EDICULA

Educational Digital Innovative Cultural heritage related Learning Activities

Project Code: 2020-1-EL01-KA203-079108

			PerpetielSI SRL		
NATIONAL TECHNICAL UNIVERSITY OF ATHENS [GREECE]	**SAPIENZA UNIVERSITA DI ROMA [ITALY]**	**BEZALEL ACADEMY OF ARTS AND DESIGN [ISRAEL]**	**PERPETIELSI SRL [ROMANIA]**	**ISRAEL ANTIQUITIES AUTHORITY [ISRAEL]**	**HELLENIC RESEARCH INSTITUTE OF THE ALEXANDRIAN CIVILIZATION [GREECE]**

INTELLECTUAL OUTPUT: **O3 EDICULA hands-on framework**
DELIVERABLE: **NTUA input to D3.4: EDICULA Guidelines for hands-on education in CH protection**
LEAD ORGANIZATION: BEZALEL ACADEMY OF ARTS AND DESIGN
DATE: 26 April 2021

Co-funded by the Erasmus+ Programme of the European Union

ΙΔΡΥΜΑ ΚΡΑΤΙΚΩΝ ΥΠΟΤΡΟΦΙΩΝ IKY

Table of contents:

1. Introduction

The following text is the NTUA input to the Deliverable 3.4 EDICULA hands-on framework. It includes three major aspects of the suggested framework that encompasses:
(a) documentation protocols of cultural heritage assets, along with the corresponding data collection forms,
(b) short description of the non destructive techniques of Infrared Thermography (IRT), Ground Penetrating Radar (GPR), Digital Microscopy (DM), Ultrasonic Pulse Velocity (US), and Schmidt Hammer (SH), along with International Standards related to practicing these techniques,
(c) list of the current European Standards related to the protection of cultural heritage, where common scientific glossary and research practices are developed.

2. Guidelines for the Documentation of Built Cultural Heritage – Integrated Protocols

NTUA previous experience, on establishing methodologies for the documentation of cultural heritage assets, was gained through participation into the EU-CHIC and INCEPTION European research projects. As a result, a series of **Integrated Documentation Protocols** was developed [Kioussi et all 2013, PhD Kioussi 2016], where collection and recording of data follow eight (8) main **Classification Categories**. A summary of this holistic documentation concept follows:

No	Classification Categories
I.	Historic
II.	Geometric
III.	Architectural
IV.	Building Materials
V.	Structural Analysis
VI.	Condition Assessment
VII.	External risks
VIII.	Conservation Interventions

In the framework of increasing complexity with increasing level, Classification Categories of data are further analyzed into Documentation Parameters. The **Classification Categories** along with the individual Documentation Parameters cover the whole spectrum of information needed to allow effective management and decision making. The main aspects of monument taxonomy, along with specific parameters of holistic e-documentation, including data, as well as metadata are presented in the following table.

Classification categories and Documentation parameters of the Integrated Documentation Protocols methodology

Classification Categories		Documentation Parameters
I .Historic	I.1	History of the building
	I.2	Values
	I.3	Stakeholders Information
	I.4	Testimonies

	I.5	Bibliography
	I.6	Uses
	I.7	Depictions
II. Geometric	II.1	Location
	II.2	Morphology
	II.3	Shape
	II.4	Size
	II.5	Land Registry
III.Architectural	III.1	General Typology
	III.2	Local Historic Architectural Typology
	III.3	Depictions
IV. Building Materials	IV.1	Building materials identification
	IV.2	Mineralogical-Petrographic Characterization
	IV.3	Physicochemical Characterization
	IV.4	Materials Life Cycle -technical and financial data
V. Structural Analysis	V.1	Bearing structure documentation – Structural system
	V.2	Structural member documentation
	V.3	Construction materials distribution in the building
	V.4	Structural member previous interventions
	V.5	Structural member structural condition assessment
VI. Condition Assessment	VI.1	Visual observations
	VI.2	Building materials conservation state assessment
	VI.3	Structural conservation state assessment
	VI.4	Depictions
VII. External Risks	VII.1	Climatic
	VII.2	Hydrological
	VII.3	Geological / Geomorphological
	VII.4	Biological
	VII.5	Human
	VII.6	Social
	VII.7	Economic
VIII.Conservation Interventions	VIII.1	General intervention data
	VIII.2	Before treatment material
	VIII.3	Conservation materials
	VIII.4	Treated material assessment
	VIII.5	Overall intervention assessment
	VIII.6	Depictions

Short description of the eight main categories

Historic Documentation describes the historic framework of the building including historic description, related dates and historic characteristics sources and external references, relevant data, historical use or function of the heritage item as well as other subsequent uses, contextualization in relation to the structure of the item and in relation to its environment and time of construction, etc.

Geometric Documentation includes the action of acquiring, processing, presenting and recording all the necessary data for the determination of the position, form, shape and size of a monument or historic building in the three dimensional space at a particular given moment in time. It includes a series of measurements, metric data acquisition for the determination of the shape, the size and the position of a building.

Architectural documentation refers to the typology of the building such as the building type, its morphology, the architectural style, the physical attributes of the building (surface, volume, and coverage), internal or external decoration, etc. Also, it registers information regarding characteristic local typologies.

Building Materials classification category includes all the necessary information that identifies the structural and non-structural materials used in the building. It investigates the type of materials, the provenance of these materials, their physical and mechanical properties, their composition [chemical, petrographic, mineralogical] as well as processing parameters [e.g. cost and availability, production, etc.].

Structural analysis information focuses on the investigation of structure [e.g. description of bearing structure, construction techniques, distribution of building materials, etc.], on its structural state and its problems [e.g. mapping of structural cracks], and also detailed dimensions and references to its performance, that can be used in computer aided tools.

Condition assessment relates to all data regarding the diagnosis of the monuments decay and damage using visual observations, non-destructive techniques, analytical testing, decay and damage mapping, etc., both on structural and non structural elements of the monument. Information on mechanism of the decay as well as on the vulnerability diagnosis [e.g static analysis, etc.] are also collected and stored to complete assessment of an overall state of conservation.

External Risks include accidental actions, human impact, social parameters, economic parameters and others. Documentation of such data enables the correlation of various hazards threatening the monument with the intrinsic vulnerability of the structure and helps reveal the impact of outer effects (long term and short-term environmental factors, atmospheric pollution, ground water contamination etc) on the building.

Conservation Interventions data investigation and recording documents all previous interventions performed on the monument, such as: past intervention works, including detailed information about the intervention materials and the techniques used, documents related to these works and basic protection works and data regarding interventions assessment.

The following tables present the **Integrated Documentation Protocols data collection Forms**, which have been successfully implemented and tested in various research works [e.g. Kioussi et al 2013, Kioussi et al 2015, PhD thesis Kioussi 2016], and can be adopted in the EDICULA hands-on framework.

Historic Documentation

History of the CH asset
Historical name
Method / Technique / Tool
Standard
Constructions Location Site
Method / Technique / Tool
Standard
Date of foundation / dating
Method / Technique / Tool
Standard
Construction's History
Method / Technique / Tool
Standard

Values	
Values of the monument	**Historical:** **Architectural:** **Symbolic:**
Method / Technique / Tool	
Standard	

Stakeholders	
Name of the Stakeholders - individuals – Organizations	
Method / Technique / Tool	-
Standard	-
Involved parts of period of Act	
Method / Technique / Tool	-
Standard	-
Tasks of involved parties regarding the building	
Method / Technique / Tool	-
Standard	-

Bibliography	
Type of Data	
Method / Technique / Tool	
Standard	
Reference	-
Method / Technique / Tool	-
Standard	-
Title	
Method / Technique / Tool	
Standard	
Author	
Method / Technique / Tool	
Standard	
Date	
Method / Technique / Tool	
Standard	
Publisher	-
Method / Technique / Tool	-
Standard	-

Variation in Usage	
Initial use	
Method / Technique / Tool	
Standard	
Period of Usage	
Method / Technique / Tool	
Standard	
Variation in usage	
Method / Technique / Tool	
Standard	

Land Registry	
Property ownership	
Technique / Tool	
Standard	
National Cadastre Code Number	

Method / Technique / Tool	-
Standard	

Geometrical Documentation

Location
Geographical Coordinates
Method / Technique / Tool
Standard
GIS Data
Method / Technique / Tool
Standard

Morphology
Type of Representation
Method / Technique / Tool
Standard
Measurement conditions
Date of documentation / recording
Operator

Architectural Documentation

General Typology
Type of Construction
Method / Technique / Tool
Standard
Architectural style
Method / Technique / Tool
Standard
(Total Area (m^2)
Method / Technique / Tool
Standard
Total area of structure (m^2)
Decoration
Method / Technique / Tool
Standard

Decoration material
Method / Technique / Tool
Standard

Building Materials

Building material Identification
General information
Type of Building Material
Inspection Area
Sampling Area
Type of Material
Natural
Artificial
Restoration / Intervention Material

3. Application Methodology of Non Destructive Testing

The sustainable maintenance, preservation and revitalization of built cultural heritage, and in particular historic sites and monuments, have been the focus of significant efforts from the scientific and technical community. In the past decades, decisions regarding conservation interventions and protection of monuments were largely based on prior experience, on inadequate and non-systematic identification of the prevailing problems and on available technological resources. This approach, however, limited the effectiveness of the implemented interventions, whereas, in some cases even caused more decay to the monuments.

Although a large array of analytical techniques is available, that can be used in the field of built cultural heritage protection, the difficulties associated with the accessibility and irreversible destructive sampling on monuments do not permit extensive use of such available analytical resources. In contrast, **the use of Non-Destructive Techniques (NDT), that can be applied in-situ and do not require destructive sampling, is preferred.** By Non-Destructive Techniques we mean the application of techniques on building scale that do not require sampling to get results about the decay of the building materials and the investigation of structure’s pathology.

Recent research and developments on these techniques’ sensors and associated data analysis software have enhanced their usefulness and is nowadays an indispensable tool in the field of cultural heritage protection for the characterization of materials, detection of their wear and degradation, assessment of the effectiveness of interventions and evaluation of compatible materials and processes applications. Thus, utilization of NDTs in nowadays is well established being a common practice.

The evaluation of the preservation state of the historic buildings requires an integrated diagnostic study that includes historic documentation, characterization of the historic materials and study of their provenance, evaluation of previous interventions and assessment of the environmental impact. It further involves monitoring of the acting environmental factors, in-situ visual observations for the materials’ preservation state and structure’s pathology, in-situ decay mapping with the aid of NDT, in-lab study of the decay products and mechanisms, and correlation of intrinsic and extrinsic factors on the monument scale. The identification of the problem is then followed by application of pilot conservation interventions and their assessment, in which NDT are specifically utilized in quality control of conservation materials, and assessment of their performance in lab and in-situ. Both functions (decay diagnosis and assessment of pilot

conservation interventions) provide essential scientific support to decision making regarding monument's protection.
Within this context, focus on the use of **Infrared Thermography (IRT)**, **Ground Penetrating Radar (GPR)**, **Digital Microscopy (DM)**, **Ultrasonic testing (US)**, and **Schmidt hammer (SH)** is provided as follows.
Specifically, digital microscopy (DM) is used for the investigation of materials surface morphology, texture, microstructure, classification of superficial decay patterns etc. Infrared thermography (IRT) provides information about the materials compatibility, moisture transfer phenomena and deterioration of materials. Ground penetrating radar (GPR) reveals the internal structure of masonries and assesses the structural integrity of the studied elements. Ultrasonic testing (US) detects voids, cracks, decayed layers depth and in general sub-surface flaws of materials. Schmidt hammer (SH) is suitable for measuring the relative surface hardness of different materials, values which are then converted into strength by using appropriate standard tables. In particular:
Digital Microscope (DM) is a non-destructive microscope that can be utilised in situ to acquire magnified, visible spectrum, images. DM is a microscope system integrating advanced optics and digital components. Whereas in traditional optical microscopy a sample is required to be placed at the microscope, with DM, no sampling is required and the image can be acquired in situ.
High resolution, high contrast magnified images of the surface can be obtained and stored digitally for further processing (e.g. Digital Image Processing), by selecting the appropriate magnification optics (e.g. 25x, 50x, 100x, 200x). In the field of cultural heritage protection, DM is employed to identify differences in the texture and composition of surfaces, for materials classification (e.g. classifications of mortars), for the study of the decay phenomena (alveolation, hard carbonate crust, etc.), to investigate materials' surface morphology, to identify defects in historic building materials, for materials characterisation, to classify decay typologies for porous stones, to evaluate cleaning interventions, consolidation interventions and incompatible interventions, and to study the preservation state of mosaics.
Infra-Red Thermography (IRT) is a valuable NDT for the investigation of structures, their building materials and their preservation state, as it offers the advantages of investigating without the need for sampling and of being able to examine large areas. The basic principle of the technique is that, since all objects above the absolute zero temperature (0 K) emit infrared radiation, it is possible to detect and map thermal variations and correlate these to variations of the materials' properties, microstructure and surface morphology. Thermal variations are measured with the aid of infrared cameras and an image of the investigated area is rendered in colour, corresponding to a temperature scale.
The passive approach is commonly used for the on site inspection of architectural surfaces, where the materials under investigation are usually examined in terms of qualitative means (detection of discontinuities/interfaces, moisture, defects, voids, etc.).
Standards related to IRT practicing are:
EN 13187:1999 Thermal performance of buildings. Qualitative detection of thermal irregularities in building envelopes. Infrared method
EN 16714-1: 2016 Non-destructive testing - Thermographic testing - Part 1: General principles
EN 16714-2: 2016 Non-destructive testing - Thermographic testing - Part 2: Equipment
EN 16714-3:2016 Non-destructive testing. Thermographic testing Terms and definitions
Ground Penetrating Radar (GPR) is an established non-destructive technique that uses radar pulses to image the examined sub-surface. It uses electromagnetic radiation (typically 100 MHz to 2.6 GHz for built cultural heritage applications) detecting the reflected signals from sub-surface structures as the diffusing pulse meets boundaries with different dielectric constants. GPR in historic structures is utilised to locate the position of large voids and inclusions of different materials, to qualify the state of preservation of the structural system, to define the presence and the level of moisture, to control the effectiveness of repair interventions, and to reveal the morphology/geometry of wall sections in multiple-leaf stone and brick masonry structures.
Nevertheless, care should be taken in identifying the subsurface features, such as voids or interfaces of materials, in GPR radargrams of the interior of the surveyed structures. The 2D or 3D "image" of a color or

grayscale radargram is often mistakenly approached as representing an image of the actual interior, whereas in reality it represents reflections (primary and secondary) from interfaces between materials of distinctly different dielectric properties; the more their dielectric properties differ, the stronger the reflections obtained and the corresponding detection capability of the method. GPR depends greatly on signal processing with specialized software and algorithms. The signal obtained from the interior of a surveyed structure is the composite result of primary reflections from distinct interfaces or targets, multiple echoes from secondary reflections and superposition phenomena of the diffusing and reflecting waves. Signal processing aims to distinguish and enhance the primary reflections in order to identify the subsurface targets.
The most recent standard presenting GPR practicing is:
ASTM D6432-19 (2020) Standard Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation
Ultrasonic testing (US) or Ultrasonic Pulse Velocity (UPV) method is an established non-destructive method that detects surface and sub-surface flaws or discontinuities in materials. High-frequency sound waves are introduced into the examined surface which travel through the material with some attendant loss of energy (attenuation) and are reflected at any interfaces encountered. The reflected beam is then detected on the surface and analysed to determine the presence and location of flaws or discontinuities. It is commonly used in transportation and construction sectors, mainly to identify flaws (cracks, inclusions, etc.) in materials. As the ultrasonic wave propagation velocity can be correlated with some of the materials microstructure parameters, and since decay directly affects the microstructure of materials, ultrasonic testing is often used to assess their decay state.
Furthermore, US can determine the depth of the decayed layer within a material, which is evaluated using the indirect ultrasonic method. Furthermore, ultrasonic testing is also used to assess of cohesion enhancement by estimation of the penetration depth of consolidation materials.
The standard related to US practicing on natural stones is:
BS EN 14579:2004 Natural stone test methods. Determination of sound speed propagation
Schmidt hammer, or rebound hammer, is a non destructive testing device that estimates the strength of building materials by associating surface hardness/penetration resistance with their strength. The device measures the rebound of a spring-loaded mass impacting against the surface of the examined surface. Its rebound is dependent on the hardness of the tested building material and is measured by the test equipment. This value is then converted into strength by using appropriate standard tables. Although Schmidt hammer is mostly used for concrete masonries, for which most of the standards apply, it is still a valuable technique for built cultural heritage applications. Standard methods for rebound number testing include **ISO/DIS 8045, ASTM C 805, BS-1881-200**, **EN 12 504-2**, and more recently **ASTM D5873-14**: Standard Test Method for Determination of Rock Hardness by Rebound Hammer Method. Rebound numbers are highly sensitive to near-surface characteristics; therefore, caution should be exercised when interpreting test results. In particular, when performed on rough surfaces, the results might indicate lower than actual hardness.

4. Current European Standards for the Protection of Cultural Heritage

During the last years a major effort has been put by the CEN (European Committee for standardization), in order to publish up-to-date European standards related to the protection of cultural heritage. The aim of the standards is not to constrain research freedom, but on the contrary, their aim is to set and establish common criteria and terminology, in order for the research community to move faster and yet thoroughly, towards more innovative approaches.
Some currently valid EN standards concerning building materials characterization, the methods/techniques that are suggested to be applied for their characterization, as well as assessment procedures of conservation treatments, in situ or in lab, are listed below:

Before conservation treatments

CSN EN 15898:2019 Conservation of cultural heritage - Main general terms and definitions

CSN EN 16096:2012 Conservation of cultural property - Condition survey and report of built cultural heritage

CSN EN 16085:2012 Conservation of Cultural property - Methodology for sampling from materials of cultural property - General rules

Techniques – Methods

CSN EN 15802:2009 Conservation of cultural property - Test methods - Determination of static contact angle

EN 15803:2009 Conservation of cultural property - Test methods - Determination of water vapour permeability (δp)

CSN EN 15886:2010 Conservation of cultural property - Test methods - Colour measurement of surfaces

CSN EN 16322:2013 Conservation of Cultural Heritage - Test methods - Determination of drying properties

CSN EN 16302:2013 Conservation of cultural heritage - Test methods - Measurement of water absorption by pipe method

CSN EN 16682:2017: Conservation of cultural heritage - Methods of measurement of moisture content, or water content, in materials constituting immovable cultural heritage

DIN EN 17655 Conservation of cultural heritage - Determination of water absorption by contact sponge method; German and English version prEN 17655:2021

Natural Stone

CSN EN 16515:2015 Conservation of Cultural Heritage - Guidelines to characterize natural stone used in cultural heritage

Mortars

BS EN 16572:2015 Conservation of cultural heritage. Glossary of technical terms concerning mortars for masonry, renders and plasters used in cultural heritage

CSN EN 17187:2020 Conservation of Cultural Heritage. Characterization of mortars used in cultural heritage

Cleaning

CSN EN 16455:2015 Conservation of cultural heritage - Extraction and determination of soluble salts in natural stone and related materials used in and from cultural heritage

CSN EN 16782:2016 Conservation of cultural heritage - Cleaning of porous inorganic materials - Laser cleaning techniques for cultural heritage

CSN EN 17138:2018 Conservation of Cultural Heritage - Methods and materials for cleaning porous inorganic materials

BS EN 17488:2021 Conservation of cultural heritage. Procedure for the analytical evaluation to select cleaning methods for porous inorganic materials used in cultural heritage

Surface protection

https://www.en-standard.eu/bs-en-16581-2014-conservation-of-cultural-heritage-surface-protection-for-porous-inorganic-materials-laboratory-test-methods-for-the-evaluation-of-the-performance-of-water-repellent-products/**BS EN 16242:2012** Conservation of cultural heritage. Procedures and instruments for measuring humidity in the air and moisture exchanges between air and cultural property

BS EN 17114:2018 Conservation of cultural heritage. Surface protection for porous inorganic materials. Technical and chemical data sheets of water repellent product

Other

BS EN 15759-1:2011 Conservation of cultural property. Indoor climate Guidelines for heating churches, chapels and other places of worship

PD CEN/TS 16163:2014 Conservation of Cultural Heritage. Guidelines and procedures for choosing appropriate lighting for indoor exhibitions

CSN EN 16853:2017 Conservation of cultural heritage - Conservation process - Decision making, planning and implementation

BS EN 17036:2018 Conservation of Cultural Heritage. Artificial ageing by simulated solar radiation of the surface of untreated or treated porous inorganic materials

CSN EN 17121:2019 Conservation of cultural heritage - Historic timber structures - Guidelines for the on-site assessment of loadbearing timber structures

BS EN 17429:2020 Conservation of cultural heritage. Procurement of conservation services and works

CSN EN 17543:2021 Conservation of Cultural Heritage - Finishes of built heritage - Investigation and documentation

5. References

1. "EU-CHIC, European Cultural Heritage Identity Card”, FP7 ENVIRONMENT, 226995, 2009-2012.
2. “INCEPTION, Inclusive Cultural Heritage in Europe through 3D Semantic Modeling”, H2020, 665220, 2015 – 2018.

3. A. Kioussi, M. Karoglou, A. Bakolas, A. Moropoulou, "Integrated Documentation Protocols enabling Decision Making in Cultural Heritage Protection", Journal of Cultural Heritage, 14S (2013) 141-146.
4. A. Kioussi, N. Skordaki, M. Karoglou, A. Bakolas, A. Moropoulou , "Integrated Protocol for Non-Destructive Testing Investigation of Historic Buildings", Sensor Letters 13(7) (2015) 565-572
5. A. Kioussi, Innovative documentation methodology regarding conservation materials and interventions, focusing on European cultural heritage, PhD Thesis, National Technical University of Athens, Greece, 2016 (supervisor Prof. A. Moropoulou)
6. Moropoulou, A., Labropoulos, K. C., Delegou, E. T., Karoglou, M., & Bakolas, A. (2013). Non-destructive techniques as a tool for the protection of built cultural heritage. Construction and Building Materials, 48, 1222-1239.
7. Alexakis, E., Delegou, E. T., Lampropoulos, K. C., Apostolopoulou, M., Ntoutsi, I., & Moropoulou, A. (2018). NDT as a monitoring tool of the works progress and the assessment of materials and rehabilitation interventions at the Holy Aedicule of the Holy Sepulchre. Construction and Building Materials, 189, 512-526.
8. https://www.en-standard.eu/ (acess 28 March 2022)