

DECISION-MAKING FOR HISTORIC BUILDING DIAGNOSIS BY LOGICAL INFERENCE IN HBIM APPROACH: THE CASE OF ONSITE INSPECTION OF TIMBER ELEMENTS

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Abstract

The paper is going to outline a methodological framework for the visual strength grading of timber structural elements, based on the Historic Building Information Modelling (HBIM) approach for data collection and management. Particularly, the development of rule-based inference routines by Visual Programming Language (VPL) is proposed in order to support the automated elaboration of relevant information toward reliable assessment of residual performances. The presentation of an illustrative case study, a small theatre in South Italy, gives the opportunity to show some representative aspects – parametric modelling of building components, integration of external databases, application of the inference algorithm and elaboration of diagnostic reports – of the proposed methods and techniques, which are meant to pave the way for further applications in diagnosis of building pathologies by automated decision-making tools.

Keywords

Building Diagnosis, HBIM, Logical Inference, Timber elements, NDTs

1. Introduction

The process of assessment and diagnosis of the state of conservation of the built heritage shows multiple levels of complexity. As a matter of fact, the information required for the qualification and critical interpretation of characteristics, pathologies and performances in historical buildings is generally heterogeneous, in terms of typology (documentary records, experimental measurements and analytical elaborations), context (building system, surrounding environment and functional uses) and disciplinary fields (historical, architectural, technological, structural, related to physical, chemical and biological sciences), with impacts on the data integration guiding expert decisions toward effective and compatible maintenance and restoration measures. To this end, the scientific community has been focused on the challenging search of innovative paradigms for knowledge systematization and decision-making support, by means of digital methods and tools enabling the smart management of the involved cognitive domains and their mutual relationships, in order to enhance both the synergic and consistent implementation of the available data and the

collaborative processes based on the exchange of information among the stakeholders (Hajirasouli, Banihashemi, Kumarasuriyar, Talebi, & Tabadkani, 2021; Messaoudi, Véron, Halin, & De Luca, 2018; Nishanbaev, 2020; Sánchez-Aparicio, Masciotta, García-Alvarez, Ramos, Oliveira, Martín-Jiménez & González-Aguilera, 2020; Yang, Grussenmeyer, Koehl, Macher, Murtiyoso & Landes, 2020).

From the methodological point of view, the Historic Building Information Modelling (HBIM) approach has undoubtedly proved to be a valuable solution to the afore-mentioned search. In fact, the employment of BIM virtual environments for morpho-typological and informative description of the artefacts allows developing digital repositories of structured hierarchies among the constituting parts, the parametric attributes related to materials, construction techniques and performances, as well as the available external databases of products and contents, not only for new buildings, but also for existing and historical ones (Apollonio, Gaiani & Sun, 2012; Bruno, De Fino & Fatiguso, 2018; Gargaro, Del Giudice & Ruffino, 2018; Mol, Cabaleiro, Sousa & Branco, 2020; Simeone, Cursi & Acierno, 2019).

Furthermore, from the operational point of view, records, parameters and attributes within the HBIM model might be exploited for the implementation of automated procedures, through interoperable toolkits running workflows, decision sequences and assessment of pre-set rules, leading from data archiving, cataloguing and interrogation to data processing and treatment for addressing decisions and resolutions (Bloch & Sacks, 2018; Bruno, Musicco, Galantucci & Fatiguso, 2020; Sousa, Prieto-Castrillo, Matos, Branco & Lourenço, 2018).

In this sense, the functionalities of BIM tools and BIM-oriented computation routines seem to fulfil different and complementary aspects within the process of assessment and diagnosis of the state of conservation of the built heritage: (i) the systematization of the preliminary knowledge, given by bibliographic-archivist documentation and direct survey, (ii) the clarification of the sequential phases that must progressively be carried out in the formulation of a judgment, which leads from the preliminary knowledge (pre-diagnosis) to the consolidated knowledge (diagnosis), through experimental tests and phenomenological modelling, (iii) the structured restitution of the diagnosis outcomes, aimed at ensuring comparability and replicability of the results for a wide range of cases. In the light of all the above issues, the present paper addresses the use of the HBIM approach and related logical inference procedures, as developed by Visual Programming Language (VPL), for a specific case, namely the in situ inspection of structural timber elements for the visual strength grading. The choice to refer to an application filed, fully codified in terms of methodology by the regulatory framework, means to validate the tools that might enable the transposition of widely accepted and operated "analogical" technical practices into automated "digital" routines.

2. Background

The in situ inspection of structural timber elements is broadly debated at normative (Riggio, D'Ayala, Parisi & Tardini, 2018) and scientific levels, with specific focus on diagnostic techniques supporting the visual survey (Feio & Machado, 2015; Palma & Steiger, 2020; Sousa, Sørensen, Kirkegaard, Branco, Lourenço, 2013). In particular, the activities required for the strength grading are included in a comprehensive framework (Fig. 1a), as reported in the standard

EN 17121:2019 and discussed in the literature, as outcome of the work by the Task Group "Assessment of Timber Structures" set within COST Action IE0601 (Cruz, Yeomans, Tsakanika, Macchion, Jorissen, Touza, Mannucci & Lourenço, 2014).

Within this framework, the first phase concerns: "Desk Survey" based on bibliographic and archivist records on the design, realization and construction evolution over the time; "Preliminary Survey", providing with an overview of the structure that is sufficient to plan the next stage identifying what provisions need to be made to gain safe access to the site; "Measured Survey" leading to the description of the geometry, technical solutions and main alterations; "Structural Analysis" for the analytical assessment of the tension and deformation conditions; "Preliminary report", highlighting the aspects requiring further investigation and the recommended methods. Thus, the second phase involves: "Detailed survey" with exhaustive mapping of representative areas, namely critical zones, in terms of decay/anomalies/defects, also by means of diagnostic techniques; "Diagnostic report" where the results of the previous activity are displayed and discussed; "Detailed design of repairs", describing the most suitable treatments.

With specific reference to the in situ inspection for strength grading, the activities move from the "Measured Survey", in which the elements are described in terms of morphology (shape, dimensions, connections, ...), historical-cultural (frames, coatings, ...) and macroscopic pathological patterns (from inherent defects of the material, biological degradation and/or mechanical damage). Then, the same activities are specified in the "Detailed survey", where the analysis focuses on some representative areas, called Vulnerable Zones (VZs) for the determination of a resistance category based on visual and instrumental investigation. In particular, the latter sub-phase is thoroughly defined by the Italian standard UNI 1119:2004, which provides with an assessment method, where the resistance category (1, 2 or 3) results from some combined qualitative and quantitative analyses on typical defects, such as wanes, cracks/shakes, single knots, groups of knots, slope of grain, radial cracks of the selected VZs for each element (Fig. 1b). The category is, in turn, related to the mechanical strength, known the wood species. Consequently, methodical data collection,

comparison of results against the normative thresholds and identification of the most cautious resistance category - the lowest from all the analyses - are required to accomplish successfully the assessment.

For data collection, the standard refers to the possible integration of manual measurements and diagnostic tests, which the technician should plan and carry out based on the information gaps, the available equipment and the operating conditions. In general, the diagnostic tests can be useful for assessment of the internal conditions of the elements, particularly for cracks/shakes, which can occur in the material without there being particular evidence on the external surfaces, and for radial shrinkage cracks, in order to detect if they are crossing and, therefore, compromising the integrity of the resistant sections. For the purpose of localization and possible quantification of the extent of internal discontinuities (Fig. 1c), both semi-destructive and non-destructive tests can be applied, as stated by the RILEM Technical Committee AST 215 “In-situ assessment of structural timber” (Dackermann, Crews, Kasal, Li, Riggio, Rinn & Tannert, 2014; Riggio, Anthony, Augelli, Kasal, Lechner, Muller & Tannert, 2014; Tannert, Anthony, Kasal, Kloiber, Piazza, Riggio, Rinn, Widmann & Yamaguchi, 2014). Among them:

- Resistance drilling: It is based on the measurement of relative density profiles of wood along the path of a small-diameter drill bit

penetrating with constant energy. The local decrease of density might be related with inner decay, cracks and hidden parts.

- Pin pushing: It is based on the measurement of the force required to let a pin penetrate into the element along a transversal trajectory, assuming that inner inhomogeneity would result in lower penetration forces.

- Digital radioscopy: It is based on the propagation of X-rays through the element, where the low attenuation of the impulse might be related to the presence of voids.

- Radar scanning: It is based on the measurement of the reflection of electromagnetic waves through the element, whenever an interface between materials with different dielectric properties (e.g. wood-air) occurs. The amplitude and extent of the reflection might be related to the presence of voids, fractures and discontinuities.

- Stress waves: It is based on the measurement of the velocity-of-flight of mechanical impulses through the element, in order to compare the recorded values against the corresponding ones of sound wood for the same species, as reported in literature. It is assumed that the more decayed and damaged is the wood, the lower the detected velocity is.

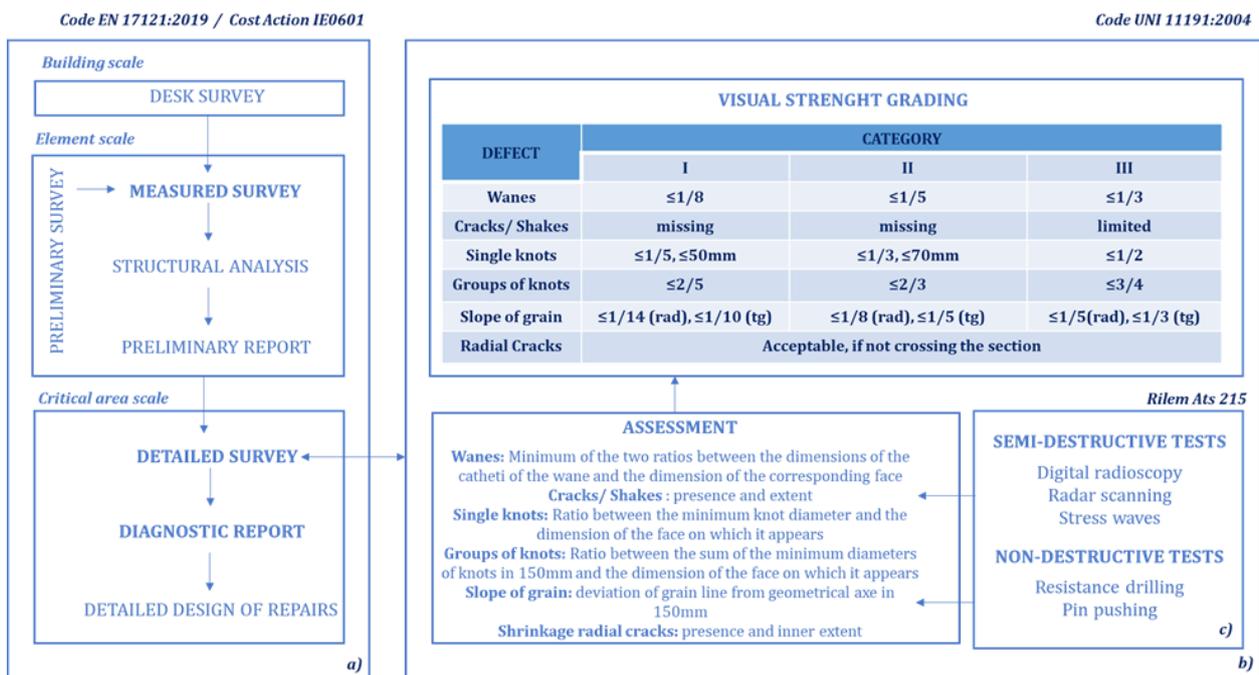


Fig. 1: General methodological framework from normative and scientific literature

3. *Methods and tools*

On the basis of the normative and scientific background, a workflow is proposed (Tab. 1) that highlights the main methodological phases and operational activities for the in situ inspection of timber structural components supporting the mechanical strength grading. In detail, functions, tools and products are listed that are usable for the evaluation process according to a guided and automated way within the HBIM approach. It should be noted that, with reference to BIM products, authors refer herein to Autodesk software (Revit®, Recap®,...), without prejudice to the transferability to other software tools.

In detail, concerning the "Measured Survey", the graphic representation of geometry, morphology and dimensions of the elements under investigation is based on the creation of a 3D model by BIM tools, starting from a reality-based survey (point clouds and polygonal meshes from digital photogrammetry and/or terrestrial laser scanner) or a computer-based survey (CAD products from direct measurements and available drawings). From the HBIM model, whose objects are associated with image galleries as customized instance parameters for photographic documentation, it is therefore possible to extract significant 2D maps of the macroscopic alteration patterns, by adding thematic textures on the 3D model or directly on the 2D elevations/sections.

Furthermore, concerning the "Detailed Survey", it is herein proposed an inferential routine, developed in VPL by Dynamo plug-in for Revit® that automatizes the logical process of classification for timber structural elements according to the aforementioned UNI 1119: 2004. For the purpose, the first activity is the creation of BIM objects representing the VZs, namely generic models, which are assigned customized instance parameters that collect the values about the defects (waned, cracks/shakes, single knots, groups of knots, slope of grain, radial cracks) for the visual strength grading. The assignment of the values to the defect indicators can be performed after the inspection, by reporting the annotations taken in situ on block notes or by entering the data in spreadsheets, previously structured by VZ, element and floor and then exported from the HBIM model. Once completed, the same Excel spreadsheet can be reloaded within the BIM model through automated BIM database management

applications (eg. Excel2R, SheetLink, Dynamo customized scripts).

Once the values for each indicator have been filled in for each VZ – typically two per element -, the customized VPL script can process the information and assign to the element the lowest category calculated for the related VZs. In particular, the algorithm performs a classification on each of the identified VZ and element, according to the scheme in Fig. 2.

In addition, if the resistance categories are high and/or there are operational difficulties in localizing and quantifying the extent of internal discontinuities, in particular cracks/shakes and radial cracks, the decision-making support tool suggests the application of the most relevant semi-destructive (Resistance drilling, Pin pushing, Digital radiography) or non-destructive (Radar scanning, Stress waves) diagnostic tests, in order to identify whether or not they are crossing the section. The application is also guided by the possibility to access an online database presenting best practices organized by case study, diagnostic technique and type of defect.

Such complementary tests will allow operators to assign a resistance category to the VZs. Thus, the lowest category of all the VZs for each element will be assigned to the element itself.

In particular, differently from the indications provided by UNI 1119: 2004, two further conditions have been added: Non Structural (NS), when at least one of the values characterizing each defect indicator exceeds the thresholds of category III. Moreover, all those elements for which it is not possible to detect at least one of the defects, due to poor accessibility, are considered Non Classifiable (NC).

Finally, all the textual and infographic information of the "Measured Survey" and the "Detailed Survey", including the decay maps, the tables summarising the defect indicators, the associated values and the categories for VZs and element, as well as the photo galleries for VZs and element are collected in a final table. The table corresponds to the "Diagnostic Report", which can be consulted within the same BIM environment, to the internal sharing platforms via BIM-based web such as Autodesk Viewer or exported to pdf to be managed even with the most traditional communication tools.

Tab. 1: Phases, tasks, HBIM-based functions and tools/products for machine-guided in situ inspection of timber elements

Phases	Tasks	Functions	Tools/products
Measured survey	Graphic representation	Reality-based or computer-based 3D modelling in BIM environment	1) Point cloud in Recap® to be imported as *.rcp in Revit® 2) HBIM model in Revit® as *.rvt and *.ifc
	Photographic documentation	Parametric modelling of BIM objects adding images	HBIM model in Revit® with customized instance parameter IMAGE per each building element. Possibility of reporting them in Sheets exportable as .pdf
	Decay mapping	Mapping of elevations and significative 2D sections as extracted from the 3D model	Elevations and sections automatically created from the HBIM model and related Sheets exportable as .pdf
Detailed survey	Identification and assessment of defect indicators for visual strength grading	Localization of VZs on timber elements as autonomous BIM objects and parametric attribution of defect indicators	“Generic model” representing the VZs with customized parameters for automatic classification
	Identification and assessment of experimental tests	Creation of a repository of best practices	Online database shareable via link through cloud service
	Identification of resistance category	Implementation of a logical inference algorithm based on the values of the defect indicators	Customized script in VPL with Dynamo as .dyn
Diagnostic report	Schematic restitution of drawings, pictures and tables	Automatic creation of the fields of diagnostic report based on data and images available in the HBIM model	Sheet from HBIM model composed with drawings and schedules, exportable as .pdf

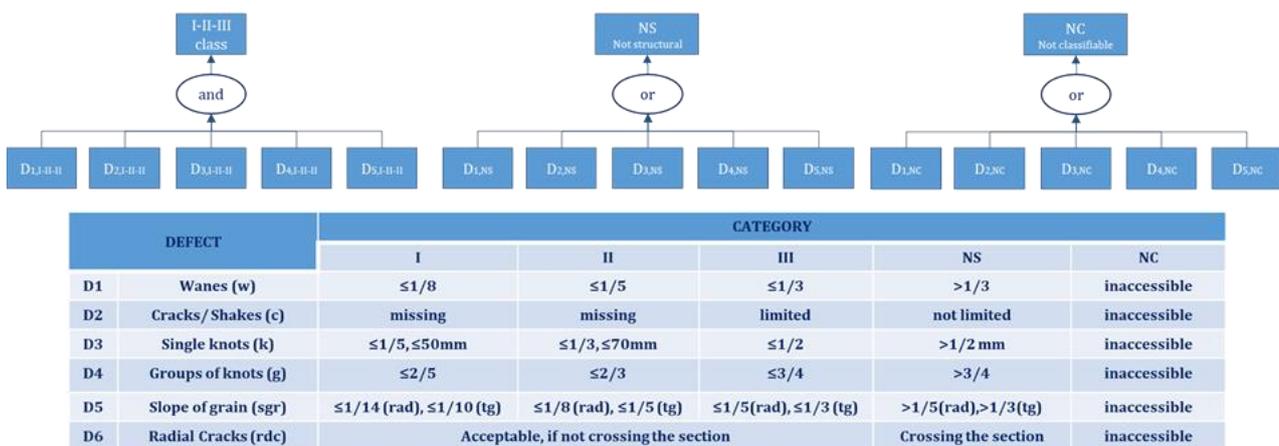


Fig. 2: Scheme of the inference logic for classification of VZs by VPL Dynamo

4. Validation

The methodological and operational framework, as presented in the section 3, was applied and validated on a representative case study, the Town Theatre of Noicattaro in the province of Bari, South Italy.

The building, dating back to the middle XIX century, was founded on a pre-existing hypogeal room. It is recognized as the smallest European “Italian-style” theatre, since it shows some distinctive features compared to the Renaissance layout, including: horse-shoe plan, separated sections of seating at different height and a deep stage that made the actors play surrounded by – and not ahead - the scenery.

The theatre (Fig. 3) is composed of two sections above the stage level. The first level was dedicated to the noble families, while the second one hosted common people. The floorings are supported by ten columns and nine beams for each level. Moreover, considering the additional timber decks connecting the audience sections with the stage and the columns bearing the roof, the theatre counts thirty-four columns and twenty-two beams.

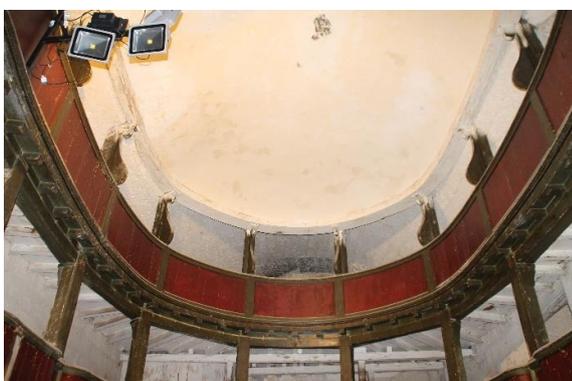


Fig. 3: Overview of the timber structures at the first level (above) and second level (below) of the theatre

Concerning the typological and architectural characteristics, the columns at the first floor show hexagonal shape, with variable sections between 0,00m and 1,20m and dodecagonal shape above 1,2m (Fig. 4), while the columns at the second floor have rectangular shape with waners of different extent.



Fig. 4: Detail of the pillar at the first level

The beams at the first and second floors are composed of two juxtaposed elements, the inner with constant square shape, the outer with variable rectangular shape, resulting in a curved profile toward the stage. All the elements are enriched by decorations with red, green and gold pictorial layers: such layers are applied on cladding boards at the first level and directly on the elements at the upper levels (Fig. 5).



Fig. 5: Detail of the pillar at the first level

As far as the state of conservation is concerned, it should be mentioned that all the elements show a general physical obsolescence, worsened by the conditions of abandonment over the last decades, with evidence of cracks, missing parts and surface alterations, particularly at the second level (Fig. 6). All the elements were investigated in order to assess their resistance category, as detailed in the

following sections. Furthermore, some preliminary activities were carried out, including the identification of the wood species, according to the standard UNI 11118:2004. In detail, based on macroscopic observations on colour and texture and optical microscopy analysis on seven specimens, it was determined the species as spruce.

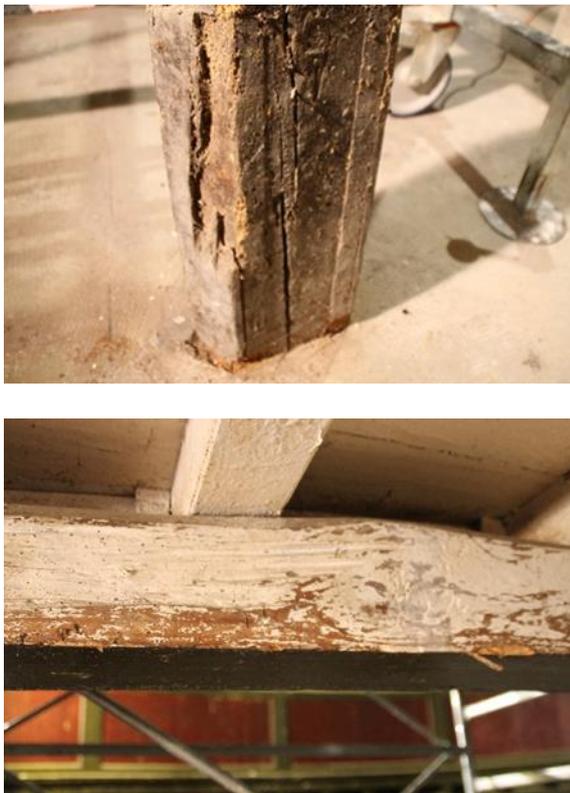


Fig. 6 Example of decay on the pillars (above) and on the beams (below) at the second level

4.1 Measured survey

According to the proposed methodology, the HBIM modelling of the wooden structure was carried out starting from existing drawings in CAD format, as digital survey campaigns were not programmed. The columns were modelled as Structural Column in Revit, Omniclass Columns Number 23.25.30.11.14.11, IfcColumn. Specifically, the columns of the first level (Pnn.1) were created as a custom family using the BIM drawing tools because they present complex sections and variable elevation. Whereas, the columns of the second and third levels (Pnn.2 and Pnn.3) were modelled using the System Families of structural wooden columns with rectangular section. The same procedure was performed for

the modelling of the beams belonging to the Beam family, IfcBeam. Likewise, all the building components have been created. During the diagnostic activity, the building elements can be represented with a reduced level of geometric detail (LOD 300), envisaging improvements of the geometric model, during the entire process, until the LOD 500 or LOD G in accordance with UNI 111337-4 2017.

In addition, the “Vulnerable Zone” BIM object (Pnn.m_VZt) was modelled since the vulnerable zones, once identified, have been classified in order to select the lowest category to be assigned to the element.

The thematic decay maps consist of further information requirements by this level of detail, and they can be represented in 2D, in the sections and elevations extracted from the model, and in 3D as BIM objects. In this case, the defects were modelled using drawing lines and filled regions on the extracted sections to simplify the operation, especially on those structural elements with grooved and decorated geometric shapes such as columns.

4.2 Detailed Survey

In this phase, direct surveys were executed through visual inspection of defects and in-depth analysis of results from non-destructive or semi-destructive diagnostic tests if necessary, in order to limit the uncertainties deriving from the visual inspection of the cracks/shakes and radial cracks. First, the HBIM model was prepared to support the information modelling of the results of these activities in order to classify the timber elements. Therefore, the shared parameters related to the classification have been loaded into “Vulnerable zones”, “Structural columns” and “Beams” BIM objects. The denomination of these attributes corresponds to the defects according to the UNI 1119: 2004 classification, also including the Non Structural and Non Classifiable categories, and they have been assigned by instance in the “Structural” parameter group (Tab. 2).

The values have been exactly reported with respect to the selected coding, so that they could be used by the inferential algorithm (Fig. 7).

Indeed, only if the parameter values are correctly imputed, including commas, spaces and upper/lower case letters, the VPL script in Dynamo will run; otherwise it would report an error. Once the codes have been assigned to the structural elements, by localization in plan and

elevation, and the parameters loaded, the spreadsheet has been exported to be compiled and updated on site with the values of each defect for the identified vulnerable zone. Afterwards, the evaluation has been executed in the office, once the spreadsheet has been loaded into the HBIM model.

Tab. 2: Semantic representation of parameters for classification of vulnerable zones and timber elements.

BIM object	Parameter name	Parameter value	Data type
Pnn.m_VZt	Wanes	As reported in Python script (Fig. 8)	Text
	Cracks/ Shakes		Text
	Single knots		Text
	Groups of knots		text
	Slope of grain - radial		Text
	Radial Cracks		Text
	In-situ class UNI 1119:2004		Text
	Image		Image
P/Tnn.m	Comments		Text
	P/T_Class UNI 1119:2004	1, 2, 3, NC or NS	Text
	Image	-	Image
	Resistance section comments	-	Text

The definition in VPL started from the selection of the "Vulnerable zone" BIM object from which the parameters and related values have been filtered for the characterization. The inference algorithm compared the indicators 'values with the previously defined rules for classification developed into a custom Dynamo node written in Python (Fig. 8):

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If (w == "≤1/8" and c == "missing" and k == "≤1/5 ≤50 mm" and g == "≤2/5" and sgr == "≤1/10 (10%)" and rdc == "acceptable, if not crossing the section"):
    c="1"
elif (w == "≤1/5" and c == "missing" and k == "≤1/3 ≤70 mm" and g == "≤2/3" and sgr == "≤1/5 (20%)" and rdc == "acceptable, if not crossing the section"):
    c="2"
elif (w == "≤1/3" and c == "limited" and k == "≤1/2 mm" and g == "≤3/4" and sgr == "≤1/3 (33%)" and rdc == "acceptable, if not crossing the section"):
    c="3"
elif (w == ">1/3" or c == "not limited" or k == ">1/2 mm" or g == ">3/4" or sgr == ">1/3 (33%)" or rdc == "crossing the section"):
    c="NS"
elif (w == "inaccessible" or c == "inaccessible" or k == "inaccessible" or g

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== "inaccessible" or sgr == "inaccessible" or rdc == "inaccessible"):
    c="NC"
else:
    c="verify the correct category with a second round of minimum requirement"
OUT = c

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If there were different conditions than those set, the algorithm would suggest carrying out a second round to obtain the minimum requirements for the correct classification, as a check of the diagnostic procedure. The lower class of the related "Vulnerable zones" have been assigned to the element. The results can be organized within a table incorporated in Revit (so-called schedules) by vulnerable zone and element.

The "Image" parameters have also been associated with the vulnerable zones and elements in order to place the photographic shots that illustrate the state of conservation, which can be recalled for the preparation of diagnostic reports.

Since the algorithm suggested performing detailed experimental tests, the customized families about the points and acquisition profiles of on-site tests (specifically, "RD_Profile" for resistance drilling and "RS_Profile" for radar scanning). As far as the tests concern, the parameters managed are semantically configured (Tab. 3).

Tab. 3: Semantic representation of parameters about diagnostic tests.

BIM object	Type	Parameter name	Data type
NDT_Profile	NDT_Profile_Pnn.mA,B,..	Mark	Text
		RD_Date	Text
		RD_Equipment	Text
		RD_Methodology	text
		RD_Comments	Text
		Image	Image

As an example of the diagnostic techniques that were carried out in order to reduce some interpretation uncertainties on cracks/shakes and radial cracks along the transversal sections, some results are reported below for resistograph tests and radar scans.

For both the techniques, the investigation concerned crossing paths that were perpendicular to the external faces showing surface defects, in order to detect their potential in-depth propagation.

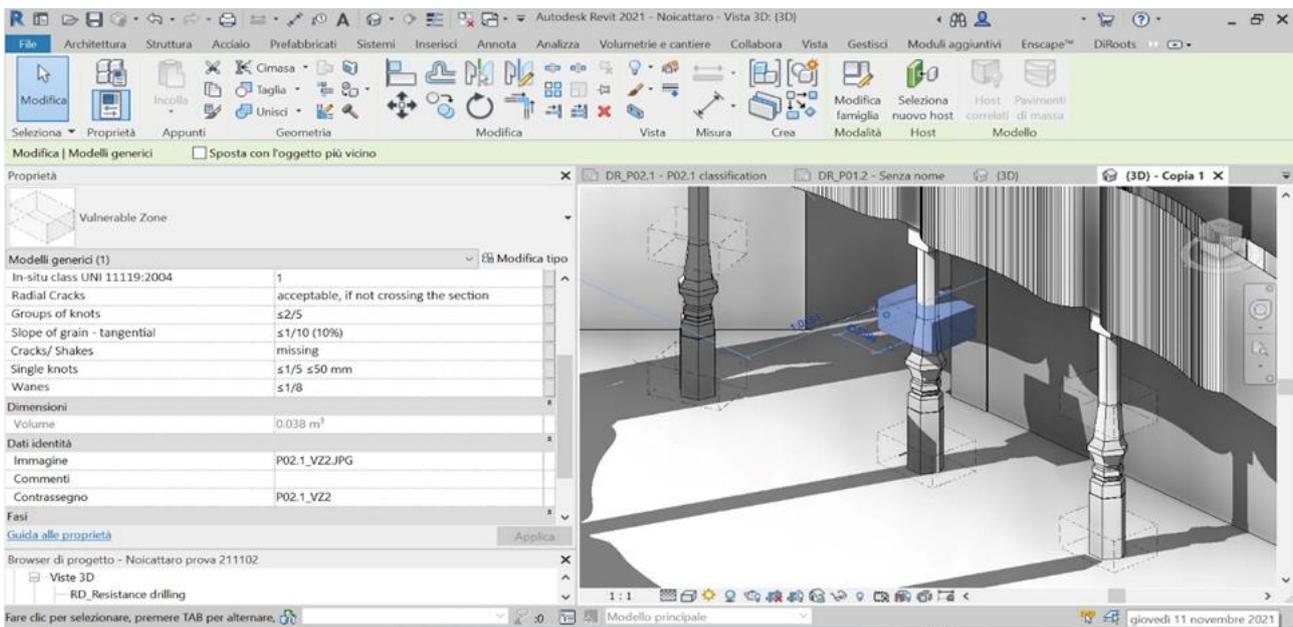


Fig. 7: BIM modelling of the Vulnerable Zone and related parameters' visualization

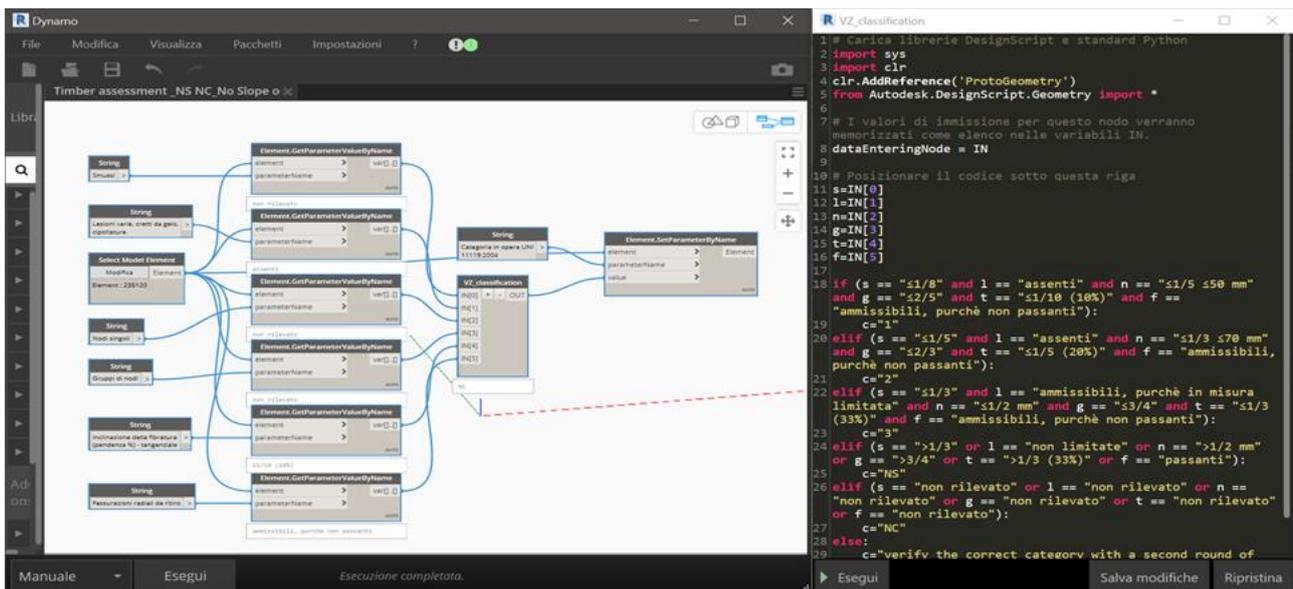


Fig. 8: Classification of the Vulnerable Zone in VPL Dynamo

The resistograph tests were performed by IML-RESI F400-S resistograph. They made it possible to measure the resistance of the material to the penetration of a metal tip with a millimetre diameter along a cross section and, therefore, to locate any density reductions, corresponding to the presence of inner cracks (Fig. 9).

The radar scans were acquired by IDS DAD Fastwave and TRHF 2000 antenna. They allowed to evaluate the behaviour of the timber elements with respect to the transmission/reflection of high

frequency electromagnetic waves, on the basis of which it was possible to identify or exclude internal cracking planes (Fig. 10). It should be noted that, as additional decision support tools, the HBIM model template contains information sheets for the application and assessment of the diagnostic tests, including the link to the online available database that collects the above-mentioned best practices of previous case studies, organized by type of test and result (Fig. 11).

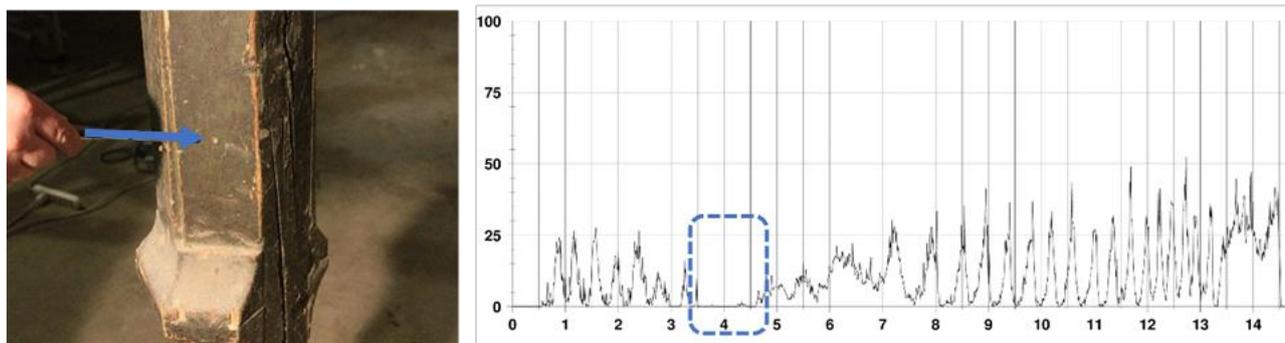


Fig. 9: Resistograph test showing a density decrease corresponding to radial cracks on the adjacent sides

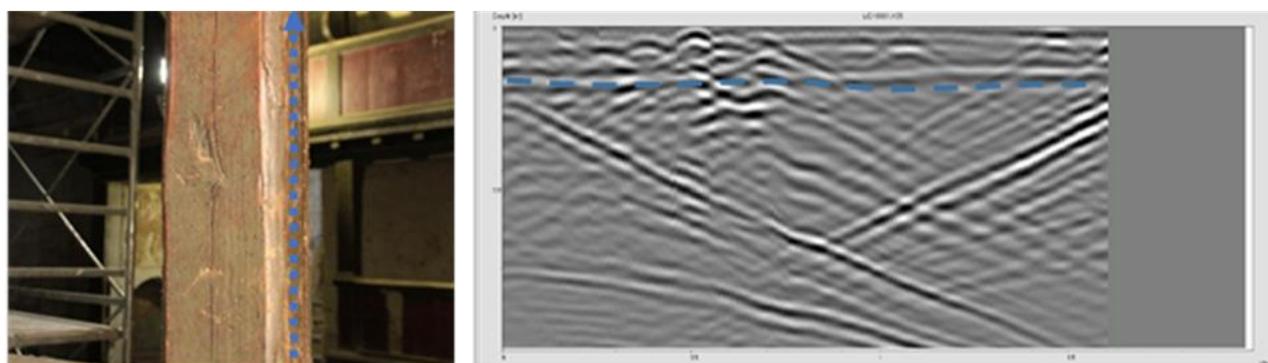


Fig. 10: Radar scan showing a continuous plane of discontinuity corresponding to radial cracks on the adjacent sides.

4.3 Diagnostic report

Based on what the standard EN 17121:2019 indicates, the “Diagnostic report” collected the observations of the entire set of investigations carried out on the VZs and on the structural elements to provide comprehensive analysis sheets. In the proposed framework, the reports were drawn up for each structural element, columns and beams, depicting the decay mapping on the elevation of each element with lines and detailed filled regions, including the automatic synoptical legend, as well as the geometric variability of the section in the columns, the height at which this variation occurs and the cladding portions.

In addition, a table has been inserted to summarize the characteristics of the element and a box with notes. In the same report, the tables deriving from the Revit schedules have been prepared to describe the identified vulnerable zones and the elements with the relative resistance classes, automatically assessed; photographs and the observations (Fig. 12).

In the same way, the tables for the diagnostic reports were prepared for each element and for each performed diagnostic investigation; table fields regarded representative graphs for the location of the acquisition point, as well as the document code, the date of the investigation, the methods of execution and the measurement equipment. These fields are the customized parameters added to the BIM object that represents the acquisition point or profile.

The same BIM object about acquisition point/profile held the photographic shot about the execution and the image about the elaborated data (resistogram or radargram), together with the concluding comments of the reported evidence (Fig. 13).

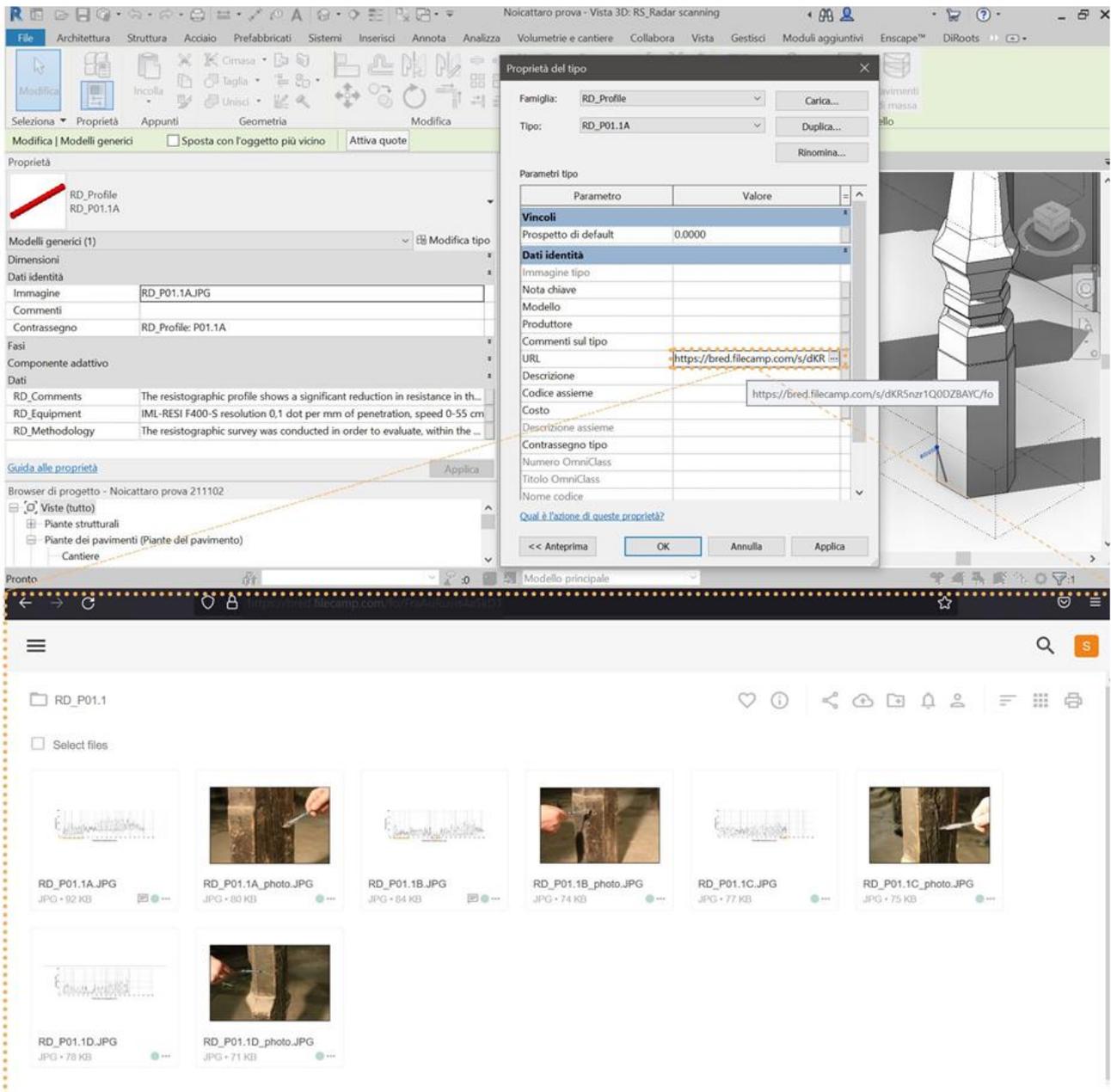


Fig. 11: BIM modelling of the NDT Profile and availability of a link to a web-based database of previous case studies

Mark	RD_Diagnostic report		
	RD_Methodology	RD_Equipment	Image
RD_Profile: P08.1	The resistographic survey was conducted in order to evaluate, within the constructive element, any variations in density due to the morphological characteristics of the material, as well as to the presence of signs of degradation and crack patterns, also in relation to the direct visual inspection.	IML-RESI F400-S resolution 0,1 dot per mm of penetration, speed 0-55 cm	

Fig. 12: Report for diagnostic tests

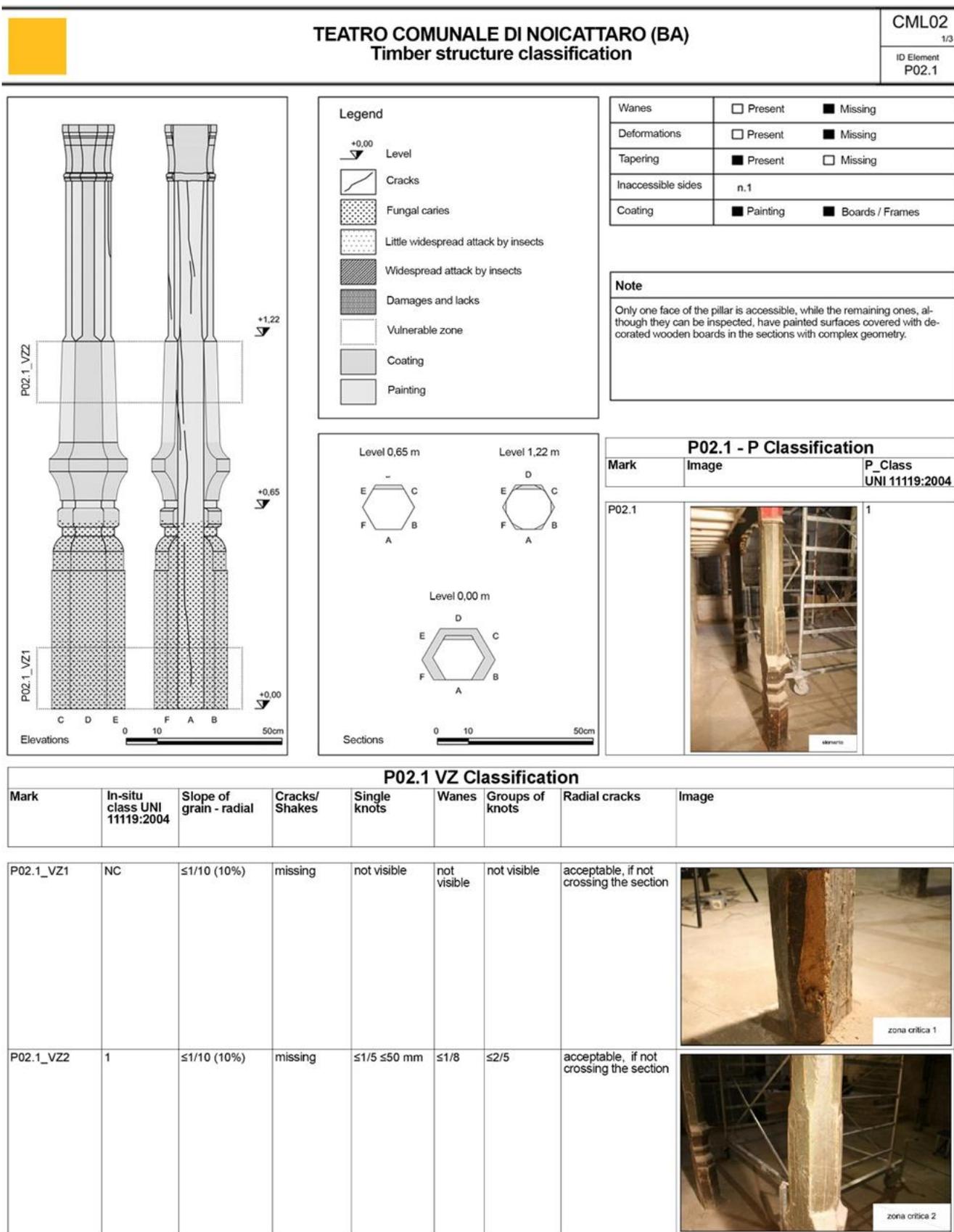


Fig. 13: Report for VZ and column classification and decay mapping

5. Discussions of results

Based on the application of the in situ visual inspection of thirty-four columns and twenty-two beams, also supported by resistograph tests on fifteen elements and radar scans on nine elements, it was possible to grade the resistance category, with the support of the proposed logical inference algorithm,

The benefits provided by the automatic routine concerned the accomplishment of a guided sequence of activities, from the attribution of the values to the defect indicators until the suggestion of suitable on-site tests that could to reduce uncertainties in evaluating those defects that can be difficult to assess only by visual surface inspection such as internal cracks/shakes and crossing radial cracks. In addition, the analysis of the outcomes from resistance drilling and radar scanning has been facilitate comparing the images and graphs with previous case histories, organized within an on-line database, available as URL parameter in the HBIM model template. The entire process avoided mistakes in visual strength grading due to the nature of the automatic algorithm, which has been developed with the aim of providing alerts if some defect indicators are inaccurate.

With reference to the overall achieved results (Tab. 4), it can be summarised that the colours and beams at the first level belong to categories from 1 to 2, except for limited cases (three) which, due to local deterioration conditions, such as crossing radial cracks, are to be considered NS. The situation at the upper levels is more critical, with beams generally of class 2 or 3 and in some cases

NS (three) and with columns in many cases NS (eleven), due to morphological defects, such as accentuated waness, extensive presence of knots and groups of knots, and/or degraded conditions, such as radial cracks and large internal areas of discontinuity.

These results, beyond the state of abandonment and disuse of the building, seem to be caused by a different constructive-architectural care in the choice of the timber members at the first level, which was intended for noble families and more immediately perceived from the main access. In fact, it was found that, here, the wood is less affected by defects and in any case protected by cladding boards that prevented direct exposure to the surrounding environment.

6. Conclusions

The methodological approach and operating procedures, as proposed in this work, are intended to provide a contribution to the challenging search for useful solutions toward the knowledge systematization and the decision support within the assessment and diagnosis of historic buildings.

In particular, the possibility of archiving and structuring data relating to construction components through HBIM digital environments allows desirable information management, especially in fields involving the integration of heterogeneous documentary sources, conceptual elaborations and instrumental tests, the correlation of both onsite and ondesk activities, as well as the communication and cooperation among different specialists. Furthermore, such aspects are strategic if extended to a broader set of

Tab. 4: Wooden elements' classification with inference logic in HBIM model

First level				Second level				Underroof level			
Column		Beam		Column		Beam		Column		Beam	
P01.1	NS	T01.1	1	P01.2	3	T01.2	2	P01.3	NS		
P02.1	1	T02.1	1	P02.2	NS	T02.2	3	P02.3	2		
P03.1	2	T03.1	1	P03.2	NS	T03.2	3	P03.3	NS		
P04.1	1	T04.1	1	P04.2	3	T04.2	3	P04.3	NS		
P05.1	2	T05.1	2	P05.2	NS	T05.2	NS	P05.3	NS		
P06.1	2	T06.1	2	P06.2	NS	T06.2	3	P06.3	NS		
P07.1	1	T07.1	1	P07.2	3	T07.2	NS	P07.3	NS		
P08.1	NS	T08.1	2	P08.2	2	T08.2	2	P08.3	3		
P09.1	1	T09.1	NS	P09.2	1	T09.2	2	P09.3	3		
P10.1	1	T10.1	1	P10.2	2	T10.2	NS	P10.3	3		
P11.1	1	T11.1	2	P11.2	NS	T11.2	3				
P12.1	1			P11.2	3						

case studies, with a view to comparability and extensibility of the results.

Similarly, the development of routines, automated by BIM-related logical inference tools and aimed at processing databases, which are homogeneously codified and implemented, for the formulation of decisions and resolutions, enables robust and reliable elaboration and restitution, in particular when serial and repeated procedures for numerous parameters and elements are involved.

Finally, there remains the need for preliminary conceptualization of the aspects and phases that characterize a certain specialist work flow, with a

view to highlighting the knowledge domains and the related relationships that ICT tools and techniques can represent and reproduce, while maintaining the critical control of the results by the operators.

7. Acknowledgements

The authors would like to acknowledge BReD srl, university spin-off of the Polytechnic of Bari, for the availability to let the authors access and further elaborate the results of the direct survey and diagnostic campaign on the case study.

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