewed and shared with other technical experts and external users involved in the process (e.g., administrative and control entities).

4. The case study: The "Palazzo Carmelo" in Cerignola (Foggia), Italy

4.1 Historical details

The "Palazzo Carmelo" is located into the historic center of Cerignola, a city at 40 km far from Foggia, in the Apulia Region (Italy) (Fig. 3). It is listed according to the Italian regulation framework of Cultural Heritage (D. Lgs. 42/2004).

Originally, it was a Carmelite convent, maintaining its original architectural morphology.

Notably, it is organized around an inner court where two main staircases connect the double level of the buildings, with a total covered surface of 1500 m^2. Moreover, according to the main Carmelite architectural rules, a big garden enriches the backyard. Despite it still hosts most of its original morpho-typological features, today the building reports the signs of XIX century, when it suffered the aesthetic transformation process into the city hall, which mostly affected the main façade

Fig. 3: Geographic location of Cerignola in Italian land (left) and position of the "Palazzo Carmelo" in the urban land (right)

(south-west) and the monumental staircases located near the inner garden. Here, Doric columns were introduced at the end of 1800. Despite the presence of three stairs (two monumental ones and an ordinary one), the pitched roof is inaccessible to be analysed. As far as materials and construction techniques are concerned, the buildings still preserve the original elements, presenting stone vaults, iron and brick slabs and few substitutions with flat ones, or introducing false ceilings. During the 90s, the city hall moved into another building, leaving the palace in an abandoned state, until now. The state of disuse generated a critical state of milieu, reflecting unsafe rooms for the detachment of materials and the absence of security measures (above all at the first floor). Moreover, the critical levels of inner humidity, the critical state of vegetation in the garden and the rooms on the ground floor, as well as the presence of pigeons in the rooms, summarize both the critic hygienic state of the buildings and the hygienic emergency for the surrounding neighbourhood.

4.2 Application of the smart methodology for the case study of "Palazzo Carmelo"

The smart methodology identified in the previous section has been applied to the selected case study. "Palazzo Carmelo" is an exemplary case due to its low level of accessibility caused by the actual state of conservation, the critical hygienic and (partial) static states.

Moreover, the recent interest in its recovery drove local administrators to activate first procedures of technical knowledge towards the activation of new uses for the municipality, such as the recent diagnostic activities, involving traditional instruments for the diagnostic analysis (jacks, radars) and the relief of the roof by means of UAVs. These have been done in 2021 thanks to B.Re.D Spin-off of the Polytechnic University of Bari. By considering the application of the methodology, extensive documentary research has been carried out (F1) collecting available historical documents and iconographic data.

For this aim, a general relation of the architecture has been created in order to re-organize the general data (regulation frame, listed codes, general historical information, administrative details). Due to the presence of historic plans and historic photographs, the survey plan has been defined (F2).

It considers 104 spherical images, counting 55 on the ground floor and 49 on the first floor. The images are planned in order to have a consecutive acquisition process, following the morphological structure of the building along each floor, and connecting them through the stairs (Fig. 4).

Spherical images (Sph_RGB) are captured in situ by means of a spherical head (Samsung GEAR 360) and a telescopic tripod (F3), due to the inherent level of the recognized accessibility.

Moreover, the low lighting quality, potentially identified for some rooms near to the garden and the absence of electricity, has been solved using LED projectors located around the tripod, guaranteeing sufficient lighting for the consequent mapping activities. In fact, the decay mapping (F4) has been carried out on-desk by means of a photo-editing application (specifically Photoshop CC© 2019), taking advantage of the spherical visualization.

In particular, decay and damps are represented using solid patterns, while cracks with lines, recognizing the main detachments starting from the UNI 11182/2006 classes.

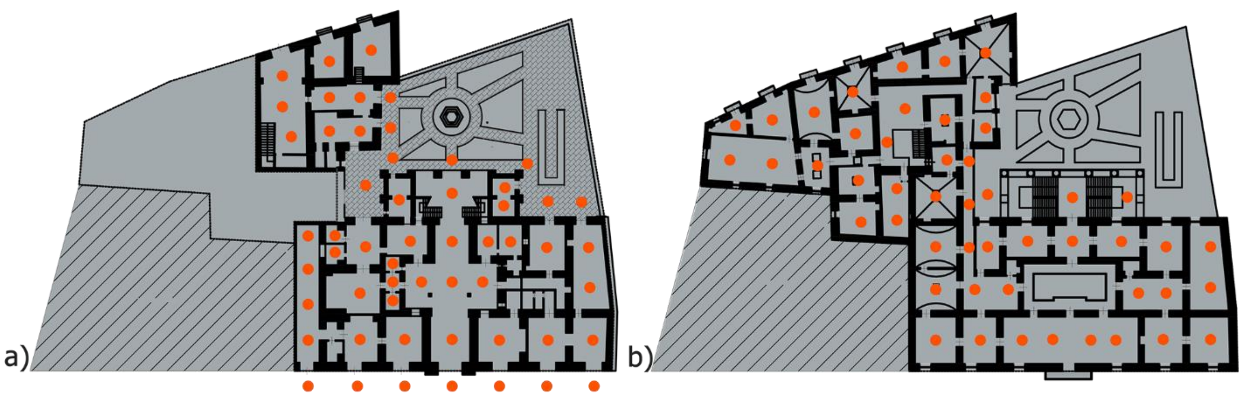

Fig. 4: Plan of spherical acquisitions at the ground (a) and first floors (b) of the "Palazzo Carmelo"

Tab. 2: Information and data collected in the first phases of the processes, qualified for contents, data type, availability and associated Level of Information (IM_0, IM_k and IM_DiagnosticReport)

IM/DB [hotspot type]	**Contents**	**Data available (A) or edited (E) by technicians**	**Data type**
IM_0/sez_zero [Hotspot with contents always available and not referenced into the scene]	1 General information of "Palazzo Carmelo"	E	.pdf
	3 Graphical plans of the architecture at the actual state	A	.pdf
	1 Video related to the roof (inaccessible)	A	.mp4
IM_k/sez_knowledge [hotspot located only in the enriched scenes and properly located into the room]	15 Historic images of monumental staircases and façade transformations	A	.jpeg
	4 Reports of historic epigraphs located on the façade	E	.pdf
	3 Historical plans of use variation of rooms	A	.pdf
IM_r/sez_DiagnosticReport [hotspot located only in the enriched scenes and properly located into the room]	113 Diagnostic Reports	A	.pdf

For each Shp_RGB, three layers are created (CrackPattern, Decay, HumidPattern) according to the method, for the creation of thematic scenes in the related conservative level. The creation of the "Palazzo Carmelo" VM (F5) followed, using the collected images (104 Sph_RGB) for the VE, and enriching it with the thematic information for the IMs creation (Shp_map, contents in Tab. 2). All the models are created using 3DVista® software. Simultaneously, all the data and information acquired (documental, as well as graphic signs) are related to the structured r-DB, using PostgreSQL.

To support the full fruition of the VM in all the thematic levels, each scene is equipped with an interactive location map. Specifically, it includes a hotspot for each created scene in the VM-r, positioned in the associated room (Fig. 5, red rectangle) and floor. Moreover, in each scene, a second level of hotspots is positioned. Considering the first associated and enriched IMs, the scenes of IM_0, IM_k, IM_r report the information collected, as in Figg. 5, 6 and 7, where the contents to the generic report of the Palazzo (always visualizable), the details of the Doric columns alterations and diagnostic reports, respectively, are linked to the scenes by using proper hotspots (see Tab. 2).

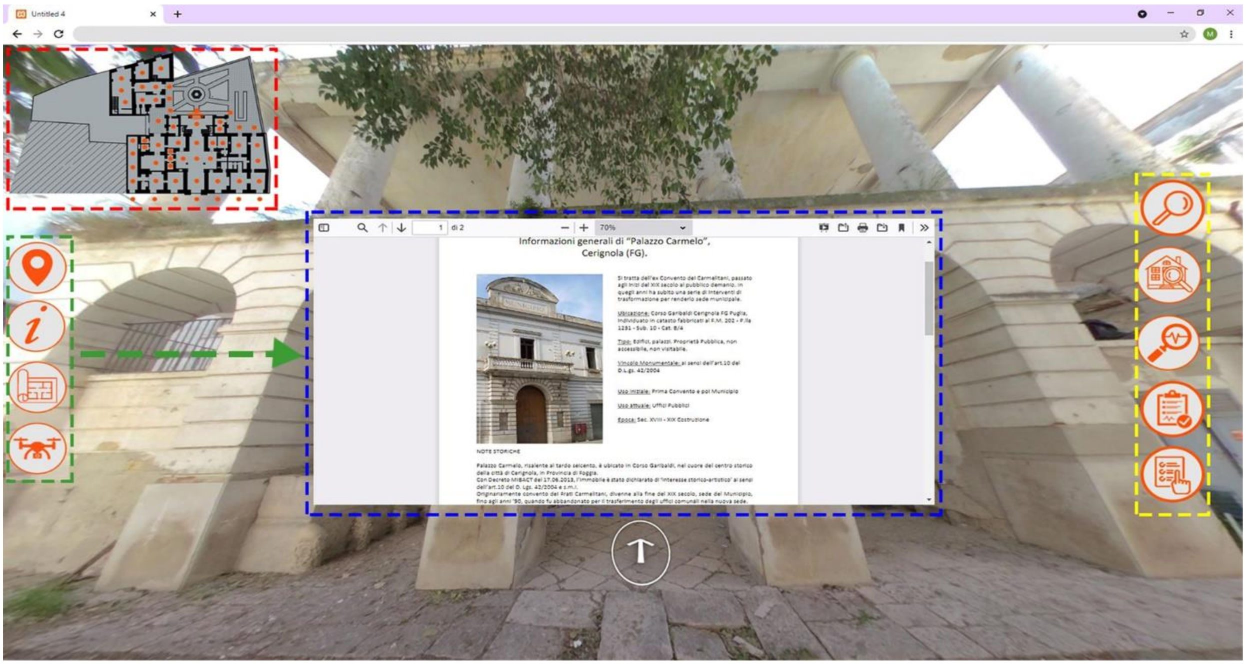

Fig. 5: Scene in IM_0 reporting the general information of "Palazzo Carmelo". In detail of contents: in red rectangle the location map, in yellow the hotspots to change information levels, in green the fixed hotspots to visualize the general information of the "Palazzo Carmelo" and in blue the main selected content to visualize in the IM_0 ("General report")

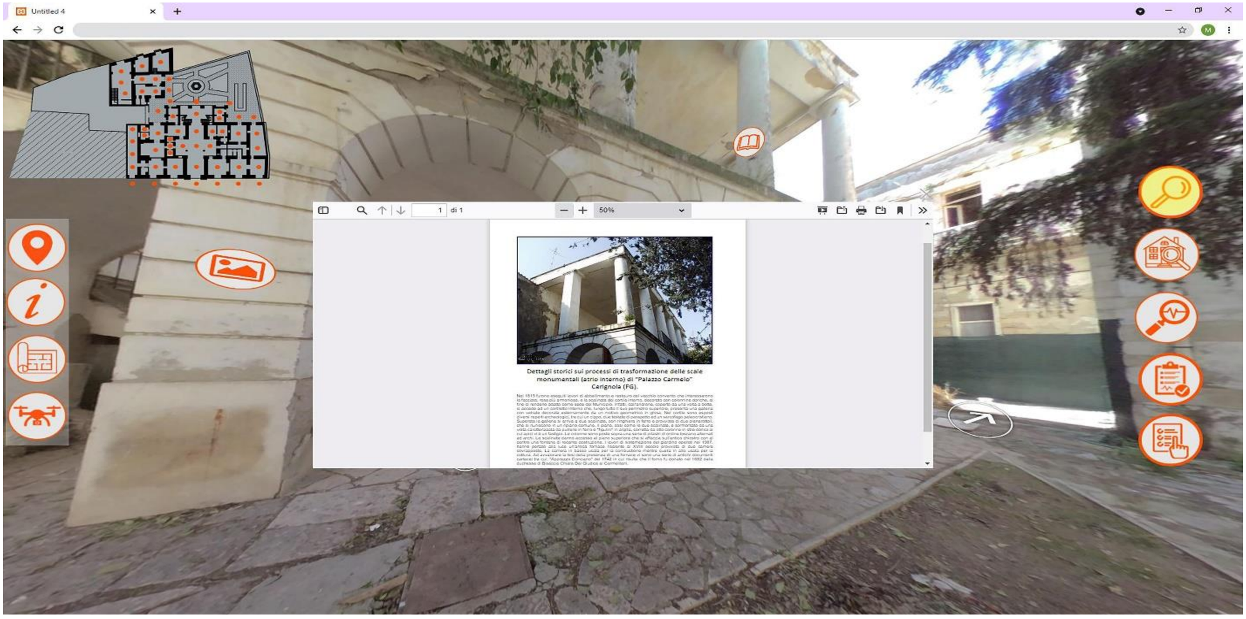

Fig. 6: Pop-windows of the IM_k reporting the knowledge information about the historical transformation of the monumental staircase in the inner garden of "Palazzo Carmelo"

Within the IM_c, the model uses the mapped images (104 Shp_Map), separating three layers of information for the enrichment of the sez_conservative. Specifically, every graphical sign is linked to r-DB entity that could be enquired using thematic hotspots, properly located with the graphical sign (Fig. 8). Here, every element of the layer can be visualized and enquired, opening the database details. In the detail of the case study, the "Palazzo Carmelo" reflected the main cases of damp patterns, above all on the first floor, both at plaster and stone levels, a bad state of conservation for plasters with detachments and the presence of vegetation.

The presence of cracks, widely spread in the building, are related to the bad state of conservation of mortars.

These are the main features highlighted in the non-monumental stair of the Palazzo (called P20) to which Fig. 8 is related, and where the lecture of legend decays (on the left) and single thematic levels can be always readable by technicians.

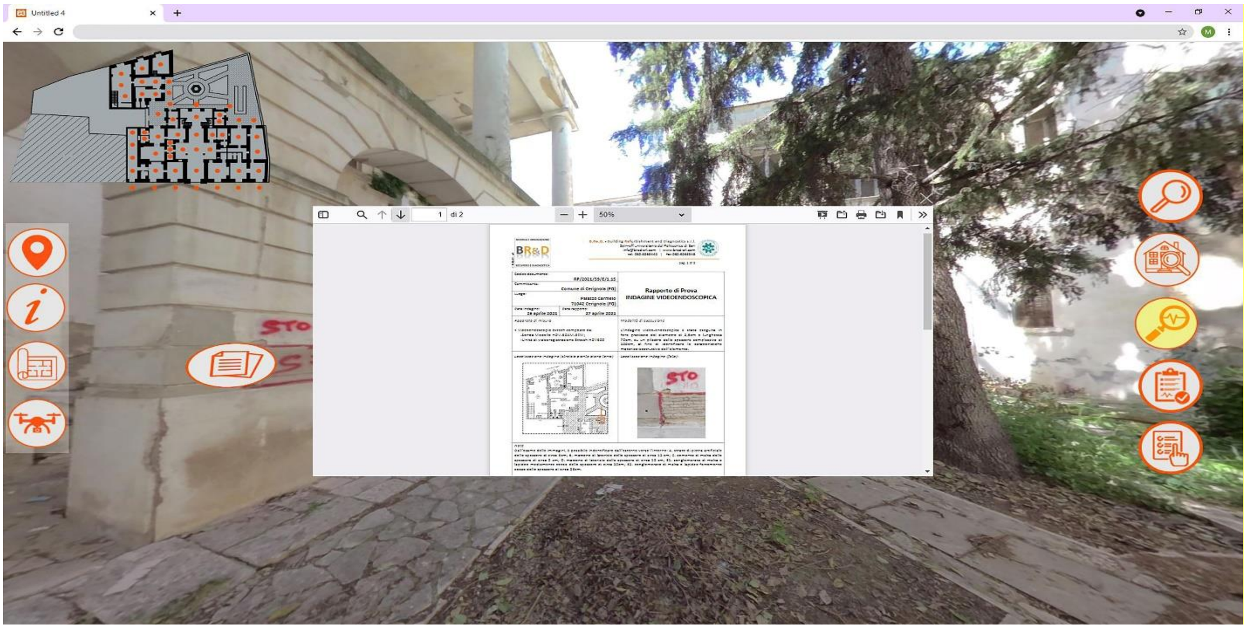

Fig. 7: Pop-window in IM_r reporting the technical level of knowledge referred to the results of the endoscopic test on the pillar at the ground floor of monumental staircase in the inner garden of "Palazzo Carmelo"

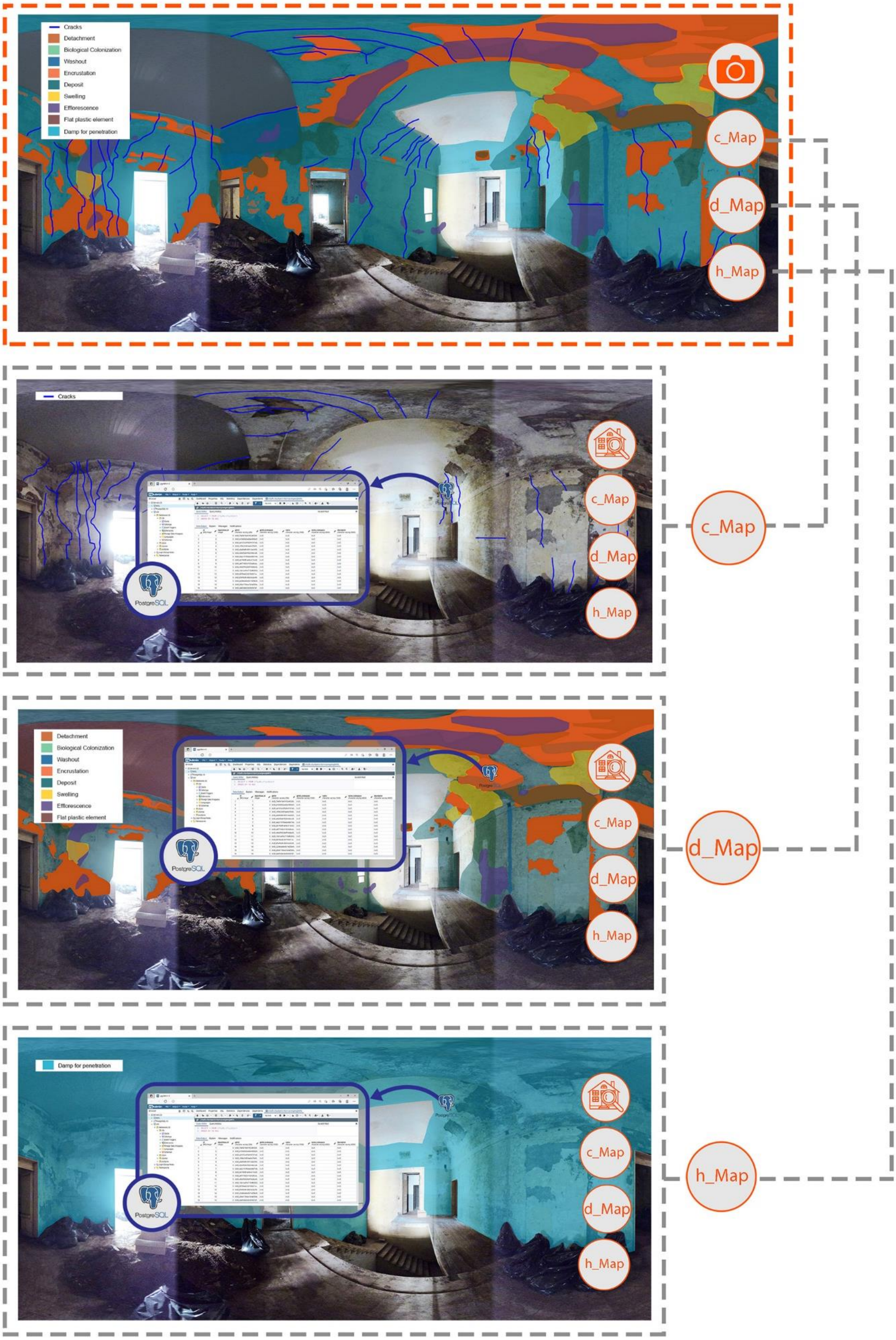

Fig. 8: Visualization of three levels of information in the IM_c model referred to the non-monumental staircase at the first floor (P20). At the top, the complete decay patterns, at the bottom contents in each level as relation to the r-DB

Fig. 9: Schematic process of validation and choice of diagnosis (top) and interventions (bottom) related to the "Plaster detachment" recognized in the room P20, within the IM_d and IM_i models, respectively

Through the management of data collected in the DB-r referred to IM_0, IM_k, IM_c e IM_r, (sez_zero, stateConservation, knowledge, DiagnosticReport), the IM_d has been prepared to be visualized and analysed for the diagnosis phase.

In fact, all the graphic signs have been reported into the scenes while the correlated information in the r-DB is generated (sez_diagnosis).

Thus, the semi-automatic process has been tested for the highlighted decays, proceeding for the diagnosis and intervention identification.

Specifically, in Fig. 9 (top) the process has been summarized for the detachment of plaster along the higher parts of the walls and the floor.

The association with the main cause "Presence of dampness phenomena" to the "Detachment of plaster" in the d_map, and the "Damp for penetration" for the "dampness" pattern highlighted and codified in h_Map are selected within a reduced option of diagnosis by the users involved in the case study, as the required validation process structured for the methods into the semi-structured r-DB. The creation of IM_i followed as detailly discussed into the methodology, showing the same scenes of IM_c but relating the mapping signs to the sez_intervention into the r-DB. As Fig. 9 shows (bottom), the semi-automatic process showed to the technical users the solution of intervention for the previous validated diagnosis. The combination of information related to dampness and detachment for plastered surfaces became fundamental in the recognition of the main causes of decays and thus to the conservation. In this case, the main cause of the plaster detachment is related to the rainwater penetration along the roof.

Such information is also related to the information details of roof, recorded into the digital content provided by the UAV survey. At the same time, the semi-structured process of choice for intervention allowed users to select the double level of action associated with the main cause in terms of "Roof recovery" and the effect as "Demolition and refurbishment of plaster", combining multiple levels of information to recognize the correct diagnosis in real cases (P20, in Fig. 9).

The whole VM-r is finally exported as .htm file in order to be shared with other devices and users for the validation of the details. The use of .htm format allowed the fruition in both an immersive and semi-immersive way.

5. *Discussion of results and conclusions*

The present work is part of the scientific activities relating the Cultural Heritage and the potentialities of disruptive technologies based on VR and VM. However, the main goal is to support the technical activities of expert users during the knowledge phase for architecture featured by a low level of accessibility or fully inaccessible ones in their recovery process. Despite many applications for tourists and end-user fruition, such tools may offer the opportunity to support technical users, declining traditional approaches towards new paradigms. With this aim, the work discussed a smart operative methodology for the described goals, involving also operative recommendations for the process. On the other hand, the approach also offers the opportunity to share the knowledge among several actors involved in the process, offering a unique Virtual Model of the Architecture to be discussed and analysed for its recovery. Moreover, the use of Virtual Models based on spherical images certainly constitutes a smart tool for the quick survey of the real environment, allowing during all the phases, the continuous visualization and the complete fruition of the places, overcoming the necessity to repeat surveys by the same user or to involve physically several actors in the architecture reading. Recent practices in sharing virtualized knowledge about the Cultural Heritage highlighted the potentialities in relating Virtual Models to external structured databases for coherent information management and a semi-structured support to technicians in solving diagnosis and intervention choices in the recovery process.

The application to the case study of "Palazzo Carmelo" shows the potentialities of the presented methodology, overcoming the traditional necessity to validate it. Inherent features of the selected architecture are not an exception within the real cases for technicians (e.g., critical hygienical features), also involved in managing different information for data type, year of acquisition and technical contents. Furthermore, the semi-structured DB-r created was tested for the goal, verifying its coherence with the traditional operative activities of experts.

Despite the good outcomes of the DB-r in supporting technical decisions in the test activities, the application still shows few remarks to be solved in future work (Piaia, Maietti, Di Giulio, Schippers-Trifan, Van Delft, Bruinenberg, & Olivadese, 2021; Ilaria Trizio, Savini, Ruggieri, & Fabbrocino, 2021; Vacca & Quaquero, 2020):

i) The higher level of complexity in relating cracks to semi-automatic procedures, leaving to technical users the whole management.
ii) The absence of real feedbacks by technicians in using the structured system of tools and the methodology.
iii) The necessity to structure a wide and coherent platform to overcome the use of several tools for the goals and thus, take advantage of a unique tool to manage the unique Relational Virtual Model.
iv) Finally, the necessity to cover the gap between three-dimensional models (e.g. BIM ones) and proportional ones (as the Virtual Tours) for the quantification of activities, as well as to solve the regulation requirements for Cultural Heritage in using BIM or HBIM procedures.

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