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Transdisciplinary Multispectral Modeling and Cooperation for the Preservation of Cultural Heritage

Third International Conference, TMM_CH 2023
Athens, Greece, March 20–23, 2023
Revised Selected Papers

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Preface

The adoption of innovative scientific methodologies and the implementation of challenging projects that mark future trends in the protection of cultural heritage have initiated a universal and wide-ranging dialogue among scholars, professionals, stakeholders, industry representatives and policy makers, within a holistic approach that fuses competences from the scientific fields of architecture, civil engineering, surveying engineering, materials science and engineering, information technology and archaeology, as well as heritage professionals on restoration and conservation, stakeholders, industry representatives and policy makers. The combined utilization of digital documentation technologies with innovative analytical and non-destructive techniques, numerical, computational and 3D techniques, archaeometric and archaeogene methods, supports the creation of a transdisciplinary multispectral modeling towards the sustainable preservation of cultural heritage. Innovation is enhancing and revealing a critical dimension of the preservation of cultural heritage along with social participation and communication.

The National Technical University of Athens interdisciplinary team "Protection of monuments" (A. Moropoulou, M. Korres, A. Georgopoulos, C. Spyrakos, C. Mouzakis), with scientific responsibility for the Holy Aedicule's rehabilitation of the Holy Sepulchre in Jerusalem, and the Technical Chamber of Greece, in collaboration with international and Greek organizations and universities, organized the 3rd TMM_CH International Conference on "Transdisciplinary Multispectral Modelling and Cooperation for the Preservation of Cultural Heritage: Recapturing the World in Conflict Through Culture, Promoting Mutual Understanding and Peace", on March 20–23, 2023 at the Eugenides Foundation in Athens, Greece, discussing modern trends in the original agora of our technological and democratic roots, with emphasis on digital documentation technologies.

The conference was organized by the National Technical University of Athens in cooperation with the Technical Chamber of Greece, under the patronage of Her Excellency the President of the Hellenic Republic, Katerina Sakellaropoulou, with benedictions bestowed by His All Holiness, Ecumenical Patriarch, Bartholomew I of Constantinople, His Beatitude Archbishop Hieronymus II of Athens and All Greece, and His Beatitude, Patriarch Theofilos III of Jerusalem.

Distinguished scientists and representatives of the National Geographic Society, the Cultural Heritage Finance Alliance, the International Council of Monuments and Sites, ICOMOS, the Organization of World Heritage Cities OWHC, the European Society for Engineering Education, SEFI, the European Construction Technology Platform, ECTP, the International Federation of Surveyors, FIG, the International Committee CIPA Heritage Documentation, the World Monuments Fund, AHEPA Hellas, and other major international and European organizations, associations, networks, universities and research centers in the field of cultural heritage preservation, participated in the international steering and scientific committees of the 3rd International TMM_CH conference.

At the 1st and the 2nd TMM_CH conferences, which were held with great success in October 2018 and December 2021 respectively at the Eugenides Foundation in Athens, with the presence of 350/650 delegates from 22/33 countries from all continents, and over 5000 online attendees, the emblematic rehabilitation of the Holy Aedicule of the Holy Sepulchre in Jerusalem was presented as an exemplary application, in the field of monument protection, of interdisciplinary and multispectral collaboration, as an outcome of innovation, not only on research but also in the implementation process, with emphasis on technological advancements, not only intersecting all the scientific fields of engineers and natural scientists but also initiating an ongoing dialogue with humanities, in domains such as archaeology, theology, sociology, diplomacy and tourism.

Revised selected papers from the above two conferences, pertaining to digital innovation, which enhances and reveals a critical dimension of the preservation of cultural heritage, were published in three volumes of the Springer proceedings series Communications in Computer and Information Science. Specifically, they were published in the volume Transdisciplinary Multispectral Modeling and Cooperation for the Preservation of Cultural Heritage. First International Conference, TM_CH 2018, editors A. Moropoulou, M. Korres, A. Georgopoulos, C. Spyrakos, Ch. Mouzakis, Communications in Computer and Information Science, Vol. 961–962, Springer Nature (2019), and in the volume Trandisciplinary Multispectral Modelling and Cooperation for the Preservation of Cultural Heritage. Second International Conference, TMM_CH 2021, editors A. Moropoulou, A. Georgopoulos, A. Doulamis, M. Ioannides, A. Ronchi, Communications in Computer and Information Science, Vol. 1574, Springer Nature (2022).

Innovative knowledge transfer through practice and education is continuing in the rehabilitation projects in the Holy Sepulchre Church, in association with the National Technical University of Athens, La Sapienza University in Rome, and the Bezalel Academy of Science and Arts in Jerusalem, in cooperation with the Israeli Antiquities Authority, through the Erasmus+ Strategic Alliance EDICULA "Educational Digital Innovative Cultural Heritage related Learning Alliance".

Following on from the achievements of the 1st and 2nd TMM_CH conferences, the latest developments in research and innovation that identify novel trends to build an interdisciplinary approach to conservation and holistic digital documentation of cultural heritage was attempted at the 3rd TMM_CH. The utilization and reuse of monuments, historic cities and sites forms the framework of a sustainable preservation of cultural heritage, in accordance with the principles of a circular economy; in terms of the respect and protection of values, materials, structures, architecture and landscape; with an informed society, able to participate effectively in the policies that will enable the design and implementation of the new strategies required. The importance of computer science, IoT and digital technologies was prominently highlighted, and various case studies were presented.

The issues discussed in the 13 sessions and 13 panel discussions at the TMM_CH 2023 were as follows:

1. Historic cities and centers: new reuse and preservation strategies applying a circular economy
2. Digital heritage: a holistic approach
3. Machine learning techniques for cultural heritage preservation

4A. Emblematic works as a source of innovation and transdisciplinarity

4B. Novel educational approach for the preservation of cultural heritage

  5. Art, Archaeology – Archaeometry – Archaeogene

  6. Preserving compatibility, the materiality and integrity of structures and architectural authenticity

  7. Earthquake protection and structural rehabilitation

  8. Resilience of cultural heritage mitigating climate change, natural hazards and pandemic risks and ensuring biosafety

  9. New European Bauhaus creative and interdisciplinary initiative

10. Green and blue deal for local and regional sustainable development

11. Institutional framework bridging heritage stakeholders, art, science, and industry

12. Advanced non-destructive and structural techniques for diagnosis, redesign and health monitoring

13. Recapturing the world in conflict through culture, promoting mutual understanding and peace

Sharing knowledge, experiences, and recommendations about sustainable cultural heritage approaches and practices at a moment of great conflicts and climate change, and energy, environment and socio-economic risks, the sustainable preservation of cultural heritage is addressing challenges through mutual understanding and international cooperation.

The TMM_CH 2023 conference was held at the Eugenides Foundation. On-site attendance and oral presentation was required and was organized according to government restrictions against Covid-19. The opening session and all panel discussions, as addressed to the general public, were livestreamed with free access via the conference's YouTube channel and website (https://www.tmm-ch.com/).

The 3rd TMM_CH conference was highly anticipated, attracting researchers from all over the world. It was held with great success, with the physical presence of over 500 delegates and online attendance of 1700 delegates in real time and approximately 50,000 online attendants for the panels. Thirteen sessions and 13 panel discussions with the participation of 142 panelists were organized during the conference, with a visibility of 2–3 million internationally through livestreaming by BCI Media Toronto.

Striving to ensure that the conference presentations and proceedings are of the highest quality possible, the scientific committee only accepted papers that presented the results of various studies focused on the extraction of new scientific knowledge in the area of transdisciplinary multispectral modeling and cooperation for the preservation of cultural heritage. 416 contributions were submitted and 163 papers were accepted for oral presentation and publication by 487 authors from 31 countries, after peer review from three reviewers on average per paper and consequent revisions, with a rate of acceptance equivalent to 40%. Accepted papers were published in this Springer proceedings volume and in special issues of scientific journals in the field of cultural heritage preservation.

The interdisciplinarity in the preservation of cultural heritage implies a holistic documentation with fusion of the various disciplines' data in 3D models. Computer-aided design and computer science advanced methodologies support an interdisciplinary synthesis regarding the assessment of the preservation state and the evaluation of the rehabilitation achieved, in relation to the integrity of materials and structures, throughout

the restoration of the authentic architecture. In parallel, new technologies are used to enhance research and education and communicate the reuse and revealing of cultural and natural assets, providing through tourism external economies to sustain local and regional development in a circular way.

Hence, 34 papers presented at the 3rd TMM_CH conference and integrating all the above aspects are published in this book, Transdisciplinary Multispectral Modeling and Cooperation for the Preservation of Cultural Heritage, within the Springer series Communications in Computer and Information Science. The editors would like to express their sincerest appreciation to all of the reviewers and authors who contributed to maintaining the high standards necessary for the implementation of the successful 3rd TMM_CH conference, as well as for the preparation of this book.

We would like to acknowledge all who made the conference possible and successful: the organizers, as mentioned above; the sponsors, Public Power Cooperation, AEGEAS Non-Profit Civil Company, GEK TERNA Group, P. Zafeiri Sons Technical Company, Dalkafoukis House Ltd., Athens Anaplasis S.A., Attica Bank, TITAN Cement Group, EYDAP Athens Water Supply and Sewerage Company, and Eurobank; the Eugenides Foundation for the kind offer of the venues of the conference; the media sponsors, ERT Hellenic Broadcasting Corporation and BCI Media Toronto; the media support offered by DNA Sequence Ltd., PerpetielSI Srl, and the Boussias Media Group; the partners of the Erasmus+ Strategic Alliance EDICULA "Educational Digital Innovative Cultural Heritage related Learning Alliance", coordinated by NTUA, for the co-organization of Panel 4; the organizers of the researchers night at the National Technical University of Athens 2022 and the partners of the research program AEI "Sustainable Development of Less Developed Areas by Creating New Tourism Resources and Products Through Analysis, Documentation, Modelling, Management and Preservation of the Cultural Preserve Using ICT Applications", coordinated by NTUA, PA 2014-2020, for the co-organization of Panel 10; the partners of the research program RESPECT "An Exemplary Information System and Methodology for the Integrated Management, Analysis and Dissemination of Digital Cultural Heritage Data Coming from the Rehabilitation of the Holy Aedicule", coordinated by NTUA, PA 2014-2020, for the co-organization of Panels 2 and 3; and the research program BIOFOS coordinated by NTUA, PA 2014-2020, "TRIQUETRA: Toolbox for Assessing and Mitigating Climate Change Risks and Natural Hazards Threatening Cultural Heritage", for the co-organization of Panel 8.

The conference would not have been possible without the commitment of the NTUA interdisciplinary team for the "Protection of Monuments"; the full cooperation of the TMM_CH editors of this volume; the scientific support of the international steering committee and the scientific committee; the support of the executive organizing committee and the technical system providers; and the valuable assistance of the CCIS team at Springer, to whom we are utmost grateful. We are very proud of the result of this collaboration and we believe that this fruitful partnership will continue.

The next TMM_CH conference has already been announced for 2025.

June 2023   Antonia Moropoulou

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Abstract

The paper reports the results of a research project funded by the University of Ferrara (FIR 2020 Program) and aimed at developing and testing some achievements of the project "INCEPTION - Inclusive Cultural Heritage in Europe through 3D semantic modelling" (H2020 EC funded research project).

The tests carried out on the INCEPTION platform functions, outcome of the research project and subsequently implemented by the homonymous spin-off, have shown the potential of semantic-BIM technologies in the field of Cultural Heritage sites maintenance.

Novel and innovative applications grounded on the platform core functions include: tools and protocols for the management of inspection procedures supported by information and instructions provided by the platform; assessment, based on inspection data, of the condition of the site and/or individual parts based on a "condition scale"; access to constantly updated condition information, shown on the virtual model as linked to the objects of the BIM model; remote analysis and evaluation of site condition data through interaction, in a virtual environment, with 3D model "objects".

The paper presents the main elements of the ongoing experimentation: the matrixes for the automatic analysis of the detected data and the assignment of the "condition score", the structure of the ontology with which the semantic tools of the platform operate, the workflows for data loading phases such as: in situ inspections, remote monitoring, planning of interventions.

The tests on features and procedures reported in the paper have been carried out on the 3D model of the church of Santa Maria delle Vergini in Macerata, as part of a wider collaboration between the INCEPTION spin-off company and the ICCD (Istituto Centrale per il Catalogo e la Documentazione) of the MIC (Ministero della Cultura).

ICT and Semantic BIM Technologies for the Advanced Documentation and Condition Assessment of Cultural Heritage Sites

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Keywords: Cultural Heritage · Conservative Maintenance · Condition Assessment · H-BIM

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1   Introduction

The digitisation of cultural heritage is accelerating rapidly due to recognising its strategic role as a new lever for value creation and as a tool for documentation and preservation. The effort is supported by the advancement of applied research and the development of ICTs and also involves the field of conservative maintenance of historical sites and buildings, offering unique opportunities (Di Giulio et al., 2020).

Preventive planned maintenance of artefacts is a well-established area of research and practice which finds in periodic inspections one of the main methods for identifying the state of conservation and promptly evaluating the major risks and vulnerabilities; direct cyclical controls also provide regular monitoring of the evolution of degradation phenomena thus aligning the maintenance plan itself.

The data acquired during the site inspections and through the - ever more frequent - digital sensor and monitoring systems installed, are quantitatively and qualitatively consistent and require effective and reliable repositories and databases capable of managing and updating heterogeneous information.

Planning the maintenance of cultural heritage has to tackle an additional challenge beyond the identification and monitoring of the condition of conservation: it has to be capable of recognising the historical and architectural value of the asset and assessing its physical consistency to knowledgeably indicate the most appropriate procedures for conservative intervention (Simeone et al., 2019).

In the field of modelling, management and interoperability of 3D digital models related to Cultural Heritage, the H2020 European research project INCEPTION (Inclusive Cultural Heritage in Europe through 3D semantic modelling), ended in 2019, achieved several innovative results which have been further exploited and developed by the start-up INCEPTION Srl, a University of Ferrara spin-off.

The core of the project is the Building Information Modelling (BIM) - and the conversion of data acquired through 3D Laser Scanner survey systems as its first implementation - whereas the main objective is the opportunity for other applications to interact with the generated three-dimensional models, hence necessarily interoperable. In these models, each 3D digital element is enriched with metadata, i.e. massive information describing features, properties, up to historical and documental data, of the corresponding real building element. The system is enabled by a semantic platform not intended to merely archive, but to search, interact, enrich, process and acquire the hosted models.

The development of novel functionalities of the INCEPTION platform, therefore, allows the creation of applications fully devoted to improving the tools and procedures for condition assessment and maintenance planning of historic buildings and sites (Di Giulio et al., 2019).

2   Toward the Use of ICT Tools in Condition-Based Maintenance

The tests carried out on the INCEPTION platform functions, had already shown the potential of semantic H-BIM technologies in the field of Cultural Heritage sites maintenance.

However, the tests were carried out using software for scheduling inspection and maintenance activities for buildings and civil infrastructures. It was then clear the limit resulting from the application of models and procedures that did not take into account the specificity of maintenance strategies for cultural heritage sites and buildings.

Working in the field of historical building it is necessary to take into account the specific data of each individual object on which you operate. Inspections and condition assessments of materials and components cannot be done "at random". Spot checks are required and, not infrequently, the checks must also be carried out on similar components or on different points of the same element. In a historical building there are often components and materials of different periods on which the degradation process, while acting on similar materials, can give rise to different defects and pathological phenomena.

On the other hand, there are very few scheduled maintenance interventions, carried out at fixed time intervals and based on standard protocols and procedures. They are configured, in most cases, as interventions of conservative maintenance if not as real restoration work.

The decision to launch this type of interventions, the deadlines for their execution, the specifications on products and technologies to be used, and the required specializations and skills of the workers who will have to carry them out, depend on decisions that must be based on the results of inspections or on the data from the monitoring systems.

It is therefore necessary to proceed according to "Condition Based Maintenance" models in which the evaluation of conditions is not a plan of routine checks aimed at optimizing the frequency of maintenance interventions, but a thorough campaign of inspections, monitoring and diagnostic investigations.

On the basis of these principles, the current research is developing a procedure to carry out controls and a tool to read and interpret the collected data enabling the operators involved in the management of the building to.

- operate remotely by interacting with the 3D H-BIM model (i.e. the digital twin) of the building;
- carry out the control activities in situ guided by information and data provided by the platform that hosts the 3D H-BIM model;
- upload to the platform, which then provides the continuous updating of the 3D H-BIM model, the data collected and have a continuously updated picture of the conditions of each part of the building.

3   Objectives and Methodology

The research objectives consist in extending the functionalities of the INCEPTION platform with tools for the management of inspections, monitoring and planning of "conservative maintenance" in cultural heritage sites and buildings.

These tools consist of a protocol for inspecting and assessing the condition of building components or parts, and applications to perform guided inspections, transfer the collected data to the platform, and later access that data by interacting directly with the building's digital twin.

The inspection and subsequent monitoring protocol is carried out in four steps:

1. analysis of the building decay supported by the data provided by the INCEPTION platform through which the inspector, interacting with the 3D H-BIM model (the building's digital twin) through a device connected to the platform, accesses all the technical information necessary to identify, interpret and report the defects of the component under examination;
2. the condition assessment of the component or elements it is made of, through the condition assessment methodology of the Dutch Standard NEN 2767 "Condition assessment built environment - Part 1: Methodology" based on a measurement expressed as a condition score on a scale from 1 (component "as new") to 6 (component in worst condition);
3. the uploading of the condition score and other possible remarks, photos, or technical documents on the platform that provides to associate all data, in form of metadata, to the component of the BIM model;
4. the remote monitoring of the building conditions through the inspection results analysis, the display of the decay levels reproduced on the 3D H-BIM model, and then the analysis of the defects found in every single component for the evaluation of when and how to perform the conservative maintenance interventions.

The tools required in the various steps of the procedure just described consist of a set of applications that integrate with those already present on the platform, in particular with those that allow to interact with the BIM model and to access data on the conditions of the building components through the semantic search tools. Items created and added to the INCEPTION toolbox include in particular:

- an application that allows to easily and quickly integrate the H-BIM model with the tools necessary to manage, for each single object, the metadata corresponding to the decay conditions;
- an automatic condition assessment system based on an application that calculates and assigns condition scores on the basis of the defects found by the inspector simplifying his task (he is therefore not required to have high levels of specialization): the inspection is limited to the identification of defects, guided by information and images provided by the platform, and to the input on the platform of data on their extension and intensity;
- the routines necessary to transfer data, in IFC format, from the H-BIM model to the platform and from the platform to the model (to keep it updated);
- a dashboard that allows to monitor and analyze data on the conditions of every single part of the building and and to interact in order to optimize the maintenance strategies.

Procedures and tools, detailed in the following paragraphs, has been tested on a portion of the H-BIM model of the church of Santa Maria delle Vergini, in Macerata (Italy), created by INCEPTION spin-off researchers in collaboration with the Istituto Centrale per il Catalogo e la Documentazione (ICCD) of the Ministry of Culture.

4   The Demontration Case

The church of Santa Maria delle Vergini is a majestic building with a Greek cross plan, surmounted by an octagonal dome erected on a drum, supported by four imposing pillars with a quadrangular base; the arms of the Greek cross end in semicircular apses, each with two cross-vaulted "scarsella" chapels (Canullo, 2016). A first plant of the church dates back to 1355 but the consecration of the current configuration of building took place in 1577. The facade, developed on two horizontal registers, does not correspond to the interior space, because it was later completed. The interior of the church has 11 chapels decorated between the late sixteenth and late eighteenth centuries. The church has also undergone the action of various seismic events: among the most recent and important we remember those of 1997 and 2016, with particular injuries to the drum supporting the dome, still under restoration (Fig. 1).

Fig. 1. Aerial photo of the church of Santa Maria delle Vergini in Macerata before the 2016 earthquake (on the left) and the dome damaged in 2016 (on the right).

For the survey of the church, the 3D acquisition has been developed by integrating different survey technologies: terrestrial laser scanner (Faro x330HDR), terrestrial and aerial photogrammetry (Dji Mavic Pro + Agisoft Metashape) and topographic survey by total station (Leica TCR1202+R100). Once the overall registration of the point cloud model has been done, data were imported in the Autodesk Recap software towards the creation of an H-BIM model. Thus, in the modeling procedure, we opted for the use of Autodesk Revit. Since the purpose of the modeling is the condition assessment, the most appropriate LOD according with the Italian regulation UNI 1137:2017 would have been LOD G. However, even if such LOD has been described, there are no technical specifications to develop it consistently. Consequently, it was decided to operate a modeling where the LOG (Level of geometric detail) and the LOI (Level of Information) would allow to accommodate the information of required for the condition assessment procedure later described. As far as possible, we proceeded to model using system families or local families within Revit, but considering the possibility of using free-form modeling

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elements with external tools when necessary. The model thus created was then exported in open IFC format, version 2×3, in order to be uploaded on the INCEPTION platform (Bonsma et al., 2016) for making use of the SOLID-ICE tool. In order to make the uploading procedure easier and the web navigation smoother, we applied preliminary geometric decimations to the IFC export, as well as optimizations and compressions of the standard file to make it as light as possible (Fig. 2).
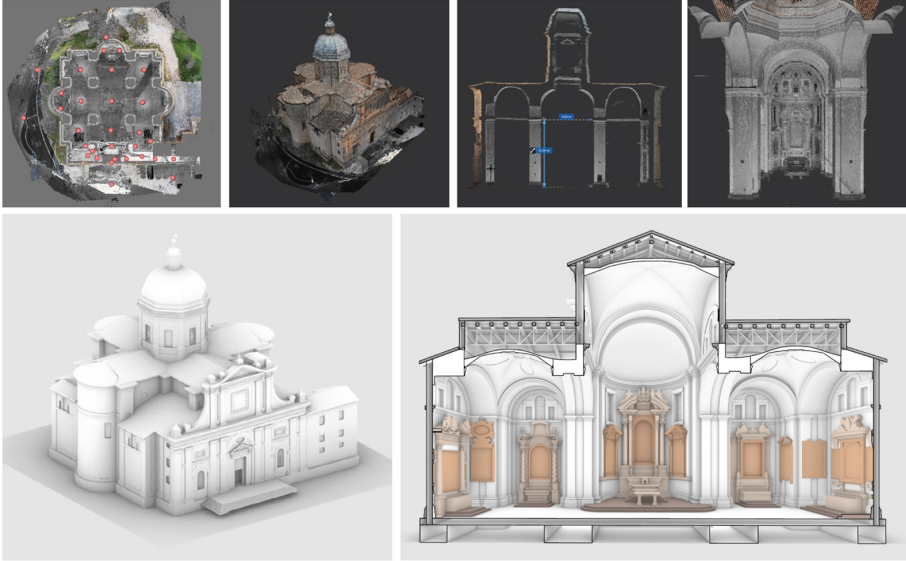

Fig. 2. Scan-to-BIM procedure applied to Santa Maria delle Vergini. Visualization of the point cloud on the top and the resulting BIM model on the bottom.

SOLID-ICE is one of the tools grounded on the Inception Core Engine (ICE), which is based on a semantic approach. This consists in transforming all the geometries of a specific BIM model into semantic triples that connect one element to another using specific predicates, defined in a dedicated semantic ontology. All these triples are stored in a semantic triple store, accessed via HTTP through a dedicated Apache Fuseki SPARQL server. SOLID-ICE client is a web application provided with a 3D WebGL viewer giving access to all the functionalities. The platform allows users to enrich their models with new semantic metadata. Indeed, the web client allows you to enrich the models with new data (e.g., a date, a value, some textual remarks, see Fig. 3) as well as attachments (e.g., pictures, thermographic images, 3D models of specific details, videos, etc.), all of which are related to the CH site or a specific geometrical element (Bonsma et al., 2018).

The generality of this approach allows you to represent both tangible and non-tangible information. To give an example, a single element (e.g.: a brick) can be linked to a wall, as well as to one or more documents, or to some metadata, or even to external information on the web, using nothing but semantic triples (Iadanza et al., 2019). In Fig. 4 is shown how the building can be enriched with documents that can be either linked to the whole 3D model or to one or more specific parts.

Fig. 3. Every element of the building can be used to perform a live SPARQL query that returns all the details for that element, according to the HBIM ontology. Each value can be updated via web, thanks to the SPARQL 1.1 Update functionalities.
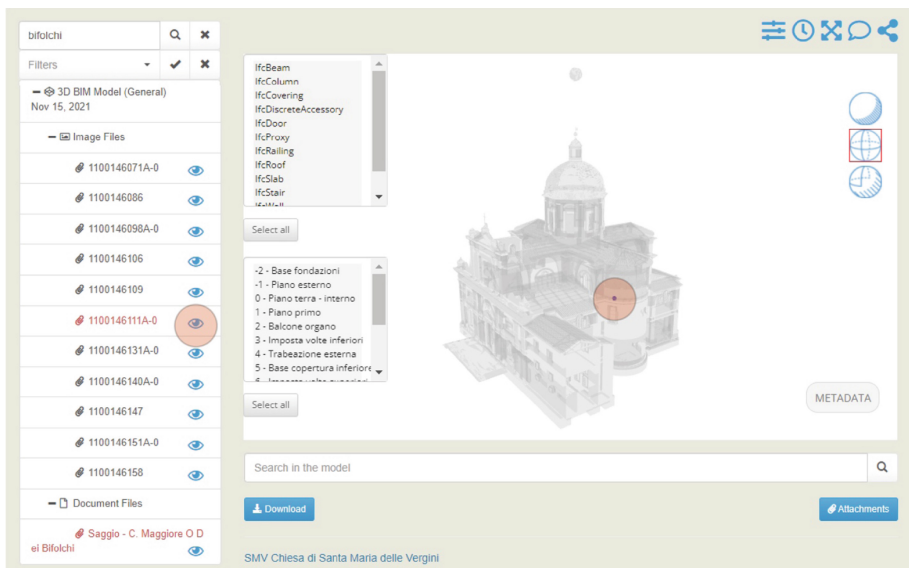
Fig. 4. The building can be enriched with documents that can be either linked to the whole 3D model or to one or more specific parts.

SOLID-ICE can be used advantageously for "Condition Based Maintenance", both for off-site and for on-site operations, allowing users to interact directly with the 3D model, also leveraging collaboration tools. As shown in Fig. 5, users can start a thread about one or more specific elements (as well as about the whole building). This functionality can be exploited for planning tasks and assigning roles in a collaborative way.

Media can be attached to elements, as well, to document the various steps of the condition assessment and maintenance process.
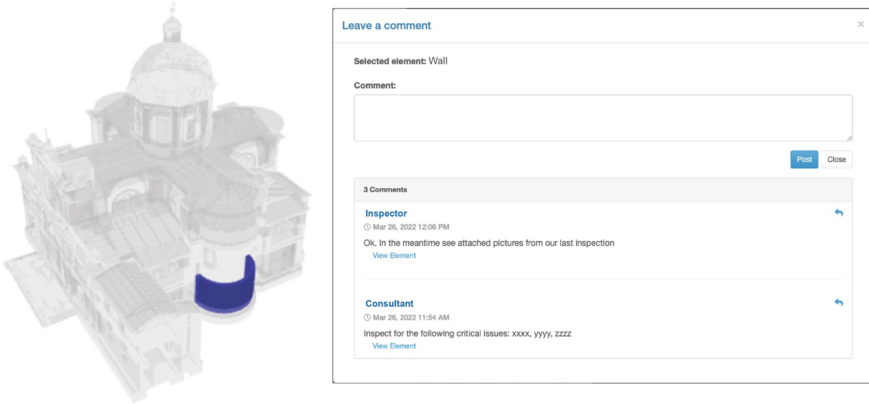
Fig. 5. Collaboration tools: users can start a thread about one or more specific elements

5   Condition Assessment Procedure and Tools

The condition assessment procedure is carried out on every single part of the building corresponding to an "object" of the BIM model. For each object the platform provides a form to be filled in, using a tablet, by the inspector who selects, from a predefined list, the defects detected. In addition to the list of defects, the platform provides data, information, photographs, and anything else useful to "guide" the inspector in identifying and evaluating defects.

To this aim, a database has been developed which associates for each building component (or plant) or every single element of the component, in the case of building components characterized by several layers (as in the case of masonry), the main defects due to natural or pathological factors.

One of the elements used in the test, for example, is the "Wooden joist", of the component "Roofing" for which the pathological phenomena found in it, such as "decay from fungi", "rotting", "cracks", "knot breakage", etc. were included.

The database, initially containing standard records relating to the standard building elements, is continuously updated with the addition of new technical elements and the corresponding lists of defects (themselves subject to additions and updates) each time the system is applied to a new building.

The above-mentioned database can be turned into a set of semantic triples, according to a specific semantic ontology, in keeping with the approach that underpins SOLID-ICE. There are numerous benefits of switching to a semantic solution. For example, using standard and open protocols makes the system intrinsically interoperable. It is worth recalling, here, that defining a dedicated ontology is much more than just defining a taxonomy (i.e., a tree of categories and subcategories). A semantic ontology, indeed,

allows you to define properties and inference rules that link one category to another. Hence, the unique chance of enabling a real semantic reasoner, or "reasoning engine", based on these rules, able to extract new knowledge.

Based on the procedures indicated in the Dutch standard NEN 2767-1, each defect has been assigned a priori the characteristic of "Importance" (generally not subject to interpretation), while the evaluation of the "Intensity" and the "Extent" is left (but guided by a range of description or values) to the evaluation and the judgment of the inspector, as synthetically specified in the following tables.

The following Tables (1 – 2 - 3) are based on the Dutch standard and define criteria and advice to be used by the inspector to identify and evaluate the defects (Straub, 2003). Inspector is provided with specific information (detailed descriptions and explanations, photos, pictures, technical reports, etc.) available in the BIM model as metadata linked to each building element.

Table 1. Framework for defects (Source: NEN 2006)

Importance	Explanation
Critical	Critical defects harm directly the function of a building components
Serious	Serious defects mean degradation of a building component without directly harming its function
Minor	Minor defects do not harm the function of a building component

Table 2. Classification of Intensity of defects (Source: NEN 2006)

Intensity class	Name	Description
Intensity 1	Low	The defect is hardly visible
Intensity 2	Middle	The defect is progressing
Intensity 3	High	The defect cannot progress any further

Table 3. Classification of Extent of defects (Source NEN 2006)

Extent class	Percentage	Description
Extent 1	<2	The defect occurs incidentally
Extent 2	2–10	The defect occurs locally
Extent 3	10–30	The defect occurs regularly
Extent 4	30–70	The defect occurs frequently
Extent 5	>70	The defect occurs generally

"Extent" and "Intensity" of the defects lead to the condition assessment (from excellent to worst) using 3 different matrices corresponding to the 3 levels of "Importance" as shown below (Tables 4 and 5).

Table 4. Six-point scale Dutch standard for condition assessment of buildings - Source: NEN (2006)

Condition rating	1	2	3	4	5	6
General condition description	Excellent	Good	Fair	Poor	Bad	Very bad

Table 5. Matrix of resulting condition ratings for critical, serious and minor defects (Source: NEN 2006)

Critical	Extent 1	Extent 2	Extent 3	Extent 4	Extent 5
Intensity 1	1	1	2	3	4
Intensity 2	1	2	3	4	5
Intensity 3	2	3	4	5	6

Serious	Extent 1	Extent 2	Extent 3	Extent 4	Extent 5
Intensity 1	1	1	1	2	3
Intensity 2	1	1	2	3	4
Intensity 3	1	2	3	4	5

Minor	Extent 1	Extent 2	Extent 3	Extent 4	Extent 5
Intensity 1	1	1	1	1	2
Intensity 2	1	1	1	2	3
Intensity 3	1	1	2	3	4

In general, a component is made up of several building elements where different decay conditions can be assessed. The system assigns to the component as a whole the condition score corresponding to that of the element in the worst condition.

The example shown in Table 6 shows a condition assessment on wooden joists: the inspector, using the tables and matrices provided by the system, enters the defects detected and the data corresponding to "Intensity", and "Extent" ("Importance" is automatically assigned). Then the system calculates, interpolating the values, the resulting condition for each defect and the overall condition of the joists.

Inspections will concern, at least in the first phase, mainly the external visible surfaces of the elements. The system, therefore, assigns, to the components where the inspection concerns two different sides or surfaces (often different as in walls, floors, and roofs), two values: one corresponding to the condition of "surface A" (inside/intrados) and one to that of the "surface B" condition (external/extrados), corresponding to two different condition assessment forms. Once the forms are completed, the resulting scores are uploaded into the BIM model.

Table 6. Wooden joists condition assessment

Element	Defects	Importance	Intensity	Extent	Condition
Wooden joists	Alteration of surface finish	Minor	Middle	<2%	1
	Knots breakage	Serious	Low	>70%	3
	Cracks	Critical	High	10%-30%	4
Total					**4**

The demo case of the church of Santa Maria delle Vergini was developed, as previously stated, using Autodesk Revit (version 2022) and the demonstration was focused on four families of objects/components: walls, floors, roofs and columns. New specific parameters had to be created for individual element identification and subsequent condition assessment. The shared parameters created are:

- ID Revit, containing the identification code of the single element generated by the software
- Man_A_1-ID, containing the "surface identification code" A of the specific element
- Man_A_2-Condition, containing the "A surface condition" of the specific element
- Man_A_3-Priority, containing the level of priority for action based on the detected conditions
- Man_B_1/B_2/B_3 as the previous ones referred to B surface
- The "surface identification code" consists of a string that considers the following elements:
- "Revit ID"_"Revit Family"_" Basic Level/Constraint"_"Maintenance Surface (A or B)"

The use of such a string is due to the possibility, even without the visual contribution of the 3D model, to understand, thanks to the analysis of the Revit family (wall, floor, etc.) and to the basic level/constraint of the element itself, if the element actually inspected corresponds to the provide condition assessment form.

The introduction of the "priority" parameter makes it possible to diversify the planning of interventions on the basis of needs that may go beyond the specific conditions of the elements.

At the end of the inspection, the data on the conditions detected in the various components (i.e. the scores assigned by the system according to the defects found), are uploaded to the 3D model which, with a specific display option, gives each component a colouration corresponding to its condition.

Figure 6 shows the portion of the model used for the test in which the various components, once updated the metadata related to their condition, automatically take on a colouration that goes from light green (corresponding to condition 1) to bright red (corresponding to condition 6).

The system, that is still under development for what concern the user interface, is equipped with a dashboard of tools to interact with the model in two main ways:

- data acquisition (inspection reports, details and images of detected defects, data transmitted in real-time by sensors, etc.);
- data elaboration (entry or modification of intervention priority coefficients, entry of diagnostic data on defects and interventions to be carried out, data entry for the activation of maintenance interventions, etc.).
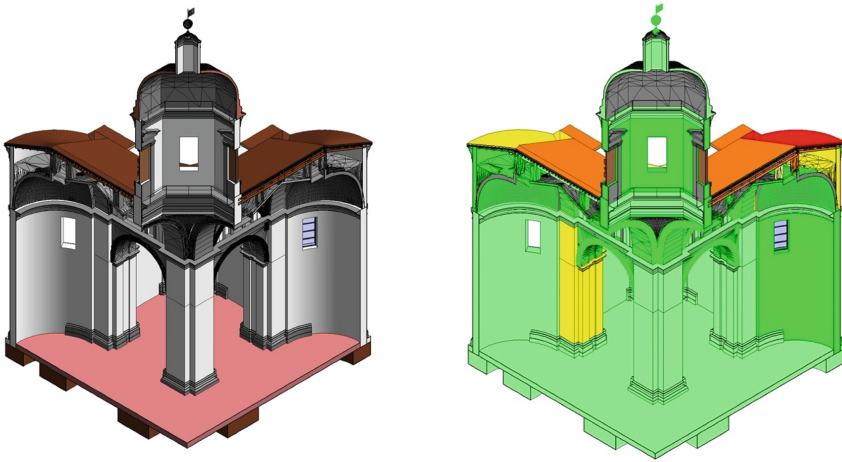
Fig. 6. Display of component conditions based on the 6 conditions scale after the inspection

The workflow and the steps of the inspection, the data upload procedure and the uploading/updating process (model to platform and vice versa) is shown in the following diagram (Fig. 7).
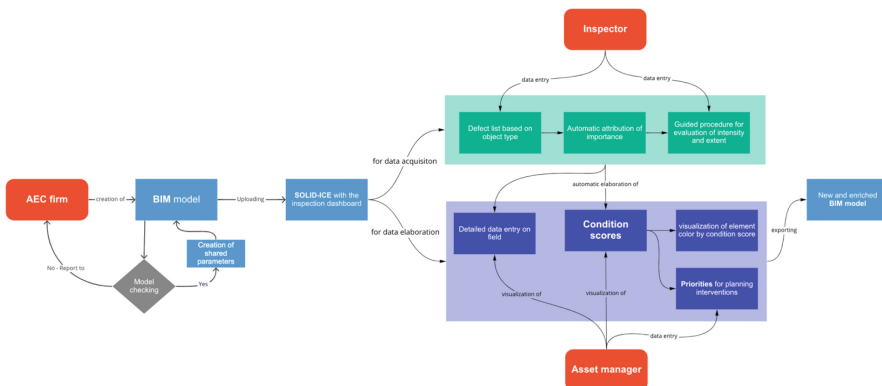
Fig. 7. Flowchart of the condition assessment process made possible by the use of SOLID-ICE equipped with the dedicated dashboard.

6   Conclusions and Further Developments

The positive results of the tests made on the case study of the church of Santa Maria delle Vergini, have confirmed the advantages of a procedure of condition assessment and remote evaluation of the data collected supported by the BIM model of the building and the tools developed on the INCEPTION platform.

However, it was remarked that:

- the procedure requires thorough inspections;
- only partial recourse can be made to "random" surveys;
- the procedures to be activated in the event of detected deterioration cannot be based on standard protocols.

The level of detail and the number of elements to be inspected shall be defined during the preparation of the BIM model. In this phase, the level of breakdown of the technical elements and of any single parts of the same technical element will have to be evaluated on the basis of the specific characteristics of the building (in the case, for example, of an intrados of a wooden floor with decorated joists, the single joists will have to be separated and the condition of each of them will have to be detected).

As for the diagnosis and planning phase of the maintenance or restoration intervention, the system can only provide some first recommendations based on the technical data that the BIM model transfers to the INCEPTION platform. These recommendations may be more detailed only after a first period of application of the system against data and technical reports on the interventions already performed. Also, in this case, the tools offered by the BIM model and the INCEPTION platform can help to optimize time and costs by operating as an effective Decision Support System.

The system developed in this first phase of research has focused on the optimization, both in terms of time and costs, of the condition assessment phase and, in particular:

- simplifying inspection procedures by means of tools to support their execution;
- calculation of condition scores by automatic interpolation of the values corresponding to the detected defects;
- transfer of inspection results into a digital twin providing a continuously updated overview of the building's condition and detailed data on the condition of individual elements.

The next steps of INCEPTION platform SOLID-ICE module development program will focus on dashboard improvements, in particular:

- completing the development of user interfaces for data acquisition activities: guided identification of defects, data and information consultation to define their intensity and extension, condition scores insertion;
- development of user interfaces for data elaboration activities: visualization of the model, remote reading of condition data, insertion of priority coefficients of interventions and specifications of interventions to be carried out;
- development of tools for scheduling maintenance work.

Author Proof

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