HERACLES

HEritage Resilience Against CLimate Events on Site

Deliverable D3.2

Development of an in-situ diagnostic protocol for quick assessment and monitoring of the weathering state and its progress on the areas of interest for the studied test beds

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HORIZON 2020

Executive Summary

Deliverable D3.2 "Development of an in-situ diagnostic protocol for quick assessment and monitoring of the weathering state and its progress on the areas of interest for the studied test-beds" aims at the development of a systematic protocol for the quick assessment by means of in-situ diagnosis of the monuments/assets to be studied in HERACLES. The protocols described herein are based on versatile screening techniques and instruments which are able to be easily transported and used on-site, offering the possibility to achieve fast information about the status of the structures with regard to the preservation state of the studied monuments/sites (in particular, structural condition and material degradation coupled with meteorological conditions).

The guidelines discussed here have been developed in parallel with D3.1 (Definition of a systematic protocol related to the diagnostic and analytical strategies for each different monument to be studied on the basis of the different structures, materials and weathering states), where the main attention was focused on the development of a more general framework for diagnostics and monitoring, involving the integration of different technologies. With the present deliverable emphasis is given to the instrumentation to be used in-situ (installed permanently or transported in place during measurement campaigns) at the four HERACLES test-beds (Town Walls and Consoli Palace in Gubbio and Knossos Palace and sea-fortress of Koules in Heraklion). Nevertheless, these guidelines can be also adopted/extended to other monuments/assets, facing similar problems. Thus, it is expected that the present deliverable provides a practical guide for in-situ quick and reliable assessment and monitoring of the materials/structures weathering state, and its evolution in time in correlation with climatic events, in the general frame of the Cultural Heritage assets/monuments.

This document aims at outlining protocols for the fast assessment of structural issues and material weathering status, on the basis of the issues and needs identified for the four monuments/assets of interest in HERACLES.

In the first part of this deliverable, a brief description of the portable systems (from in-situ sensors/instrumentation for structural survey to portable analytical instruments for material characterization) and the specialized sensors (Meteorological – Oceanographic), which are expected to record changes in the structural conditions, in the material weathering state and in the environment of the monuments, is given. The second part describes the suggested protocols.

The effectiveness of the protocols outlined here will be verified through the demonstration phase planned in WP8 with the aim to be refined and optimised.

The document is organised in separate Sections outlined in the following Introduction (Section 2).

1 Introduction

1.1 Reference Documents

Document name	Reference number
HERACLES – Annex 1: Description of Work	Grant Agreement nr. 700395
HERACLES- Survey on guidelines and procedures for CH management	Deliverable D1.1
HERACLES - Definition of the end-users requirements with emphasis on HERACLES test beds	Deliverable D1.2 Milestone MS1
HERACLES - Definition of methodologies for climate change impact evaluation and risk and vulnerability analysis	Deliverable D1.3
HERACLES- Definition of a systematic protocol related to the diagnostic and analytical strategies for each different monument to be studied on the basis of the different structures, materials and weathering states	Deliverable D3.1
Please, refers to all the docs in Section 7 of the present document	Please, refers to all the docs in Section 7 of the present document

1.2 Acronyms and Abbreviations

ARPA	Agenzia Regionale per la Protezione Ambientale
ASCII	American Standard Code for Information Interchange
BP	Band-pass filter
CC	Climate Change
CCD	Charge Coupled Device
CIRIAF	Centro Interuniversitario di Ricerca sull'Inquinamento e sull'Ambiente "Mauro Felli"

CH	Cultural Heritage
CIRIAF	Centro UInteruniversitario Ricerca sull'Inquinamento da Agenti Fisici
CNR-IREA	Consiglio Nazionale delle Ricerche-Istituto per Rilevamento Elettromagnetico dell'Ambiente
DAQ	Data Acquisition
DRMS	Drilling Resistance Measuring System
EDS	Energy-Dispersive X-ray Spectroscopy
ERT	Electrical Resistivity Tomography
FORTH-IACM	Foundation for Research and Technology – Hellas, Institute of Applied and Computational Mathematics
FORTH-IESL	Foundation for Research and Technology – Hellas, Institute of Electronic Structure and Laser
FOV	Field Of View
FTIR	Fourier Transform InfraRed
GPR	Ground Penetrating Radar
IR	Infrared
LED	Light Emitting Diode
LIBS	Laser Induced Breakdown Spectroscopy
LVDT	Linear Variable Displacement Transducer
MSI	MultiSpectral Imaging
MWT	MicroWave Tomography
NE	North-East
NI PXIe-1071	National Instrument Controller
OPD	Optical Path Difference
PM5, PM10	particle pollution, also called particulate matter of size 5 or 10 Parts

	per Million (ppm)
QA	Quick Assessment
RBR duet	Commercial temperature and depth logger- recorder
RH	Relative Humidity
SEM	Scanning Electron Microscopy
SHD	Salt Hydration Distress
SHM	Structural Health Monitoring
UniPg	University of Perugia
UoC	University of Crete
UV	Ultraviolet
VOC	Volatile Organic Compound
XRD	X-Ray Diffraction
WP	Work Package

1.3 Scope and Objectives

One of the objectives of the HERACLES project is the definition and implementation of specific guidelines for long-term prevention and maintenance actions, able to specifically account for the CH site features and the risks affecting them, as well for the operational risk management procedures.

Starting from deliverable D1.1, where guidelines and procedures for CH management have been surveyed, deliverable D1.2, where the end-users requirements have been traced, and deliverable D1.3, where methodologies for climate change impact and risk and vulnerability analysis have been defined, the present document aims at outlining a protocol for the quick assessment and monitoring of the structural condition and the materials weathering state, which includes natural ageing and hazards due to critical climate events and/or pollution conditions.

1.3.1 The quick assessment concept

QUICK ASSESSMENT (QA) is considered as a fast investigation methodology able to provide information and data useful to highlight possible criticalities, in order to plan and prioritise actions in compliance with the real needs.

The quick assessment is a well recognised concept in civil engineering and its main aim is to acquire information particularly on some constructive details, material degradation and damage types with the final objective to support a more detailed evaluation of the vulnerability, thanks to the application of more sophisticated numerical models. Therefore, quick assessment allows to assess if the structural parameters are in the expected range and to provide insights that may help in the interpretation of more sophisticated analysis.

This methodology is well diffuse in the frame of civil infrastructures to acquire information not only during ordinary conditions but also after crisis events. In particular, a large literature is available on the quick assessment, particularly with respect to the damage after seismic events [1, 2].

At present, the concept of quick assessment extends also to the Cultural Heritage field, in particular with respect to the seismic vulnerability. In HERACLES, one of the novel aspects regards the possibility to carry on the quick assessment with respect to the climate change long-term effects, which can have detrimental and dangerous impacts. The need of a fast analysis requires the use of in-situ technologies, which have to be simple to use, to allow fast acquisition and able to provide results ready to use.

The techniques/methodologies included in the QA protocol can be chosen and tailored to fit specific needs, guaranteeing flexibility and a general applicability.

For these particular purposes, taking into account the QA peculiarity, only portable, in-situ instruments have been considered.

With respect to the deliverable D.3.1, which refers to the description of sensing tools at a general and comprehensive level, from wide area to local scale, together with a number of laboratory-based material characterization methodologies and techniques, **this deliverable focus on specific in-situ instruments able to provide quick information about the structure and material status**. These in-situ technologies are organised in a diagnostic protocol for an effective and quick assessment of the weathering state and its evolution during time on the CH assets/structures.

This deliverable is linked with the activities of WP1 that stated the Users' needs/Sites' Requirements, Risk and vulnerability analysis and technologies survey

This deliverable is linked to the activities of WP4 concerning the development of eco-innovative solutions and materials suitable for maintenance, protection, restoration and conservation of CH.

This deliverable is linked with the activities of WP2, concerning the models used

This deliverable is linked with the activities of WP8 concerned with the demonstration activities.

1.4 Document Structure

The document is organised as follows:

- Section 2 provides a very short summary of the hazards occurring at the areas of interest for the considered test-beds.
- Section 3 deals with a brief review of the portable instruments which are considered in the project, and it is mainly focused at underlining the advantages that they offer in terms of diagnosis and monitoring at the HERACLES test sites.
- Section 4 defines a protocol defining the analyses that should be performed and the instruments that should be adopted to provide an in-situ quick and effective assessment and monitoring of the structural conditions and the involved materials state.
- Section 5 summarizes the overall deliverable, highlighting the scope and strong points.
- Section 6 lists the documents and bibliographic sources cited in D3.2

1.5 Relation with Other Deliverables

D1.1 (CNR) Survey on guidelines and procedures for the CH management – 6 month (11/2016)

D1.2 (CNR) Definition of the end-users requirements with emphasis on HERACLES test beds – 9 month (02/2017)

D1.3 (FORTH) Definition of methodologies for climate change impact evaluation and risk and vulnerability analysis – 9 month (02/2017)

D1.4 (FORTH) Survey of the state of art of the technologies of interest for HERACLES

D2.1 (e-geos): Geomorphological and structural modelling and monitoring, Report-M14

D2.2 (SISTEMA): Climate change, extreme weather conditions and anthropic pressure modelling, Report-M18

D2.3 (e-geos): Approaches for correlation/integration of the sensing technologies, Report-M18

D3.1 (FORTH) Definition of a systematic protocol related to the diagnostic and analytical strategies for each different monument to be studied on the base of the different structures, materials and weathering states - 12 month (04/2017)

D3.4 (CNR): Intermediate analysis of the experimental and theoretical aspects underlying the state-of-the-art application of in-situ sensing technologies, Report- M13

2 Survey of the main causes of weathering occurring at the areas of interest and discussion on the quick assessment concept

In order to provide the QA protocols, the different scenarios present in the HERACLES project have to be taken into account. In fact, the test-beds are in two different Countries, facing two different environments and consequently different main risks/issues.

Based on the results of the activities regarding the deliverables D1.1 (Survey on guidelines and procedures for CH management), D1.2 (Definition of the end-users requirements with emphasis on HERACLES test beds), D1.3 (Definition of methodologies for climate change impact evaluation and risk and vulnerability analysis) and D1.4 (Survey of the state of art of the technologies of interest for HERACLES), the main problems to assess in the two areas/sites are different. Specifically:

The main criticalities in Gubbio are linked to Structural issues

The main criticalities in Heraklion are linked to the material degradation

More in details, the main hazards occurring at the areas of interest for HERACLES demonstration activities can be summarised as follows.

The areas of interest located at the Gubbio town, i.e. medieval Walls and the Consoli Palace, suffer mainly of issues related to their structural stability. Specifically, the chosen areas are affected primarily by hydrogeological risks (most in terms of heavy rain and associated effects i.e. flood, landslides), which can be even worsened by other natural hazards (seismic events). Accordingly, water infiltrations, as well as damages caused by water erosive action (i.e. slow and progressive structural deformations, crack patterns and material degradation) should be promptly detected and continuously monitored, since they significantly endanger the structural stability of the assets and have a direct impact in their preservation status.

Other important issues affecting Gubbio is the significant environmental pollution, and the sudden temperature changes. These issues influence the condition of the building materials and, combined with the effects of climate change, can become extremely critical for the monuments health.

On the other hand, the Heraklion sites, suffer mainly from issues related to material weathering, closely connected with extremely fragile and vulnerable construction materials and their exposure to critical environmental conditions, due also to their proximity to the sea (i.e. Koules). Specifically, one of the principal restoration issues of the archaeological site of Knossos is the degradation of its unique selenite components. Selenite, the mineral phase of gypsum, is an extremely fragile material particularly susceptible to humidity and weather conditions. Moreover, the preservation status of the selenite is also badly affected by unsuccessful restoration interventions which used materials not compatible with the ancient ones and which worsen its weathering state.

Similarly, the sea-side fortress of Koules experiences extreme environmental conditions due to the pollution and the salty northern winds, which cause severe material degradation. In particular, corrosive phenomena due to pollution and salinity, affect the preservation state of its building materials and accelerate the natural ageing process.

According to this framework, the methodologies developed for the quick assessment of the HERACLES test beds conditions had to be approached from different perspectives, paying attention to the critical needs of the monuments, as well as, to their locations, local environments and risks. In Gubbio attention will be given to the definition of a protocol aiming at a quick assessment of the structural condition and integrity, focusing on the Town Walls and the Consoli Palace. In Heraklion, a protocol fine-tuned to the fast in-situ evaluation of materials and their degradation state will be considered for the Knossos Archaeological site and the sea-fortress of Koules.

Specifically, in Gubbio in-situ tools for ground and structural surveys will be used

Specifically, in Heraklion portable instrumentations for optical and laser spectroscopic material analysis will be used

Moreover, in both locations a common survey, with the same techniques/methodologies will be carried on to assess microclimate dynamic monitoring and material mechanical characterization.

In the following sections, these two protocols for quick assessment are discussed and justified on the basis of the end-user requirements for each site by providing an integrated frame of the available sensors and portable instruments for each particular risk.

3 In-situ Instrumentations

The in-situ instrumentations considered in the HERACLES project can be classified in three groups according to the survey to be performed, as it is schematically sketched in Figure 1. In particular, Group #1 concerns surveys giving information on *structural stability.* Two subclasses of sensors are included: the geophysical one, such as GPR, holographic radar and ERT and the pointwise sensors for analysis of local deformation and vibration of the structure, such as LVDT and accelerometers. Group #2 is related to *material surveys* and involves portable instrumentations based on optical and laser spectroscopic analysis, i.e. multispectral imaging, LIBS, Raman spectroscopy, the prototype of 4D surface/ volume topography developed for HERACLES, as well as DRMS for material drilling resistance evaluation. Group #3 concerns in-situ installed weather stations, as well as, portable microclimate sensors and wave gauges for *microclimate and sea wave monitoring.*

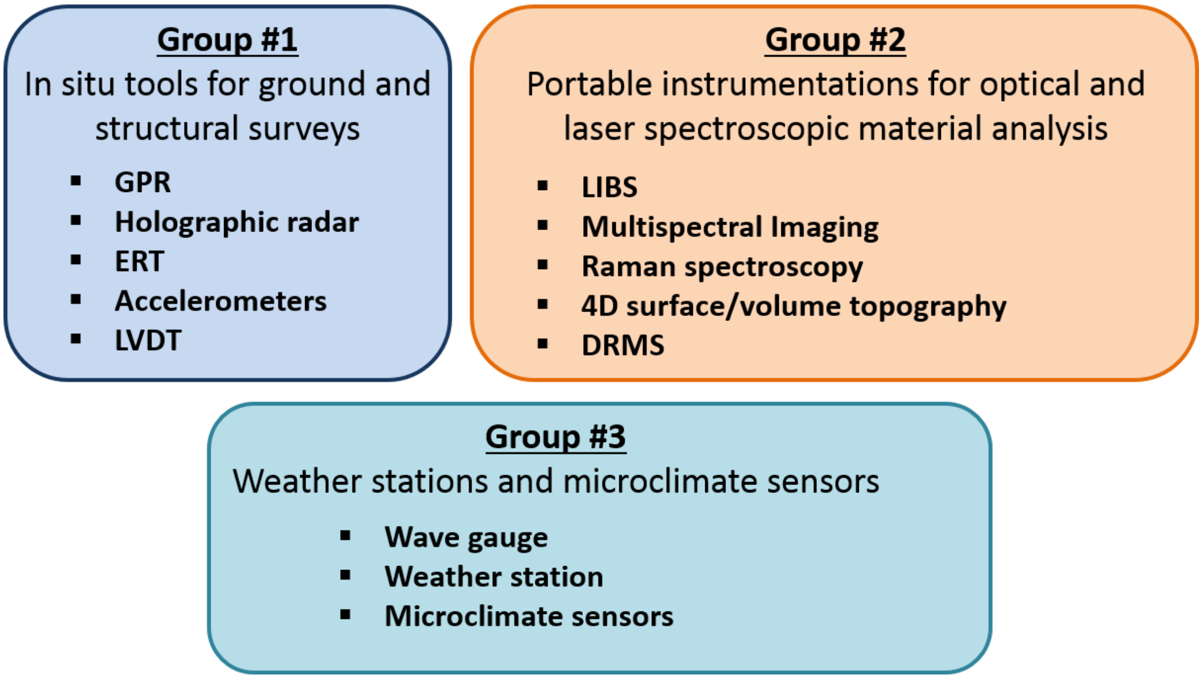


Figure 1: In-situ instrumentations classified according to the purpose of their performance

A schematic description of the technologies included in Figure 1 and their performances in the framework of CH diagnosis and monitoring are briefly summarised below, while a their main characteristics are given in Tables 1, 2 and 3, which are referred to Group #1, Group #2 and Group #3, respectively.

3.1 In-situ tools for structural surveys

In this sub-section the in-situ tools for structural survey are described, highlighting their performances with respect to the QA.

3.1.1 Radar technologies

Radar technologies (GPR and holographic radar) are useful to obtain images of the investigated region inner part (subsoil or structures), gaining information about structural hazards, which can be caused by important weathering phenomena or extreme natural events related to climate changes.

The main advantages of radar technologies are [3]:

- moderate cost and easiness of employ;

- portability (unless very low frequencies antennas are exploited);

- flexibility that is ensured by the use of antennas working at different nominal central frequencies, which can be straightforwardly changed on site

- capability to perform non-destructive and non-invasive sub-surface surveys.

The working principle of these technologies was described in detail in deliverable D3.1 and a brief summary of their characteristics is given in Table 1.

As reported in deliverable D3.1, radar technologies use microwaves to detect, localize and characterize the geometry of non-visible and hidden objects.

In general, radar data contain, in most cases, a lot of information but an effort has to be made to extract it under a form that is useful for the end-users. Indeed, from a physical point of view, radar data contain information about dielectric permittivity, electrical conductivity and on changes of these properties in the investigated area. Therefore, an interpretation stage is required to relate the information contained in the radar data to that ones relevant for CH diagnosis and monitoring. To facilitate this task, there is the necessity of developing and applying automatic processing approaches able to give clearer, clever, and easily interpretable images compared to the raw-data.

In this framework, microwave tomography has become an increasingly popular interpretational tool for GPR applications [4, 5]. In fact, the possibility of recasting the data processing as an inverse scattering problem leads to an improvement of the interpretability of the results compared to the simple radargrams. In addition, the adoption of suitable models of the electromagnetic scattering phenomenon can help to understand crucial aspects of a specific problem at a much deeper interpretational level. Furthermore, the theoretical investigation of the inverse scattering problem allows to evaluate the reconstruction performances in terms of available resolution limits achievable in a reconstructed image, and to give guidelines about the spatial and frequency sampling to be adopted in the survey criteria.

Based on the above considerations, the radar technologies, equipped with suitable data processing approaches, allow to generate high resolution images, which provides 2D and/or 3D representations of the subsurface features of the structure under test [6].

Accordingly, radar techniques can be exploited as a non-invasive, flexible and cost effective tools to perform ground surveys, structural integrity assessment and quick damage evaluation. In particular, radar technologies can be used on demand for the following purposes:

- non-invasive surveys devoted to characterize soil and its stratigraphy
- imaging substructures, reinforced structures, cavities and cracks, whose detection and characterization are useful to infer information about the status of structures
- detection and localization of not directly observable defects, such as water infiltrations and material changes due to natural ageing process, as well as, by crisis events such as seismic, hydrogeological and extreme weather actions.

As an example of the potentialities offered by MWT enhanced subsurface radar surveys, in Figure 2 is reported the result of a measurement campaign carried out by means of a high frequency GPR system on a retaining wall, made by reinforced concrete. In particular, Figure 2a shows a picture of the surveyed wall and the measurement setup, while Figure 2b shows the tomographic image corresponding to the constant depth slice at 7 cm from the air-wall interface. This image provides a detailed representation of the reinforcement structure from which it is possible to obtain information about the geometry and conservation state of the iron bars.

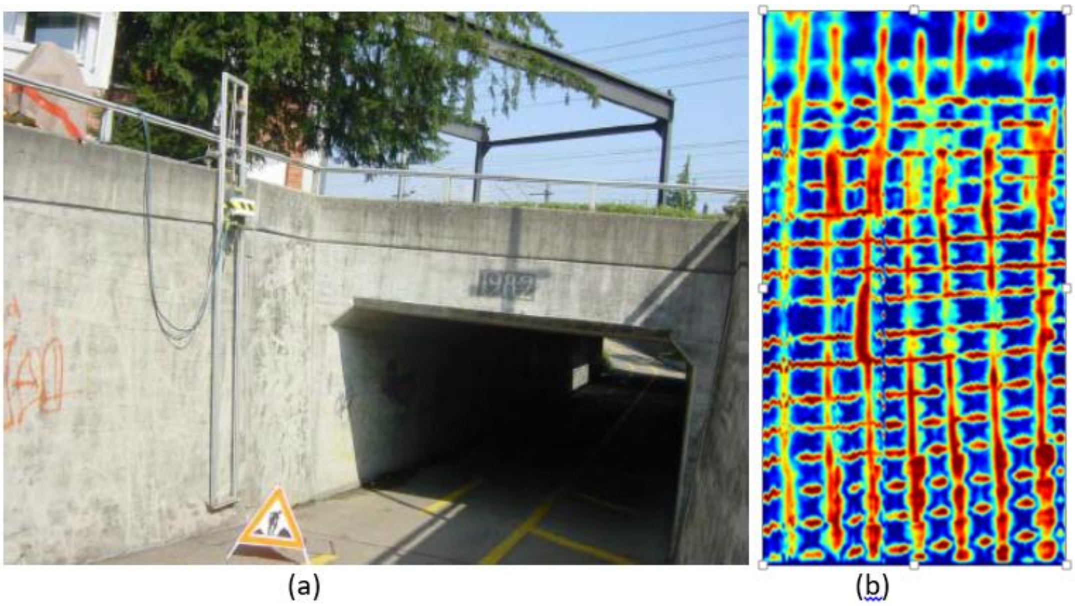


Figure 2: GPR survey of retaining wall: a) picture of the investigated scenario and of the measurement setup. b) Tomographic image showing the constant depth slice (depth of 7 cm)

3.1.2 Electrical Resistivity Tomography

ERT is used to obtain 2D and 3D images in terms of spatial distribution of electrical resistivity. It is suitable for application in many applicative fields, such as in geology for stratigraphy and cavity detection, fault characterization, landslide studies, in hydrogeology, regarding environmental problems for contaminant plume detection and waste dump characterization for coastal salt water intrusion detection, in agricultural as well as in archaeological and cultural heritage studies.

The ERT exhibits significant potentialities in terms of high resolution and flexibility of the investigation depth, which can be varied in a simple way, by varying the electrode spacing.

Thanks to this flexibility, ERT can be used not only to investigate the ground where structures of CH interest are located, but also to perform structural surveys, even if some issues have to be taken into account. In fact, a structural survey requires an electrode spacing ranging between one centimeter and some decimeter; this entails the necessity to miniaturize the sensors to have “pointwise” transducers (i.e. smaller with respect to the dimension of the investigated volume). Then, a low contact resistance has to be guaranteed in order to put an adequate current injection.

In order to meet these requirements, several devices can be used such as Cu flat-base electrodes with conductive gel, Ag/AgCl medical electrodes and nails Cu-$CuSO_4$ electrodes. Main limitation of these devices is the difficulty of installing them on a vertical or steeply slope surface, even worse under a ceiling. Moreover, medical electrodes are not stable in time, while flat-base electrodes are not suitable for the asphalt, where the only possibility to apply the ERT is making holes in order to put the electrode in the substratum.

Despite of some limitations may arise, ERT can been successfully applied on masonry, floors, and artworks in order to detect fractures, voids, previous restoration works, structural particulars, moisture.

As an example, Figure 3 shows the result of an ERT survey carried out on a reinforced concrete beam. In particular, the measured ERT pseudo-section is superposed on the image of the beam and compared with the visible details internal to the beam. In particular, a low resistive shallow zone is compatible with a concrete layering more rich in water due to two casts concrete occurred at different times during the beam building. Moreover, localized resistive anomalies correspond to rebars positions. This evidence can be explained considering that the inner cage produces a circuit warping unexpectedly the electrical field.

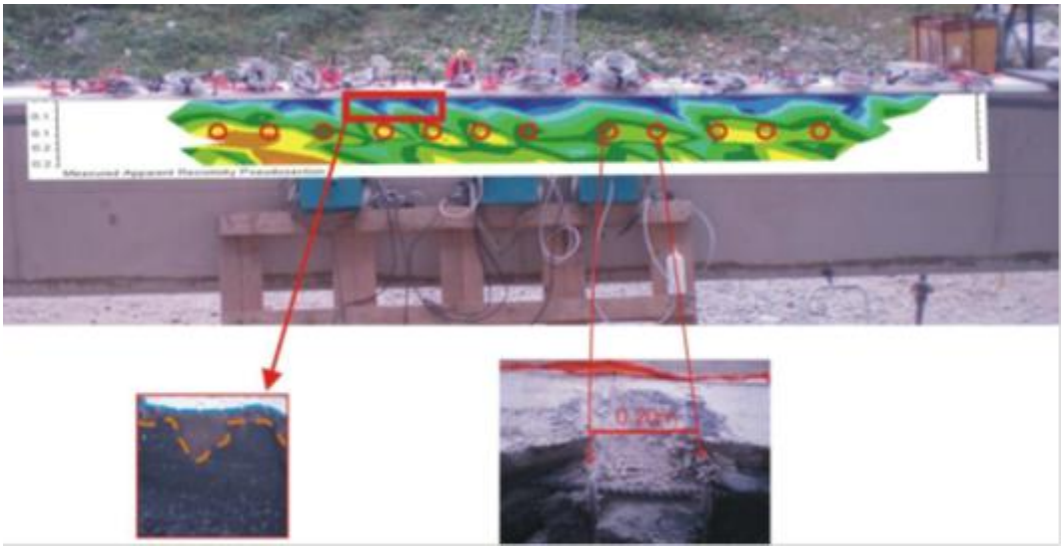
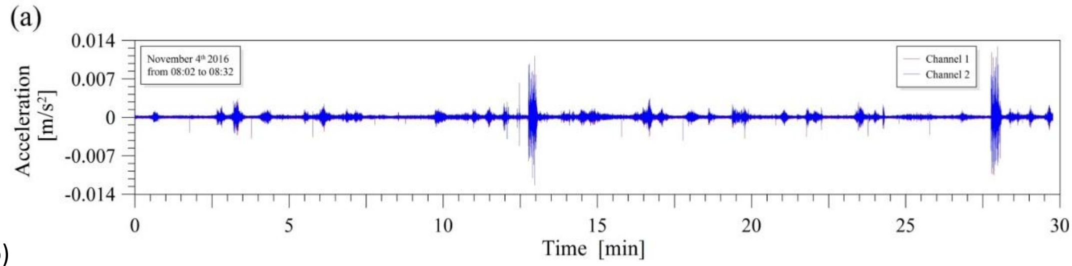


Figure 3: ERT carried out on a reinforced concreate beam: electrical resistivity pseudo-section referenced to the beam and its internal structures

3.1.3 Accelerometers, LVDT and inclinometers

The accelerometer is a type of sensor generally installed on structures subjected to vibrations due to several actions (environmental, urban, seismic, etc.). The sensors can give both local information regarding the level of acceleration measured in a specific point of the structure and global information about the structural dynamic behavior when an array of sensors is deployed. In HERACLES, high sensitivity piezoelectric uniaxial accelerometers are used to carry on a continuous dynamic monitoring in order to extract the time histories of the natural frequencies of the structures and to detect possible anomalies related to the occurrence of damages. The hardware of the acquisition system is described in detail in the Section 4.3.4 of the Deliverable D3.1. The sensors have been already installed on Consoli Palace, in Gubbio and typical acquired data are illustrated in Figure 4, where are visible the effects related to the environmental actions and swinging bells.

(a) 



(b)

Figure 4: (a) Image of high sensitivity piezoelectric accelerometers. (b) Time history of accelerations required by an accelerometer installed on Consoli Palace, in Gubbio

The Linear Variable Displacement Transducers (LVDT) measure low relative movements between two points (Figure 5a). Typically, this kind of sensors is applied across a crack in order to carry on a static monitoring of the crack. Generally, the time history of the opening displacement of a crack is affected by environmental condition, mainly temperature. For this reason, it is preferred to support the LVDT with a temperature sensor in order to compensate the environmental (temperature) effects. Within the project, two LVDTs and two thermocouples will be installed across two main cracks detected on the Consoli Palace, in Gubbio. Similarly, the inclinometers are sensors devoted to the inclination measure of the support on which are installed (Figure 5b). In the specific case, three inclinometers will be probably installed on the Town Walls of Gubbio. Both LVDTs and inclinometers constitute the static monitoring system, which give an output of the measure entities as reported in Figure 6. More details about these sensors and the installation are described in the Section 4.3.4 of the Deliverable D3.1.

(a)  (b) 

Figure 5: Images of an LVDT (a) and of an inclinometer (b) to be installed on the Consoli Palace and the City Walls in Gubbio

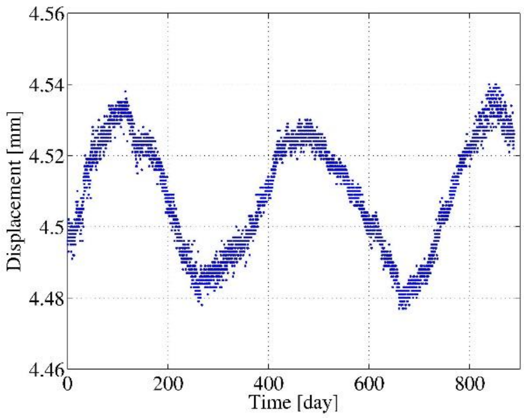


Figure 6: Example of a time history of the displacement measured by an LVDT.

3.1.4 Environmental monitoring sensors

In HERACLES, the microclimate dynamic monitoring will be carried on to assess the local environmental conditions in terms of the main indoor and outdoor environmental parameters.

This experimental monitoring campaign will be performed mostly by means of specific portable tynitag sensors (http://www.geminidataloggers.com/) (see Figure 7). Such a TGP-4500 equipment is able to monitor temperatures from -25 to +85°C, and relative humidity from 0 to 100% using built-in sensors. The coated RH sensor offers good resistance to moisture and condensation.

Figure 7: Tynitag temperature and humidity sensor

An example of output from the post-processing of the data collected by means of the above described tynitag sensor is provided in the following Figure 8:

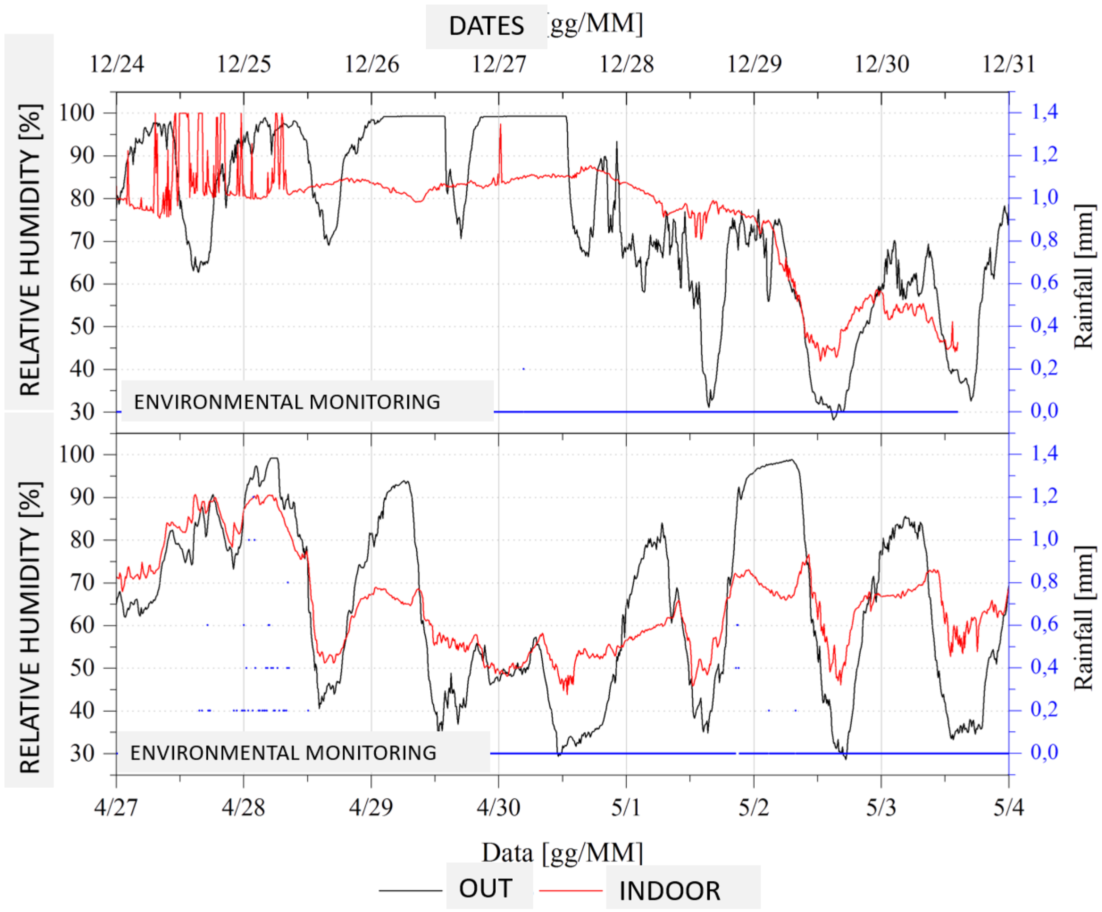


Figure 8: Example of output from the microclimate monitoring campaign: trend over time of the relative humidity and rainfall over time.

Moreover, a brand-new portable experimental equipment specifically developed by UniPg for the scope of HERACLES, i.e. payload, will be employed. The miniaturized sensors integrated in the payload are able to collect: air temperature [°C], surface temperature [°C], relative humidity [%], wind speed [m/s], wind direction [°], air quality (CO, CO_2, PM5, PM10- [ppm]), and illuminance level [lx]. The technical characteristics of the sensors are not available since they are still in a "development" phase (Figure 9). All these experimentally collected data will be integrated to site-based infrared videos and pictures taken in the case study areas, which example is provided in the following figure (Figure 10).

Figure 9: Experimental brand new setup – environmental payload: instruments and calibration in environmental chamber at UniPg

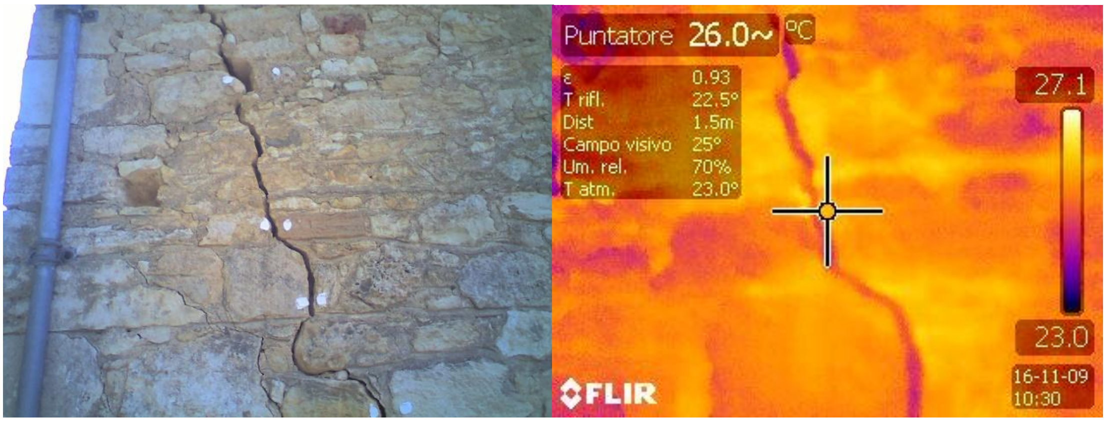


Figure 10: Example of output from the measurement of the surface temperature (°C) by means of infrared camera

3.2 Meteorological – Oceanographic sensors

Meteorological station and oceanographic sensor description and specifications for the Venetian fortress of "Koules" and the Knossos Archaeological Site test-beds, are detailed in deliverable D.3.1. A brief summary is in Table 2 and further details in the following.

The two meteorological stations will be installed on a 3-meter metal mast. The stations are the Davis Vantage Pro2 Plus with 24-hr Fan-Aspirated Radiation Shield and UV & Solar Radiation sensors. The meteorological station will provide raw data (time series of wind speed and direction, temperature, humidity, rainfall, barometric pressure, solar radiation and UV Index). The provided scientific data are time-series of the measured quantities, acquired at specific points of measurement (Knossos and Koules test-beds). The data will be used for multiple scopes: the characterization of the local meteorological cycles over the test-beds; the cross-correlation with the satellite weather data, as input data for the computational weather predictions; the risk assessment analysis for the Koules test-bed. In particular, the wind data can be combined with wave gauge data for the coastal hydrodynamic calculations.

Oceanographic Sensors will measure water level and sea temperature and will be deployed at the sea bottom in front of the test-bed of Koules. The provided scientific data are time-series of the measured quantities (sea level and temperature) acquired at specific points of Koules site; no historical data are present for this kind of measurements.

3.3 Portable instrumentations for material characterization

The working principle of the portable instrumentations was described in detail in the deliverable D3.1 and a short summary of their characteristics is given in Table 3. Below, their usefulness for diagnostic and monitoring purposes, is briefly reported.

3.3.1 Multispectral Imaging

Multispectral Imaging (MSI) combines digital imaging with spectroscopic analysis in order to recover spatial and spectral information for an object/surface. It is a particularly advantageous analytical technique in CH field as it is contactless and non-invasive able to operate remotely. MSI is implemented by recording a sequence of images, each one acquired at a narrow spectral band. In general, imaging techniques require an active system to illuminate the object under study and an imaging sensor to capture the light backscattered from the object. For the purposes of MSI, a monochromator, most often a series of bandpass filters, is interfered in the light path, either in front of the illumination system or in front of the imaging sensor. The outcome of this technique is a set of successive images, one spectral image for each spectral band, called spectral cube. Subsequent processing of the spectral cube allows the extraction of useful information on the materials of the object under study. MSI is a useful tool for restorers, archaeologists and art-historians [7]. Stratigraphic analysis [8], monitoring of deterioration phenomena or conservation interventions [9] and enhancement of fainted patterns are among the potentials of MSI in CH.

IRIS II (Figure 11a) is a lightweight portable MSI system comprising a high resolution camera, a filter wheel able to interchange 28 filter positions and fast electronics, developed by FORTH. The sensor allows sensitivity to the UV region (350nm up to 400nm, BP10nm), to the visible (400nm-700nm, BP25nm) and to the Near IR region (700nm-1200nm, BP50nm). The dynamic range of the camera is set to be 8 bits for each data point. With this system, 28 narrow band images are collected (Figure 11b), so to obtain a 3D spectral cube with dimensions of 2560 X 2048 X 28 data points. The system is portable so that it can be used in-situ for measurement and analysis.

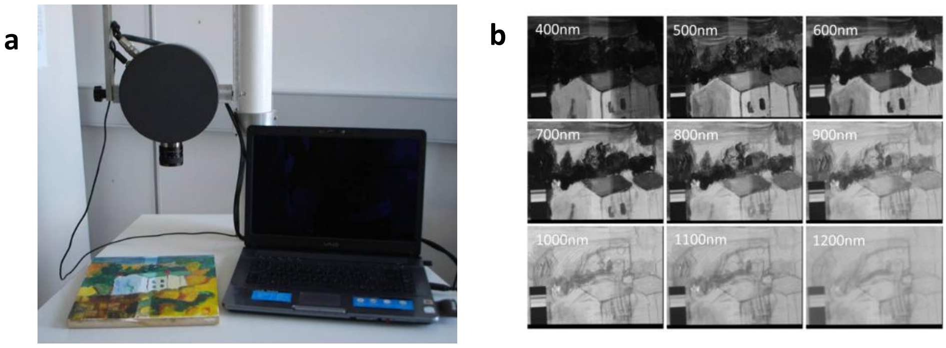


Figure 11: a) The IRIS-II system with the object under study and b) The spectral images at different spectral bands

For the acquisition of the spectral cube, the camera is placed against the object under investigation. The illumination sources are placed at approximately 45 degrees relatively to the object surface axis.

For each transmission band, a standard acquisition process is followed according to the steps below. The focus is properly adjusted. A white highly reflecting target (Spectralon, R = 99% @250-2500nm) is placed in front of the object and the camera-lens are adjusted in order to reach the maximum possible mean intensity value. Spectralon is a fluoropolymer, which has the highest diffuse reflectance of any known material or coating over the ultraviolet, visible, and near-infrared regions of the spectrum. A white image is captured. Next, keeping all settings unchanged, the white target is removed and an image (spectral image) of the object is captured. Finally, still keeping all settings unchanged, light entrance is blocked in front of the camera and a black image is captured. This black image corresponds to the electronic noise of the camera. The process is repeated for all the 28 bands.

Data acquired from the IRIS-II are initially analysed by viewing the spectral images in a series starting from the lower to the higher wavelengths. The technique enables the stratigraphic analysis of the surface layers since light increases its penetration with wavelength.

Furthermore, the acquired spectral cube can be normalized by subtracting the noise from the spectral and the white images, separately for each transmission band and by performing the division of the resulting images. The resulting quotient for each pixel is a value between 0 and 1 and is correlated to the reflectance of the corresponding point/area of the object. In order to re-transform these values in image values, the quotient is multiplied by a constant. The value of the constant depends on the final image dynamic range. The whole process is performed automatically via custom made software programmed in Labview (version 2013). Image registration is then applied and the spectral cube is extracted.

Finally, the spectral cube is analysed by means of imaging spectrometry, where each image point and/or image area can be expressed as a reflectance spectrum. From the reflectance spectrum, valuable information can be extracted about the material and its condition. Furthermore, by comparing the spectra acquired at fixed time intervals, useful results can be extracted about the time-evolution of a phenomenon/process.

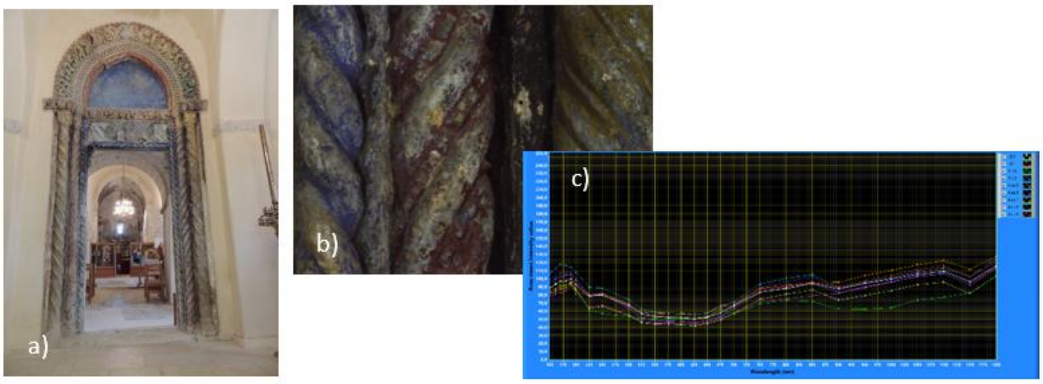


Figure 12: Study of the pigments at the church of Agios Georgios, Kamariotis, Heraklion, Crete. a) The analysed gate b) The area of interest in magnification c) The extracted spectrum from different points of interest.

IRIS-II also allows fluorescence imaging, which is obtained by illuminating the object with a lower wavelength illumination, often a UV (360-380 nm) light, so that the object surface emits at a higher wavelength e.g. at the visible. This is highly useful for imaging and discriminating among material of different types. Binding media, biological contaminants, restoration and protective materials can be mapped with this technique. Fluorescence imaging is a straightforward process and does not require further post-processing for the extraction of the results.

IRIS-II will be deployed for in-situ remote mapping of the various weathering features present on the monuments (Figure 12), such as efflorescence salts and other crusts, as well as for the monitoring of their evolution. For this purpose, periodic campaigns will be scheduled in order to capture spectral images from the areas of interest during different seasons and weather conditions. The data will be regularly processed and compared with the previously collected data. In this way, the time-evolution of the weathering state will be followed and correlated to the environmental conditions.

3.3.2 Portable Raman

Raman spectroscopy is a well-known analytical technique enabling identification of various types of materials, both inorganic and organic. The technique probes vibrational, rotational and other low-frequency modes (motions) in molecules and materials and thus gives information about the chemical bonding.

The Raman process (Figure 13) represents the inelastic scattering of light by matter. Light in the visible, near-IR or near-UV, typically from a laser source, interacts with molecules by transferring part of its energy to chemical bonds that vibrate at characteristic resonance frequencies. In general, scattering of light can be elastic or inelastic. The elastic process is called Rayleigh scattering and the energy of scattered radiation is at the same frequency (wavelength) of the incident radiation. The inelastic one is termed Raman scattering, and is distinguished further into Stokes and anti-Stokes Raman when the scattered frequencies are lower or higher compared to the one of the incident radiation, respectively.

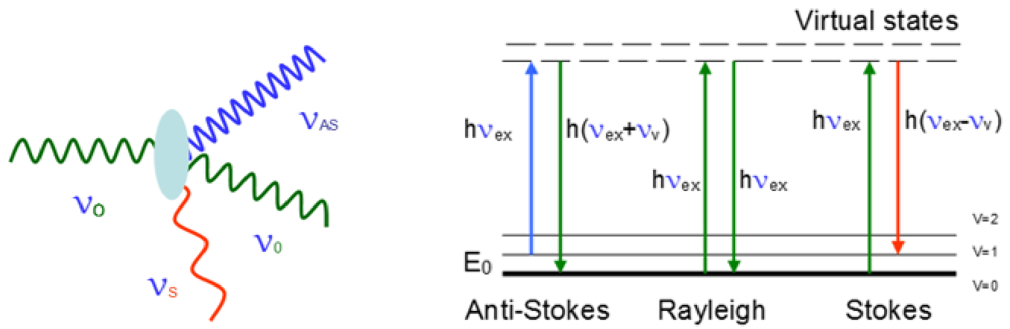


Figure 13: (a) Schematic diagram indicating the different scattering waves, Rayleigh, Stokes and Anti-Stokes Raman, arising from a molecule irradiated by light at frequency ν_o. (b) Energy level diagram indicating the different processes involved in the Rayleigh, Stokes and Anti-Stokes Raman scattering following irradiation of a molecule by light at frequency ν_o.

According to the schema in Figure 13, incident monochromatic radiation at frequency ν_o (and energy $E=h\nu_o$) excites the molecule from the ground state into a non-stationary (virtual) excited state. From this state, the molecule relaxes back to the ground state, releasing a photon of equal energy in the case of Rayleigh scattering. In the case of Stokes Raman scattering, the molecule relaxes to an excited vibrational level of the ground electronic state, releasing a photon whose energy (frequency: $\nu_S = \nu_o - \nu_v$) is lower by the corresponding vibrational quantum. Similarly, in the case of anti-Stokes Raman scattering, the molecule initiates a transition from an excited vibrational level of the ground electronic state to a virtual state and relaxes to the ground level releasing a photon of energy increased by one vibrational quantum (frequency: $\nu_{AS} = \nu_o + \nu_v$).

The main parts of the portable Raman micro spectrometer are shown in Figure 14 and are briefly listed below:

1. Excitation Source : cw diode laser (λ_{exc}: 785 nm)
2. Optical Probe Head (Mirrors, Filter, Viewing camera, LED for illumination)
3. XYZ micro-positioning stage for optical probe head
4. Grating spectrograph
5. CCD Detector
6. Power supply for laser
7. Power supply for detector

All parts, except the Optical Probe Head and the XYZ micro-positioning stage, are fitted in a compact arrangement, which allows the system to be portable and to operate outside the laboratory as well as to face successfully a number of different diagnostic arrangements (bulky or tiny objects, wall paintings and other vertical surfaces, objects exposed in a museum environment etc.).

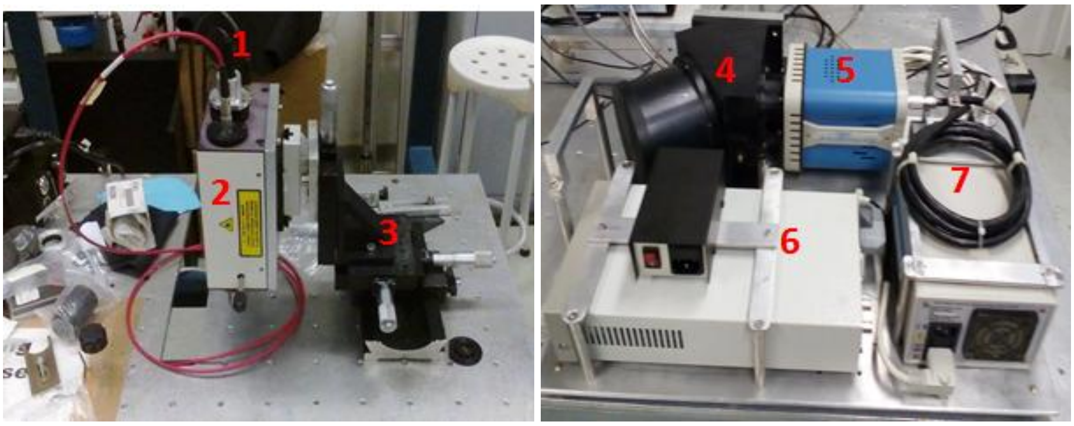


Figure 14: Mobile Raman system

The portable Raman system will be deployed to characterize extraneous layers on the monuments. Black crusts, salts (i.e. efflorescence), biological formations and other layers will be analysed on the basis of their molecular signature, in order to identify their composition and thus approach their origin (pollution, sea-water circulation i.e. for Koules etc.). Such a knowledge is important in order to take decision on the preservation/conservation interventions on the studied surfaces (i.e. cleaning/treatment).

Within HERACLES project, Raman analysis of samples, taken from selected areas, will be initially carried on in the laboratory. On the basis of the detailed database of Raman signals that will be achieved by laboratory measurements, on-site campaigns will take place with the aim to identify in situ the extraneous crusts and assess their nature and extent.

3.3.3 Portable LIBS

Laser Induced Breakdown Spectroscopy (LIBS) is an analytical technique that enables the determination of the elemental composition of materials, on the basis of the characteristic atomic emission from a micro-plasma produced by focusing a high-power laser on, or in a material. The LIBS technique has been used in a wide variety of analytical applications for the qualitative, semi-quantitative and quantitative analysis of cultural heritage materials, in oil paintings and frescoes, stone and metal sculpture, pottery, glass etc. [10, 11, 12]. Figure 15 shows a) the principle of operation of LIBS and b) a typical LIBS spectrum. Furthermore, Figure 16 and Figure 17 show typical examples of LIBS analysis and applications.

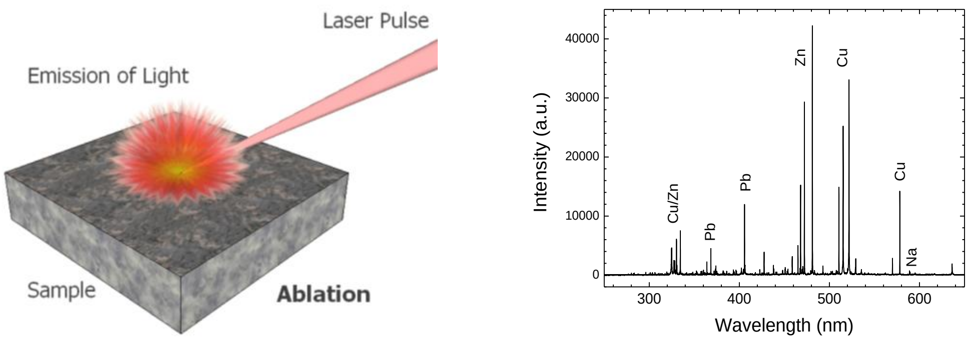


Figure 15: Simple diagram of the LIBS process (left). Typical LIBS spectrum of bronze sample (right)

LIBS portable system will be employed to quick screen extraneous layers on the monuments. Black crusts, salts (i.e. efflorescence), biological formations and other layers will be analysed by determining their elemental composition. This information will be complementary to the Raman data in order to identify the composition of these crusts and thus to gain information about their origin (pollution, sea-water circulation i.e. for Koules, etc.). This information, combined with the Raman results, will help to approach the composition and the origin of these crusts and decide on the subsequent conservation interventions.

Within HERACLES, similarly to Raman technique, LIBS analysis will be initially carried on in the laboratory. The detailed database of laboratory collected LIBS data will permit to improve the results of in-situ campaigns for the identification and monitoring of extraneous crusts.

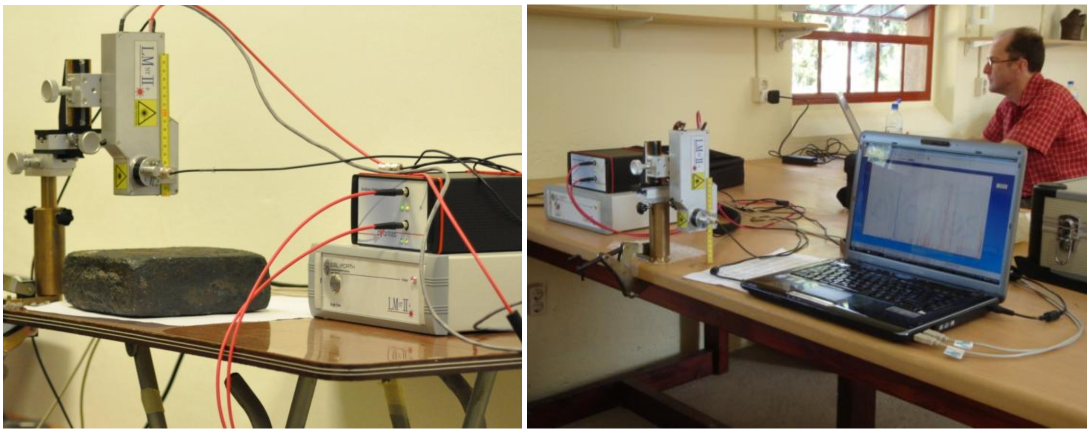


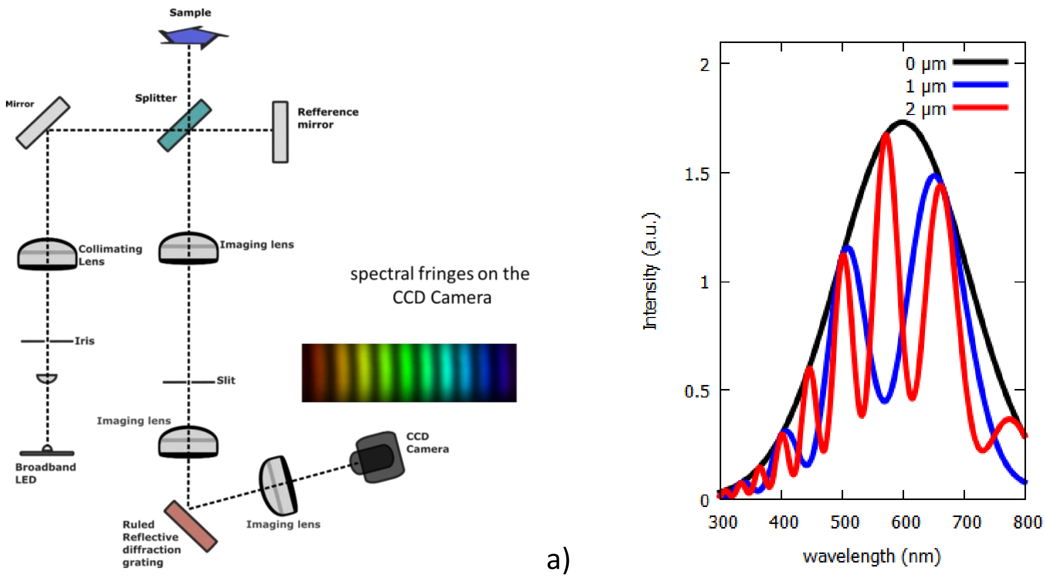
Figure 16: Analysis of Frankish silver coins in the Archaeological Museum of Ancient Corinth (left). Analysis of the bronze ingot exhibited in the Archaeological Museum in Nafplio (right).

Figure 17: Analysis of Venetian and Ottoman stone inscription in the Historical Museum of Crete [11].

3.3.4 4D Surface/ Volume topography

4D surface/volume topography measures the topology of a surface and its variations over time (4D). This problem will be approached by exploiting information from two supplementary optical techniques, such as spectral interferometry and white light scanning interferometry. Since both techniques use low coherence white light, they are non-invasive, non-destructive, with a capability of being portable and low cost [13, 14]. For the purposes of HERACLES project, prototype instruments will be developed and tested in the laboratory and on-site.

Spectral interferometry uses the interference in the spectral domain to measure the topology of a surface.



a) b)

Figure 18: Basic principles of spectral interferometry (a) experimental setup (b) modulation of the spectrum for 0, 1, 2 μm surface height steps for a 10% reflecting surface.

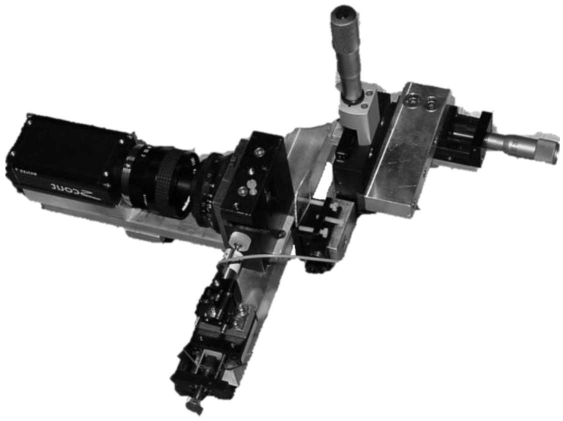
A typical spectral interferometry setup in Figure 18 (a), is shown. It consists of an interferometer, spectral analysis, and illumination components. Variations in the surface profile on the sample lead to variations of the optical path difference (OPD) in the interferometer. In the spectral domain this results to a spectral phase variation proportional to the ratio of OPD/λ, where λ is the wavelength. Thus, a modulation of the surface height leads to a modulation of the spectral intensity as shown in Fig. 18 (b). This technique is optimal for fast, high resolution and line profiles of surface topology.

Advantages: No moving parts are present so it is possible to carry on high repetition rate measurements (>100 Hz) with sub-wavelength precision (<λ/70).

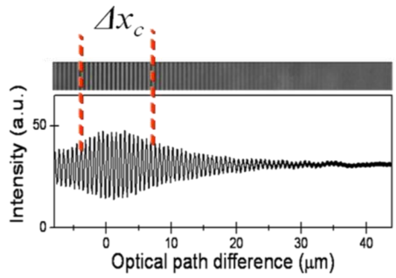
Drawbacks: Topological information is retrieved only along a single line and there is a maximum height difference which can be measured (typically ~ 200 λ).

Portability: Portable devices, with potential of being hand-held, can be developed using this approach.

White light scanning interferometry uses the interference fringes from a low coherence source (white light) to measure the surface topology.



a)



b)

Figure 19: White light scanning interferometry (a) FORTH lab prototype (b) typical interferogram: Δx denotes the coherence length.

A typical setup (lab prototype) is shown in Figure 19(a). White light interferometry is a variation of the classical interferometry where the monochromatic source is replaced by a broadband incoherent source (white light). The optical path of a reference arm in an interferometer is varied by moving a mirror. Due to the low coherence of the source, interference fringes are observed only near zero optical path difference, as it is shown in Figure 19(b). This technique is optimal for in depth, high resolution and measurements of the surface topology

Advantages: capable of 2D surface topology measurements of sub-wavelength precision (<λ/50) without practical limits on the surface height.

Drawbacks: Scanning (of 0.1 μm resolution or better) is required, the repetition rate is slow and anti-vibration control (passive or active) during the measurement, is needed.

Portability: Portable devices with tripod based support can be developed using this approach.

3.3.5 Drilling resistance measuring system (DRMS)

In HERACLES, the use of the drilling resistance measuring system [15, 16] will have two distinct aims: i) the evaluation of current state of preservation of the stone building and architectural elements of all the HERACLES test beds; ii) the sampling of the drilling residue (dust) from distinct interval depths for further physico-chemical analyses. The materials will be tested and evaluated in-situ.

Figure 20: The application of DRMS for the on-site evaluation of the preservation condition, of the stone architectural elements of the Cathedral of Santa Maria del Fiore- the Duomo of Florence (left) and the of the Parthenon at the Acropolis of Athens (right)

DRMS is an automatic instrument able to measure the drilling resistance of stones, mortars and other materials of similar properties (example of application as shown in Figure 20 and Figure 21). The drilling resistance is evaluated continuously by the measurement of the drilling force versus depth thanks to a load cell. The DRMS can detect fluctuations in the drilling resistance with depth around the mean value. The test allows to find the cause of these fluctuations, which can be attributed to non-homogeneities in the material, such as different sedimentation layers, different grain size and resistance, micro and macro cracks etc.

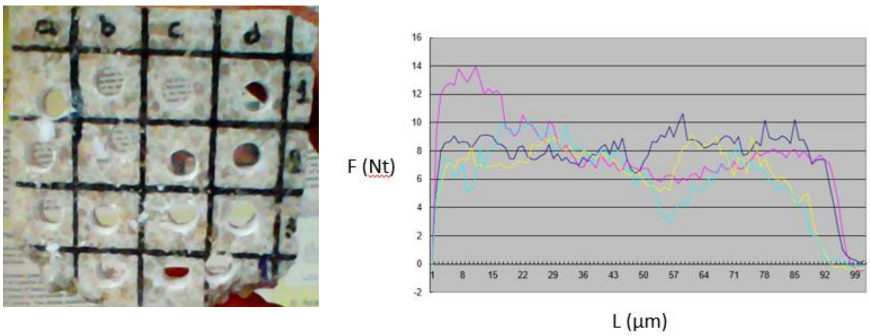


Figure 21: On the left experimental application of the DRMS for the state of preservation evaluation of a selenite specimen (5x5x1cm). The values of drilling force by depth on the produced plot, are presented (right).

By drilling the materials with special diamond type drilling bits, the system can measure continuously:

1. Penetration force
2. Actual drill position
3. Rotational speed
4. Penetration rate

During operation, rotational speed and feed rate are both kept constant, and can be continuously regulated between minimum and maximum values. In a CH diagnostics context, the drilling resistance measurement system can perform simple but precise drilling resistance measurements, by giving accurate evaluation of the rock toughness.

Through this method, the evaluation of the surface degradation in terms of depth (μm) and penetration resistance (Nt) will be obtained; this permits to evaluate the effects of several parameters as the different environmental conditions with respect to the position of a stone in the monument and the different lithological characteristics. Furthermore, based on the correlation of the uniaxial compressive strength (UCS), the drilling resistance and UCS values can be correlated to the well-known Mohs hardness scale.

At the same time, DRMS can be used as a high precision sampling tool; in fact, the drilling residue (dust) can be collected at specific intervals of depth and then analysed with several other techniques depending on the parameter under investigation. In this way, it is possible to have information about the state of preservation of the successive strata of the examined rock and special lithological characteristics (inclusions etc.), can be extracted. This approach is extremely important for the determination of the thickness and the nature of thin encrustations.

Table 1: Characteristics of the in-situ structural technologies

Method	Incident radiation	Detection	Information	Analysed depth	Spatial resolution	HERACLES partner
GPR	Microwaves	Time domain backscattered electric field	Characterization of hidden objects by means 2D and 3D images	variable according to the wavelength of the probing wave and the electromagnetic features of the investigated material	10-75 cm subsoil <7,5 cm vertical structures	CNR-IREA
Holographic radar	Microwaves	Amplitude of the interferometric signal between the incident wave and the backscattered one	Characterization of hidden objects by means 2D images	variable according to the wavelength of the probing wave and the electromagnetic features of the investigated material	< 10 cm vertical structures	CNR-IREA
ERT	DC current	Potential field	2D and 3D image of the electrical resistivity in the investigated subsoil	variable according to the electrode spacing	1-10 m	CNR-IREA
Accelerometer	AC current	Time domain	Acceleration of a structural point		10 mV/g	UniPg
LVDT	AC current	Time domain	Relative displacement between two points		< 0.1 mm	UniPg

Table 2: Characteristics of the weather stations and microclimate sensors

Method	Information	HERACLES partner
Wave gauge	Time series of sea level and temperature	FORTH-IACM
Weather station	Time Series of wind speed and direction, temperature, humidity, rainfall, barometric pressure, solar radiation and UV Index	FORTH-IACM
Microclimate sensor	Spatial and temporal distribution of air temperature [°C], surface temperature [°C], relative humidity [%], wind speed [m/s], wind direction [°], air quality (CO, CO_2, PM5, PM10-[ppm]), and illuminance level [lx]	UniPG-CIRIAF

Table 3: Characteristics of the portable instrumentations for material characterization analysis

Method	Incident radiation	Detection	Information	Analysed depth	Depth resolution	Lateral resolution	Sample dimension	HERACLES partner
Multispectral Imaging	UV-VIS-NIR Illumination	Diffuse light	Stratigraphic analysis, materials differentiation, monitoring of alterations	extremely high (5MP, versatile imaging lenses can modify FOV)/moderate spectral resolution	≈1 mm	Depends on magnification	any	FORTH-IESL
Raman spectroscopy	laser	Raman emission	Determination of molecular composition of materials	point analysis/extremely high spectral resolution	max 100µm	≈20µm	any	FORTH-IESL
LIBS	laser	Plasma emission	Determination of elemental composition of materials	point analysis/extremely high spectral resolution	10-50µm	150-200µm	any	FORTH-IESL
4D surface/volume topography	Visible Illumination	Interference effect	Topography of the area	High spatial resolution	λ/50 (λ=wavelength)	High versatile instrument	any	FORTH-IESL
DRMS	Drill bit	Drilling resistance	Drilling resistance by depth/sampling	Drilling resistance: F/Nt, Drilling depth: L/µm	10cm	High resolution	any	UoC

4 Definition of the systematic protocol

The systematic protocol related to the diagnostic and analytical strategies for each different monument, to be studied on the basis of the different structures, materials and weathering states, was the subject of the deliverable D3.1. Differently, the present document refers specifically to the use of in-situ diagnostic techniques for the quick assessment of the weathering state.

In this case, attention is focused only on the portable instruments and the sensors to be installed and **used in-situ** with the aim to monitor specific weathering processes or environmental and weathering events, with emphasis to a fast response and diagnostic procedures that will enable responsive actions.

Figure 22 shows the general protocol developed within D3.1, but here modified, accounting for the quick assessment analytical strategies using in-situ diagnostic tools (evidenced by the red circles), herein discussed:

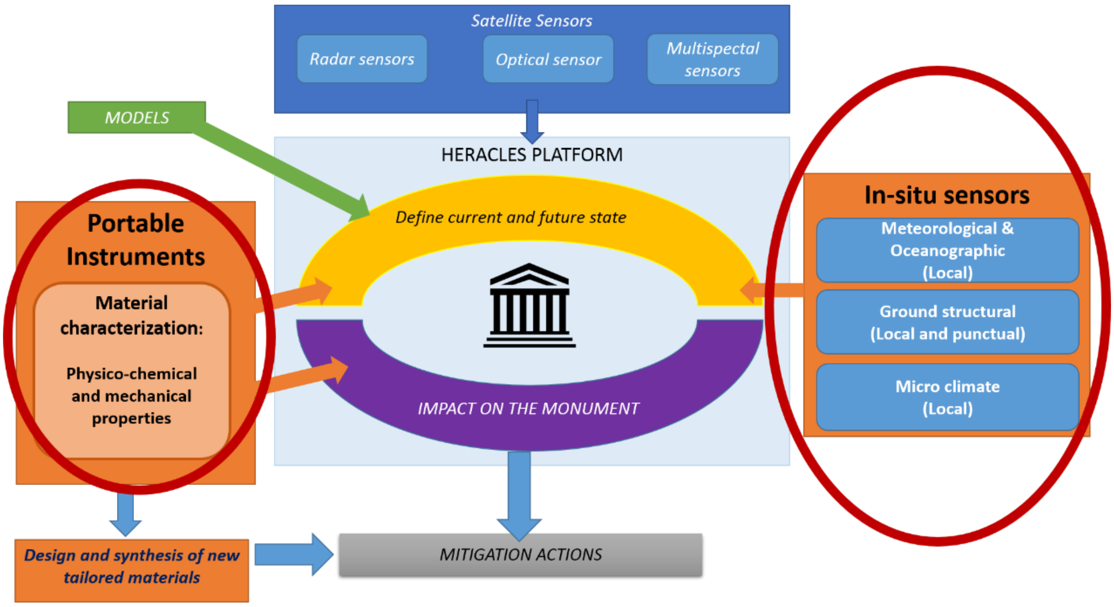


Figure 22: Schematic representation of the systematic approach of HERACLES protocols as regards the sensing, diagnostic and analytical strategies for quick assessment (evidenced by the red circles).

In this respect, the main features of the in-situ quick assessment protocols are:

A) The use of in-situ sensors to measure meteorological and micro-climate data (Figure 22, on the right)
B) The use of in-situ sensors to acquire information on ground structural state (local and punctual) (Figure 22, on the right)
C) The use of portable instruments for determination and characterization of materials and their degradation state and evolution (Figure 22, on the left).

As discussed in Section 2, the in-situ diagnostic protocol will be specified for the different cases considered in HERACLES demonstration activities, according to:

A. Quick assessment of the structural integrity/condition of the monument, which involves criticalities of the monuments/assets due to structural issues and risks. This case refers mainly to the Gubbio test-beds.
B. Quick assessment and monitoring of material degradation, mainly due to erosion, weathering and degradation of the original or restoration materials. This case refers mainly to the two test-beds in Heraklion.
C. Quick assessment of the microclimate dynamic monitoring and material mechanical characterization. These refer to all the HERACLES test-beds

The decision to consider different quick assessment protocols, specifically thought for the different HERACLES test-beds, is clearly driven by the diversity of the test-beds features (location, type of monuments, local environmental conditions, others) and the risks affecting each site. The definition of the protocols is also a tradeoff between the possible higher costs associated to surveys using non-usual technologies and the advantage to gain additional information about the status of the site; it is evident that the protocol definition will depend on the peculiarities of the site.

The same schema used in the definition of the general systematic protocols, developed in deliverable D3.1 will be adopted here for the QA protocols. In the following is reported the Outline.

OUTLINE OF THE QA SUGGESTED PROTOCOL

On the basis of the general protocols developed in deliverable D3.1, the in-situ diagnostic protocol for quick assessment and monitoring of the weathering state and its progress on the areas of interest for the studied test beds have a similar structure, which is outlined in the following:

1. Aim of the diagnostic and analytical strategy vs user needs

First, the objectives of the in-situ diagnostic and analytical strategy are specified for the test area, by focusing on the quick assessment and evaluation of the structural condition and the weathering state of the involved materials. It was based on the detailed end-user requirements for the HERACLES test-beds as described in detail in deliverable D1.2, and the comprehensive protocols described in deliverable D3.1.

2. Selected zones and elements of significance

Subsequently, the identified areas and the elements of the monument where the in-situ protocol will be applied, is presented.

3. Outline of the sensing, diagnostic and analytical strategies

This section provides the protocol, outlining how the in-situ diagnostics technologies are organised in a logical and temporal way (observational chain). This protocol is coherent with the issues outlined in deliverable D1.2 and the comprehensive approach developed in deliverable D3.1.

4.1 Gubbio

The multi-risk scenario of the Town Walls and Consoli Palace, is described in detail in the deliverable D1.2, while the systematic protocols to approach the specific analytical and diagnostic needs of both monument have been the object of the deliverable D3.1. Here, the in-situ quick assessment protocols for these two monuments, are discussed.

4.1.1 The aims of the in-situ diagnostic and analytical strategy

As described in details in deliverable D1.2, Gubbio is mainly affected by hydrogeological risks, structural hazards and material degradation, which are caused by extreme climate events, most in terms of heavy rain and sudden temperature changes, pollution in addition to natural hazards such as seismic events. Accordingly to this view, the in-situ diagnostic protocol is designed for the Gubbio test sites (i.e., medieval Walls and Consoli Palace) considering three main aspects:

- Hydrogeological risk evaluation
- Structural Health assessment
- Material degradation analysis

The hydrogeological assessment will concern the geographical areas where the historical structures are located and will aim at improving knowledge about possible hazards such as landsides and subsidence phenomena. The quick assessment of the hydrogeological risk will be carried on by means of in-situ subsurface investigation technologies as GPR and ERT and local pointwise sensors as inclinometers.

Gubbio is affected by structural instabilities caused by extreme climate events, as it is testified by the existing and progressive slow deformations and crack patterns, which involve ancient structures. This situation will be analysed in HERACLES at both the two test sites (medieval Walls and Consoli Palace). In the frame of the HERACLES project, structural surveys are performed by using radar technologies (GPR and holographic radar), stand-alone inclinometers as well as static and dynamic sensors, i.e. LVDT and accelerometers. Detecting and monitoring possible structural instabilities, the knowledge about the structures under test will be improved, if incomplete.

It is worth underlining that through the HERACLES project:

- the surveys carried on at the medieval Walls will be mainly devoted to investigate structural status of the walls and gain information about their constructive modalities;

- the surveys carried on at Consoli Palace have the two-fold purpose to improve knowledge about its architecture and to characterize structural instabilities.

Material degradation is a recurring issue in the frame of CH and it deserves huge attention in Gubbio. The constituent materials (limestones, travertine, sandstone-Serena stone, plasters, binders) used for building and restoration of the medieval Walls and Consoli Palace are affected by the detrimental actions of climate change and pollution and in particular by a high CO_2 concentration and intensification of rainfalls including acid rains.

In this framework, the characterization of the degraded materials will help in defining the degradation mechanisms. Specifically, characterization of the degraded materials is performed ex-situ, by means of laboratory analysis carried on by using high performance instrumentations, while the study of the evolution of degradation mechanism will takes advantage also by the use of in-situ meteorological sensors. These sensors record precipitation and temperature time series by exploiting local microclimate monitoring campaigns and provide useful data to investigate the possible correlation between peculiar local climate conditions as well climate change phenomena and material deterioration.

The combination of the different just mentioned tools permit to improve the knowledge on the architectural elements and (original and new) materials as well as to detect risk factors due to natural aging, extreme climate events and air pollution.

4.1.2 Selected zones and elements of significance

4.1.2.1 Town Walls

As detailed in deliverables D1.2 and D3.1, one of the main risk factor occurring at Gubbio is the presence of a significant soil accumulation against the medieval Walls.

This soil accumulation can be considered as a hydrogeological issue caused by torrential rains and often associated with landslides. In this context, a knowledge of the subsoil features is very useful to understand the causes of the phenomenon, to foresee its possible evolution in time and to properly prevent/manage it.

The GPR and ERT technologies will be used in the areas selected on the basis of joint surveys with Gubbio municipality, where these criticalities result more evident and need of hydrogeological assessment. These areas (Figure 23) have been identified and described already in deliverables D1.2 and D3.1 and are identified as:

i. Area 1; in Zone 1 (“*Forte di Parco Ranghiasci*”);

ii. Area 2; in Zone 2 (“*Cassero*”);

iii. Area 3; between zone 3 (“*Torre*”) and zone 4 (“*Porta S. Ubaldo*”)

iv. Area 4; between zone 4 and zone 5 (“*Bughetto*”)

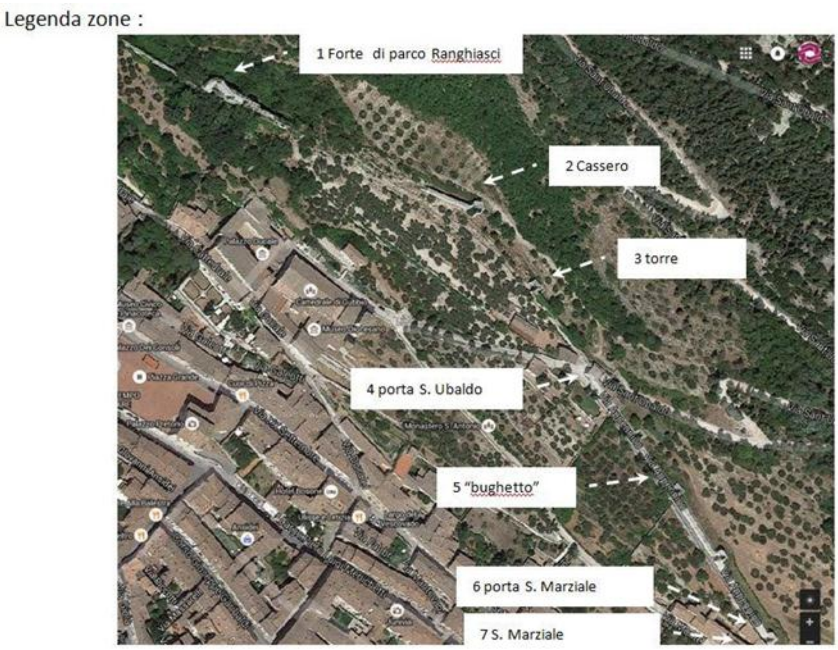


Figure 23: Area of interests for the medieval Walls of Gubbio

Although restoration actions, mainly devoted to remove the backfill material, have been performed in the past in some of these areas, the hydrogeological risk still persist. Accordingly, it is mandatory to carry on a quick assessment of the hydrogeological risk to understand the level of the seriousness and properly plan future mitigation/prevention actions. Subsoil investigations will be performed in all the areas aiming to achieve complementary information about the soil characteristics.

4.1.2.2 Consoli Palace

Consoli Palace is mainly affected by structural instability and material degradation. Some parts, affected by these problems have been identified and selected to be studied, according to their deterioration state and physical accessibility. In Figure 24 example of indoor and outdoor areas which are worth being investigated, are shown.

In particular, investigation will be performed at the floors to gather information about the structural characteristics of the foundations and possible hazards affecting them. Moreover, vertical structures will be investigated to detect and monitor cracks and risk factors, such as water infiltration, and to investigate material deterioration.

(a) (b) (c)

Figure 24: Consoli Palace a) Picture of the main entrance from the staircase in “Sala dell’Arengo”; b) Picture of the superior external loggia; c) Picture of the external façade with the staircase.

4.1.3 Outline of the sensing, diagnostic and analytical methodologies for quick assessment and monitoring of the weathering state and its progress

The protocol for quick assessment and monitoring of the weathering state and its progress at the two HERACLES test-beds in Gubbio is here discussed on the basis of the main problems affecting each test-bed and on the basis of the different portable instruments and sensors that will be employed for the individual hydrogeological, structural and material degradation issues present in the monuments.

4.1.3.1 Town walls

4.1.3.1.1 Hydrogeological Assessment

Subsoil investigations will be performed in all the areas around the Walls by exploiting both ERT and GPR technologies. In fact, these instrumentations provide, complementary and/or cooperative information about soil characteristics.

In particular, ERT, which is a geophysical imaging technique, is used to perform subsoil surveys devoted to gather information about the spatial distribution of resistivity contrasts of the soil under test. By exploiting these images, ground features, sliding material and bedrock can be identified. Hence, based on ERT results it could be possible to identify potentially unstable areas.

On the other hand, GPR is useful to obtain two dimensional horizontal and vertical transects devoted to detect possible subsurface inhomogeneity in terms of dielectric permittivity. Therefore, these kinds of investigations can be useful to detect and localize materials interfaces and then to gather information about soil stratigraphy.

In this respect, it is worth noting that to make effective the GPR surveys, a suitable penetration depth has to be reached. Accordingly, the GPR system has to be equipped with low frequency antennas, i.e. antennas working at a nominal central frequency belonging to the range from 200 MHz to 600 MHz.

During the surveys, both ERT and GPR surveys provide images of soil features. Collecting images of the same area at different time periods, it will be possible to obtain historical information very useful to detect the occurrence of soil features variations occur and to correlate them with climate events.

To gain a more complete vision, also the possibility to correlate the GPR and ERT measurements with the ones of inclinometers installed in the area, will be considered.

4.1.3.1.2 Structural Surveys

Structural surveys will be performed by using radar technologies (GPR and holographic radar), stand-alone inclinometers as well as static and dynamic sensors, i.e. LVDT and accelerometers.

GPR system equipped with high frequency antennas, i.e. antennas working with a nominal central frequency equal of higher than 900 MHz, and the holographic radar, will exploited to investigate vertical structures. These surveys will involve portions of the medieval walls selected together with Gubbio municipality, where parts of the reinforcement wall were built (Area 2 -"Cassero", Figure 23). Aims of both GPR and holographic radar investigations are: i) the detection and localization of hidden anomalies such as water infiltrations and cavities; ii) the imaging of the reinforcement structures; iii) the characterization of crack and fractures.

Stand-alone inclinometers, LVDT and accelerometers will be installed on the walls and allow to gather time-continuous data. Therefore, they will be able to track the evolution of structural behaviour during the monitoring period and to reveal possible anomalies.

Stand-alone inclinometers are useful to monitor structures affected by out-of-plane rocking risk and their use at the areas of the medieval Walls, mainly at Area 3 near Porta S. Ubaldo, is strongly suggested by the evidence, from inspections on site. Therefore, their installation is planned here.

4.1.3.2 Consoli Palace

4.1.3.2.1 Structural survey

GPR systems equipped with low frequency antennas, i.e. antennas working at a nominal central frequency from 200 MHz to 600 MHz, are suitable to investigate floorings. Accordingly, they will be used to perform foundation inspections and to investigate the degradation status of the flooring, especially of those parts exposed to climate events.

It is worth remarking that radar systems perform a diagnosis analysis that provides images characterizing the investigated structure at the time of the survey. Hence, periodic radar surveys will be necessary to collect data for monitoring the evolution of the present hazards and detecting the occurrence of new ones.

LVDT measures the evolution of the crack pattern while accelerometers record continuously the vibration of the structure, for long-term structural monitoring purposes. Accordingly, they are very useful in the south-west part of the Consoli Palace, called “loggia”, which is affected by an out-of-plane rocking mechanism as it is made evident by a widespread crack pattern, and in the west side, in which the external wall is affected by a detachment phenomenon.

4.1.3.2.2 Assessment of the surface degradation by means of portable systems

The evaluation of the stone degradation in depth and in extent will be performed by means of DRMS. Specifically, with this technique it is possible to estimate, quantitatively and qualitatively, the percentage of salts inside the stone mass by means of the analysis of the drilling residue collected from several, well defined interval depths. Moreover, through DRMS the current state of preservation of several stones of the same lithotype will be evaluated in respect to the different environmental conditions indoor and outdoor the Palace.

The in-situ methodology will initially involve on-site application of DRMS collecting the drilling residue (dust) from distinct interval depths. The stone preservation condition will be evaluated on the basis of comparative measurements on several stones from the internal masonries of the Palace.

At a second stage, the collected drilling residues/samples will be analysed with several techniques (SEM-EDS for micro morphological examination and elemental analysis), XRD (mineralogical analysis) and spectroscopic techniques (FTIR, µRaman for molecular mineralogical analysis). Through this approach it will be possible to assess the qualitative and the quantitative composition of the salts, as well as their extent within the affected stone, from the surface.

4.1.3.2.3 Micro climate Sensors

The use of these sensors is recommended at both Gubbio test-beds, i.e. medieval Walls and Consoli Palace, in order to assess the correlation between local microclimate parameters and the degradation of the construction materials surfaces. In fact, the local inspection already highlighted local darkening of the materials and the appearance of mould and humidity on the building surface.

Based on the above considerations, a local microclimate monitoring campaign is planned in the close proximity of Area 2 and Area 3 of the Walls in order to investigate the possible correlation between the detected terrain stack and the local climate change phenomena. To this aim, the main local microclimate parameters to consider are dry bulb temperature [°C], relative humidity [%], surface temperature[°C], air quality in terms of CO_2, VOC, CO [ppm], wind speed [m/s] and direction [°]. These data can be statistically analysed and correlated to weather data provided by the ARPA weather stations positioned in the surrounding area.

Outdoor and indoor dedicated microclimate monitoring campaigns are also planned for Consoli Palace, with the aim to investigate the local environmental conditions in terms of dry bulb temperature [°C], surface temperature [°C], relative humidity [%], air velocity [m/s], air direction [°], and air quality in terms of pollutants concentration [ppm].

4.1.3.2.4 Material Degradation analysis

The investigation approach is similar to the one chosen for the medieval Walls described in the previous section.

Specifically, characterization of the degraded materials is performed by means of laboratory analysis (ex-situ) carried on by using high performance instrumentations, while the study of the degradation mechanism takes advantage by the use on in-situ meteorological sensors.

For this reason this ex-situ activity is not a part of the quick damage assessment, even if it will provide a useful support to the overall evaluation.

4.1.4 Systematic in-situ diagnostic protocol for quick assessment and monitoring of the weathering state and its progress on the areas of interest for GUBBIO

In the previous sections all the criticalities affecting the two test site in Gubbio have been briefly described and the methodologies suggested for their quick assessment were discussed.

Figure 25 and Figure 26 give a schematic representation of the in-situ diagnostic protocol for quick assessment of the weathering state of the Town Wall and Consoli Palace in Gubbio, aiming to outline in a clear and easy way the methodology suggested for a quick screening of the weathering state, using portable instruments and in-situ sensors at the monument.

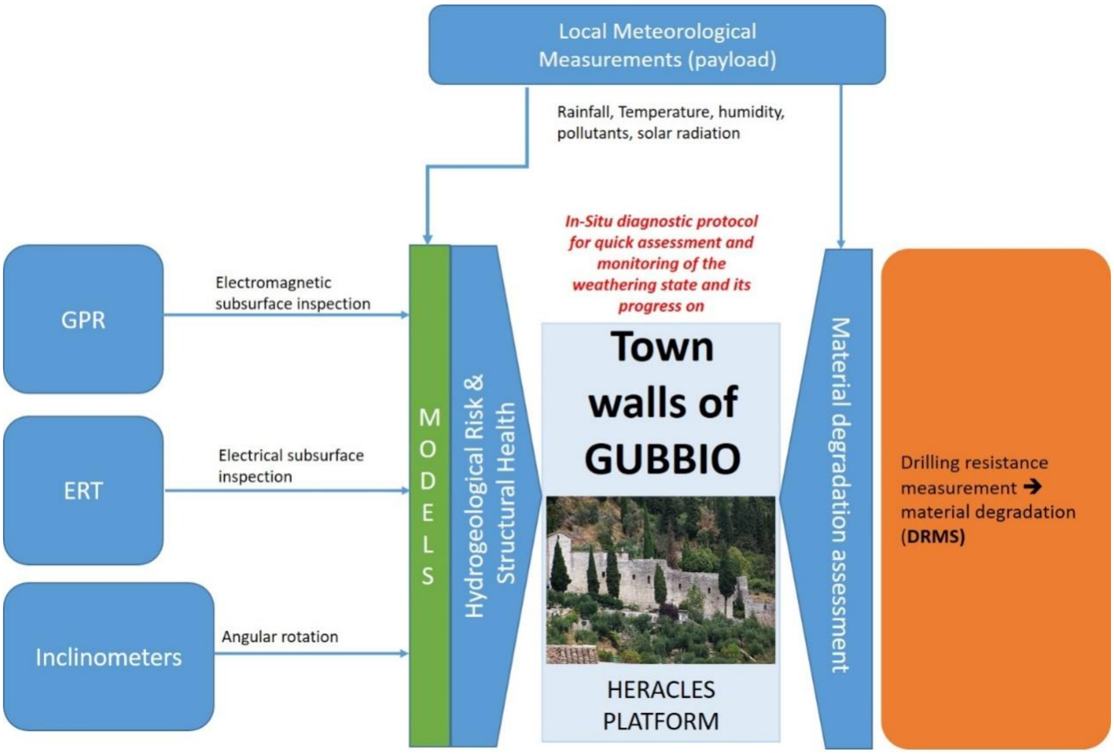


Figure 25: Schematic QA protocol flow for Gubbio, Town Walls

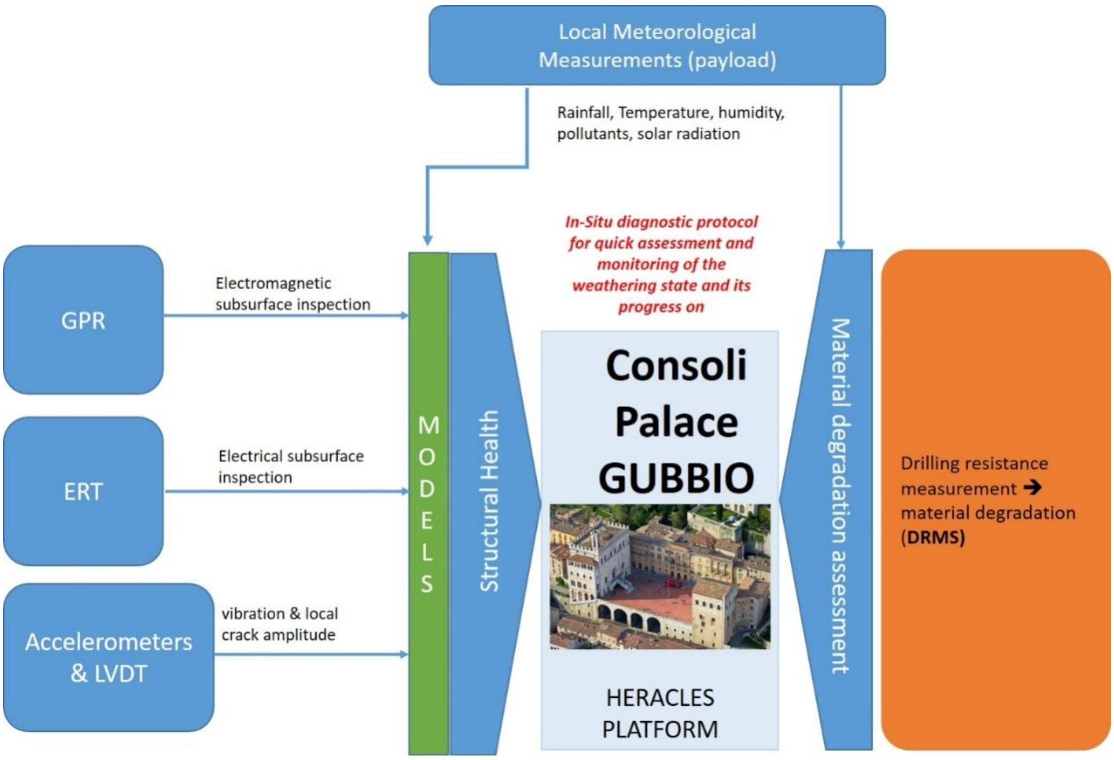


Figure 26: Schematic protocol flow view for Gubbio, Consoli Palace.

Besides the sensing technologies described above, the two protocols, depicted in the figures below, show clearly how the quick assessment is an important tool to feed the models for a detailed and reliable analysis.

In particular, by considering the Town Walls, the data coming from the geophysical techniques combined with the inclinometers can be considered as input data to the geomorphological modelling. The same considerations hold for the Consoli Palace, where the two class of in-situ techniques for structural survey (GPR and the techniques for the static and dynamic monitoring of the structures as LVDT and accellerometers) provide important data for the structural modelling aiming at the vulnerability assessment of the building.

4.2 Heraklion

The Venetian sea-fortress of Rocca a Mare (Koules) and the Archaeological site of Knossos, are subjected to a multi-risk scenario, which is described in detail in the deliverable D1.2 on the basis of the end-user requirements. Threads and damaging effects due to pollution, extreme weather conditions and the sea are the most prevalent risks for the two Cretan monuments having a direct impact mainly on their constituent materials, as well as, on their structural integrity. According to this framework, complete and systematic protocols to approach the specific needs of both monuments with analytical and diagnostic tools, were outlined in deliverable D3.1.

Referring to this approach, the in-situ quick assessment protocols for both monuments have been designed to address their most critical challenges, namely material weathering and degradation. Furthermore, issues related to monitoring and prediction of the sea-effects are also approached via in-situ measurements.

4.2.1 The aims of the in-situ diagnostic and analytical strategy

Material weathering and degradation is a common issue for both monuments under study, in Crete. Specifically, a number of extraneous materials, such as black pollution deposits, bio-deterioration and efflorescence salts, cover major parts of the surface of both monuments, while, on the other hand, their construction materials undergo significant erosion due to climatic change effects (in particular the selenite and newer reinforced concrete restoration elements at the Knossos site).

HERACLES strategy is to develop a quick assessment protocol for mapping and monitoring the extent of the extraneous accumulations, as well as the degradation and loss of the construction materials. The suggested protocol is also strictly related to the ex-situ measurements, described in deliverable D3.1. These measurements aim at determining the chemical composition of the extraneous materials and to understand the reasons that influence their appearance, as well as to approach remediation strategies to prevent material loss.

4.2.2 Selected zones and elements of significance

In the following, the areas chosen for the development and testing of the quick assessment protocol for in-situ diagnostics are presented and justified on the basis of their specific issues and risks.

4.2.2.1 Venetian sea fortress- Koules

The sea fortress of Rocca a Mare, Koules, is subjected to risks related to materials degradation mainly due to the impact of the sea-waves and coastal flooding, wind effects and the environmental pollution. Consequent effects are stone erosion and accumulation of extraneous compounds (i.e. pollution crusts and efflorescence), which compromise the appearance and the preservation/conservation of the monument.

Specifically, the suggested in-situ diagnostic strategy for Koules involves the following steps:

a) the quick assessment of the accumulation and evolution of extraneous material such as: black deposits, hard white encrustations, biological activity and efflorescence salts. Consequently, monitoring and mapping of the environmental pollution, of moisture level, of the air-quality levels and of temperature cycles, are planned, to organise any preservation actions.

b) the effective and fast evaluation of “salt hydration distress" (SHD) action resulting into loss of original material, is planned as well. This is an indirect effect from the transportation and accumulation of soluble salts within the bulk of the stone and refers to the repeated reconversions of a salt between its anhydrous and hydrated forms involving significant crystal lattice expansion (i.e. in the range of 317% as in the case of the conversion of anhydrous sodium sulfate (thenardite) to the decahydrate (mirabilite)).

The major risk issue for the sea-fortress of Koules comes from the impact of the sea. The monument is exposed to the prevailing North winds in the area, and the consequent sea waves high intensity and coastal flooding have a significant impact on its surfaces and structural components.

The suggested in-situ protocol related to the monitoring of waves includes the use of low cost portable wave gauges in two points. The scope is to acquire data about the waves height and to compare these results to those obtained from the meteorological stations, in order to cross correlate them with the modeling outputs. This activity aims to validate and improve the calibration of wave models, in order to provide more accurate data for the climatic change risk assessment. The instruments will acquire measurements continuously. The data recovery is not automatically made, and it will be carried on every six months, by means of data recovery missions made by FORTH-IACM. Data acquisition will be made by scuba diving with the use of water- proof loggers.

Figure 27 shows some areas of the Koules sea-fortress (indoors and outdoors) in which extraneous materials such as black crusts, salts encrustations and efflorescence are observed. In these areas sampling of materials for ex-situ analysis has already been and will be performed; as well, in-situ tests for mapping the presence of the crusts and following their evolution, are foreseen, with the use of portable instruments.

Figure 27: Map of Koules: the labels indicates the areas where different accumulations, crusts and stone corrosion patterns (i.e. alveolar) are observed and that will be tested for the purpose of the quick-assessment diagnostic protocol under development.

In Figure 28 the areas of the fortress subjected to the wave impact and sea-flooding are shown (red zone). The effect of the sea waves impact produces important effects on the structural stability in the zones evidenced in green. Area a) (red), where the sea wave impact is more severe will be studied by means of numerical modelling and in-situ measurements, derived from two wave-gauges that will be positioned in two locations. The first will be located at approximately 3 m in depth with approximate coordinates 35°20'41.84"N 25° 8'11.42"E, while the second, at approximately 10m in depth with approximate coordinates 35°20'42.79"N 25° 8'10.14"E.

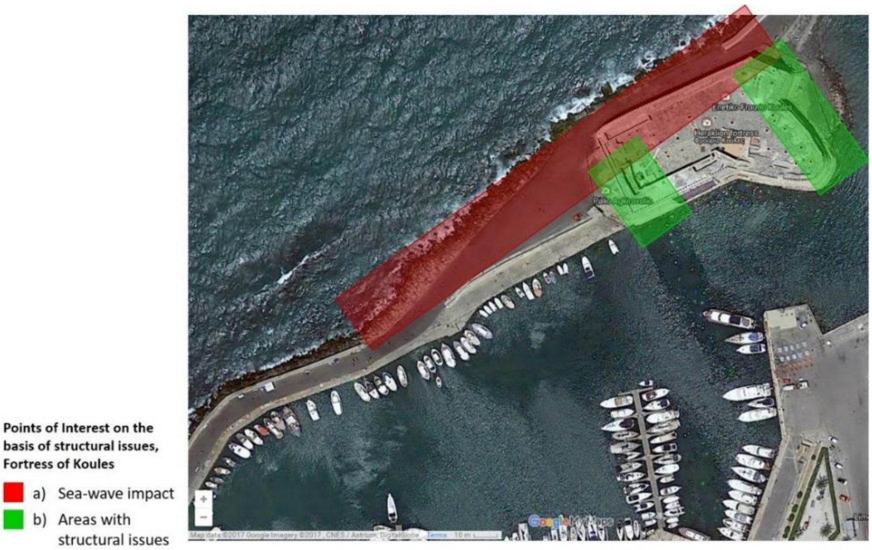


Figure 28: Koules fortress areas that suffer from the effects of waves and will be studied for the purpose of the quick-assessment diagnostic protocol under development

4.2.2.2 Archaeological Site of Knossos

The archaeological site of Knossos Palace, is characterised by its unique construction material, the **selenite**, which is used extensively across the site, both as ornamental and building element. Originating from the local quarry this exceptional material gives a unique iridescent appearance to the monument but, due to its susceptibility to humidity and other environmental parameters, its damage results severe and extensive. The effects of climatic changes and pollution on the structural integrity of the selenite components of the archaeological site are particularly crucial and it will be very important to monitor their weathering state and ensure their preservation.

In Knossos, other materials to be studied and assessed on-site are:

- **Ancient (original) and historic (past restorations) mortars:** they present degradation phenomena induced by time and their weathering state must be assessed and monitored, as well as the compatibility between ancient and modern materials will be critically addressed.
- **Reinforced concrete** elements, added to the monument by Sir A. Evans at the beginning of 20th Century. Their inspections/investigation on the basis of their weathering state and stability, will be critically approached for future conservation interventions.

Figure 29 shows the areas with intense material weathering phenomena at the Knossos Palace, selected to be studied in HERACLES. They are located in four areas of the archaeological site:

1. **West Magazines**. Located in the West site of the Palace from North to South, this partly sheltered area, involves eighteen store rooms. A large number of selenite blocks can be found in this area, exposed to the weather and intense temperature variations between day and night.

2. **Tripartite Shrine**. This is a multi-level sheltered area with dominant presence of moisture. In this case, moisture is spreading out among the different levels/floors through openings at the contact points between selenite and the reinforced concrete, and causes irreversible damage to the Minoan selenite pillars of the lower levels.

3. **East Wing**. Showing materials weathering problems similar to the Tripartite Shrine ones, this sheltered area has been chosen because it has been restored and thus the restoration interventions and the materials used have to be evaluated. Creeping effects and crack patterns are also present.

4. **South House**. Located in the South of the Palace this area presents a significant number problems of interest to HERACLES. In addition to the material degradation deriving from intense moisture, this area shows a number of structural issues such as soil movement, static problems, collapses, cracks and delamination of concrete due to the movement of soil and falling of trees caused by the presence of groundwater.

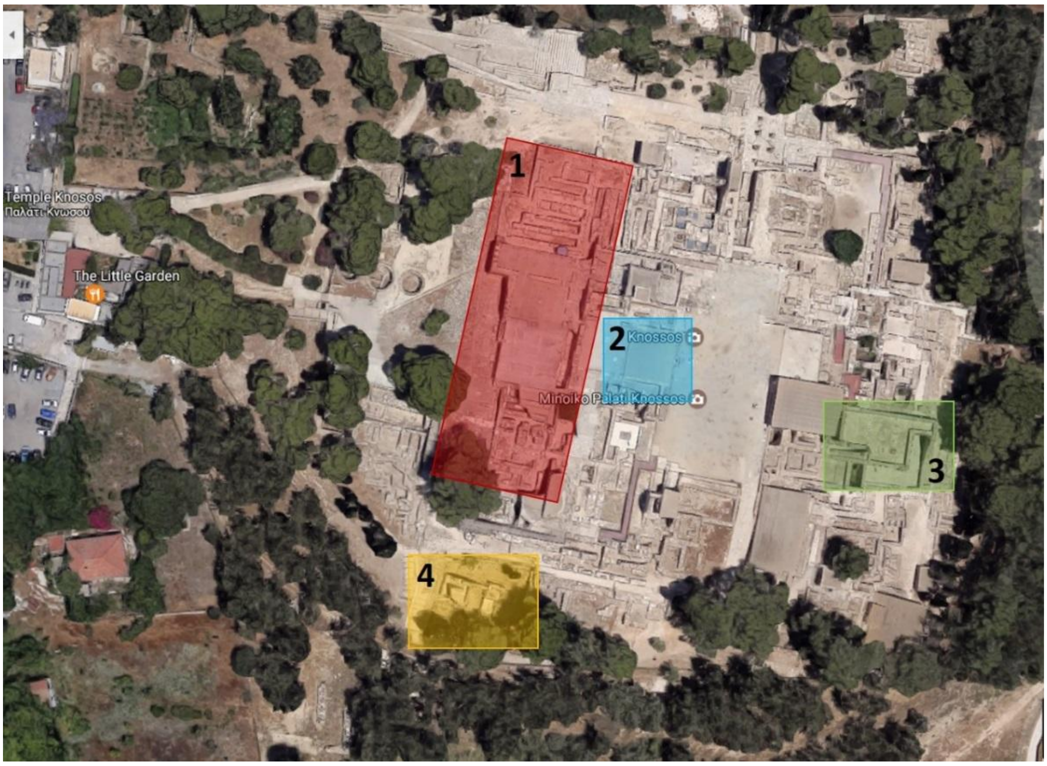


Figure 29: The four areas in the Palace of Knossos to be studied in HERACLES as regards their material weathering for the purpose of the quick-assessment diagnostic protocol under development: 1. West Magazines, 2. Tripartite Shrine, 3. East Wing, and 4. South House

Figure 30 shows areas where encrustations are present and where the sampling of materials will be carried on.

Figure 30: Areas in the Palace of Knossos to be studied in HERACLES, on the basis of materials are: 1. West Magazines, 2. Tripartite Shrine, 3. East Wing, 4. South House.

4.2.3 Outline of the sensing, diagnostic and analytical methodologies for quick assessment and monitoring of the weathering state and its progress

In Heraklion, the material weathering is a common issue for both the two test-beds and will be addressed using the same methodologies and the same approach. In addition, in Koules the sea waves phenomenon have to be studied.

The protocol for quick assessment and monitoring of the weathering state and its progress at the two HERACLES test-beds in Crete is here discussed on the basis of the different portable instruments and sensors that will be employed to assess the weathering issues and sea waves phenomenon and related effects .

4.2.3.1 Portable imaging instruments to map and monitor the evolution of the weathering effects

Crusts deriving from pollution accumulations, from insoluble salts and efflorescence, associated with increasing levels of moisture, air pollution and sudden temperature changes, appear on the surface of the studied monuments, jeopardising their appearance and longevity. An effective screening of the evolution and propagation of these extraneous materials on the surface of the monument will be addressed on the basis of portable imaging instrumentations as follows:

- Multispectral Imaging and 4D Surface Volume Topography are imaging techniques, and they will be used to map the extent of the deposits. Multispectral Imaging (MSI) will be used to map the crusts accumulation on the Koules fortress walls. MSI provides 2D information and it can be used remotely, providing high resolution images by using the suitable imaging system, while the field of view is adapted according to the area of interest. Moreover, MSI operating at various narrow bands can provide high contrast 2D images which allow the sharp determination of the borders of the crust. Periodic inspections of the area will allow the monitoring of the pathology during time, for determining the factors which contribute to the evolution of the crusts.

- 4D Surface Volume Topography will be also used in order to provide high resolution information about the shape and the volume of the crusts while using this technique periodically the accumulation rate will be defined. The same technique applies to weathering cases, like alveolar disaggregation. In this case the extent and the rate of disaggregation can be defined by using the 4D Surface Volume Topography.

This technique has been first tested in the laboratory on artificial samples and a prototype system is currently under development to be used on-site for detailed and high-resolution measurements of the studied weathering effects.

4.2.3.2 Mapping and quick screening of material weathering by means of portable laser spectroscopic systems

A precise determination of the chemical composition of extraneous materials is important as it contributes in the identification of the mechanisms responsible for their development and thus can support their remediation solution. Such studies are typically carried on by ex-situ analysis and in HERACLES were the objective of the protocols described in deliverable D3.1.

Nevertheless, where possible, it is particularly important developing protocols related to their preliminary mapping and monitoring on site (in-situ), using portable optical and laser spectroscopic instruments (LIBS, Raman).

Specifically, the suggested quick assessment protocol for the mapping and in-situ determination of the qualitative composition of the crusts and other accumulations involves the use of portable Raman and LIBS systems. These two techniques are complementary: LIBS provides elemental information, while Raman provides molecular information. Generally, it is desirable to know the exact composition of the crusts, and for this reason the Raman technique will be preferred in most cases. But, still, there are limitations (e.g. strong fluorescent signal) limiting the Raman performances. In this case, the LIBS portable system will be used to define the chemical elements in the crust, and thus allowing an indirect definition of the crust composition.

The in-situ methodology will follow two phases:

- PHASE A: a series of preliminary studies will take place ex-situ, in laboratory, using samples selected from the most representative areas in the monuments. The aim is to create a database of different crusts and salts to be considered as reference compounds for the portable measurements.
- PHASE B: referring to the laboratory data base, the two portable instruments will be transported on-site, where measurements will take place in pre-arranged time-periods or after major events (heavy rainfall etc.), following the suggestion by the Ephorate.

4.2.3.3 Assessment of the surface degradation by means of portable systems

In the case of Koules fortress, an implemented estimation and evaluation of the depth and extent of the salt accumulations inside the stone mass will be obtained through the application of DRMS. The collection and analysis of the drilling residue from several and well defined interval of depths will give a qualitative and quantitative estimation of the salts present beneath the surface of the stone. Moreover, through DRMS, the current state of the surface degradation of several stones of the same lithotype will be evaluated with respect to the different environmental conditions inside the fortress.

The in-situ methodology will have the following phases:

- PHASE A: in-situ DRMS in order to collect the drilling residue (dust) at different depth intervals. For this purpose several representative stones have been selected from the internal masonries of the Koules fortress.
- PHASE B: the so-collected samples will be analysed ex-situ, in lab, with several techniques (SEM-EDS for micro-morphological examination and elemental analysis), XRD (mineralogical analysis) and spectroscopic techniques (FTIR, µRaman for molecular mineralogical analysis). Through this approach it will be made possible to assess the qualitative and the quantitative composition of the salts at different depth from the surface of the affected stone.

In the case of Knossos, the Knossian mineral gypsum will be studied. The main parameter to be evaluated via DRMS is the depth and extent of degradation (loss of cohesion between crystal aggregates). In this case, DRMS will be used as a mechanical test for the assessment of the state of preservation of the original materials and for the performance evaluation of the consolidating compounds.

The in-situ methodology will have the following phases:

- PHASE A: a series of preliminary studies will take place in the laboratory using samples selected from the most representative varieties of Knossian mineral gypsum (selenite). The main objective of these studies is to create a baseline regarding the depth of degradation. It will represent a useful indication for the correct penetration depth that the consolidating material have to reach, ending before reaching the pristine stone. The beginning of its polymerization process has to be taken into account, too.

Additionally, based on the high depth resolution of the DRMS, the drilling residue (dust) collected at different depth intervals, will be examined in the laboratory in order to designe and evaluate the formation of the consolidating compounds both on morphological (SEM) as well as on chemical level (spectroscopic analyses, XRD, EDS). In terms of surface coordination chemistry, it will be also possible to evaluate the implementation and hence the performance of different consolidants with respect to their penetration depth and the development of consolidating compounds inside the stone mass.

- PHASE B: after the laboratory phase, the DRMS will be transported on-site. Two large blocks of selenite, located in the west magazines area have been selected for the testing.

4.2.3.4 Recording of the local weather and environmental data

Knossos: in Knossos, erosion problems are clearly evident. The meteorological station data in Knossos are useful to estimate the atmospheric hazards. The meteorological station will provide time-series data on external temperature, humidity, wind speed and direction, solar radiation and UV Index, pressure and rainfall. All the provided data can be correlated with the corresponding satellite data distributions of the area, for calibration and correction purposes.

The rainfall time-series will clearly indicate rain duration and severity patterns in the area.

The wind speed and direction measurements–are important for two reasons. First, they will be used for weather pattern predictions affecting particulate matter and pollutants transport in the area. Second, they will assist on a yearly basis in estimating how the wind-speed gusts, especially those related with strong south winds, severely influence the local vegetation (e.g. large trees surrounding Knossos) and they will help in estimating the vegetation stress mapping, that will be performed using satellite imaging. The ground based data from the meteorological stations will assist in correcting the satellite data distribution, too.

As far as the monument materials are concerned, the information provided by the meteorological station on seasonal temperature, humidity and temporal variation between day and night will represent invaluable information for the preservation actions to be planned by the regional stakeholders.

4.2.3.5 Definition and Monitoring of the Microclimate

Koules & Knossos: A local microclimate monitoring campaign will be carried on in the close proximity of the fortress to investigate the possible correlation between microclimate issues and material degradation due to the local climate change phenomena or extreme events, i.e. heavy rain events, which occurred during the last few years.
A local microclimate monitoring campaign will be carried on in selected areas of the Knossos test-bed, too, with the aim of assessing the local microclimate conditions as possible cause of the materials degradation.

To this aim, the main local microclimate parameters (i.e. dry bulb temperature [°C], relative humidity [%], surface temperature[°C], air quality in terms of CO_2, VOC, CO [ppm], wind speed [m/s] and direction [°], etc.) will be collected. Such local microclimate monitoring will be carried on both from the ground (i.e. at pedestrian level) and from the air, for instance by means of drones, in order to be able to assess the materials surface degradation level at different heights. For Koules, the acquired data will be statistically analysed and correlated to weather data provided by complete weather stations positioned in the surrounding area. After the preliminary experimental campaign, a calibrated microclimate model of the area will be elaborated to investigate the impacts of local climate events on the materials in terms of air and surface temperature, relative humidity, and air quality.

Similarly to the previous case study,in Knossos the main local microclimate parameters will be collected at different heights, i.e. from ground and from air, if possible. The acquired data will be post-processed and correlated to weather data provided by complete weather stations positioned in the surrounding area.

The final aim is to understand the possible microclimate causes of degradation and consequently to propose solutions.

4.2.3.6 Monitoring of sea-waves and coastal flooding at the Venetian sea-fortress of Koules

This approach refers only to the sea-fortress of Koules, as HERACLES monument, but it can be generalised for any other coastal monument affected by the sea impact.

The impact of the sea waves causes a number of issues, mainly structural, to the monument. The installation of meteorological station and wave gauges positioned in the area will record the phenomena and will give input on their evolution and possible prevention actions. Specifically, the sea front areas of the fortress is subjected to the wave impact and sea-flooding events, affecting the structural integrity of the monument. These effects will be monitored by means of in-situ investigation using two wave gauges positioned in two locations and the input of the meteorological stations. Numerical modelling is also considered. The suggested in-situ protocol related to sea wave evaluation, includes the use of low cost, portable wave gauges positioned in two points. The scope is to correlate the wave height measured data with those measured with the meteorological stations, in order to cross correlate them with the modeling outputs. This activity aims to validate and improve the calibration of wave models, in order to provide more accurate data for the climatic change risk assessment. The instruments will supply measurements continuously. Moreover, sea levels and wave height can be correlated to the material degradation, too.

The impact of the sea, together with extreme weather phenomena, such as heavy rains and winds, affects directly the building materials of the monument (dissolution and alveolar disaggregation of the sandstones) as well as its surrounding area (i.e. damages deriving from the displacement of breakwater structures due to intense wave impact). Therefore, wave action previsions can give valuable information for mitigation actions towards the reducing of sea wave intensity, and sea level rise by implementing coastal protection solutions.

For the above areas of interest the impact of waves can be estimated by the meteorological station data and the wave gauges displaced in the area close the monument. A third-generation regional wave model will be used to evaluate the most significant wave parameters for the surrounding area of the specific site. The model results will be correlated with those provided by the wave gauges for rectification purposes. More information, are given in the sub-section 5.2.1.1.3 of the deliverable D.3.1.

4.2.4 Systematic in-situ diagnostic protocol for quick assessment and monitoring of the weathering state and its progress on the areas of interest for Heraklion

In the previous sections all the criticalities affecting the two monuments in Crete, the Venetian sea fortress of Koules and the Archaeological site of Knossos, have been briefly described and the methodologies suggested for their quick assessment were discussed.

Figure 31 shows a schematic representation of the in-situ diagnostic protocol for quick assessment of the weathering state of sea-fortress of Koules in Heraklion, aiming to outline in a clear and easy way the methodology suggested for a quick screening of the preservation state, using portable instruments and in-situ sensors at the monument.

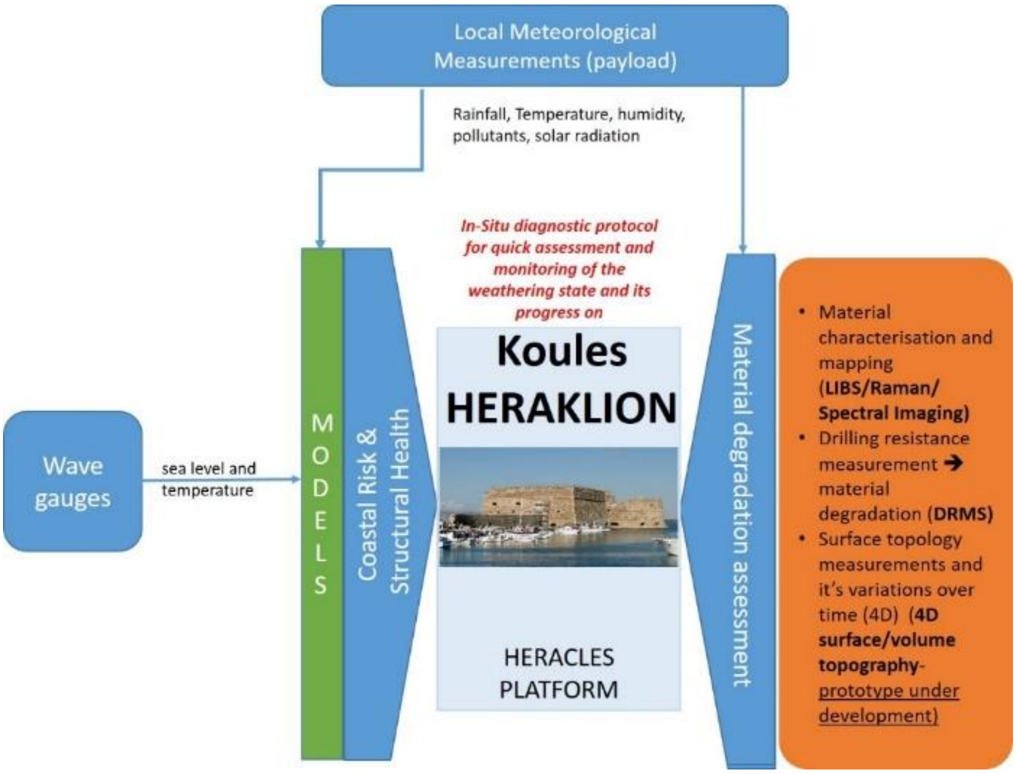


Figure 31: Schematic protocol flow view for Heraklion, sea-fortress of Koules

Similarly, Figure 32 gives a schematic representation of the in-situ diagnostic protocol for quick assessment of the weathering state of the archaeological site of Knossos in Heraklion, aiming to outline in a clear and easy way the methodology suggested for a quick screening of the preservation state using portable instruments and in-situ sensors at the monument.

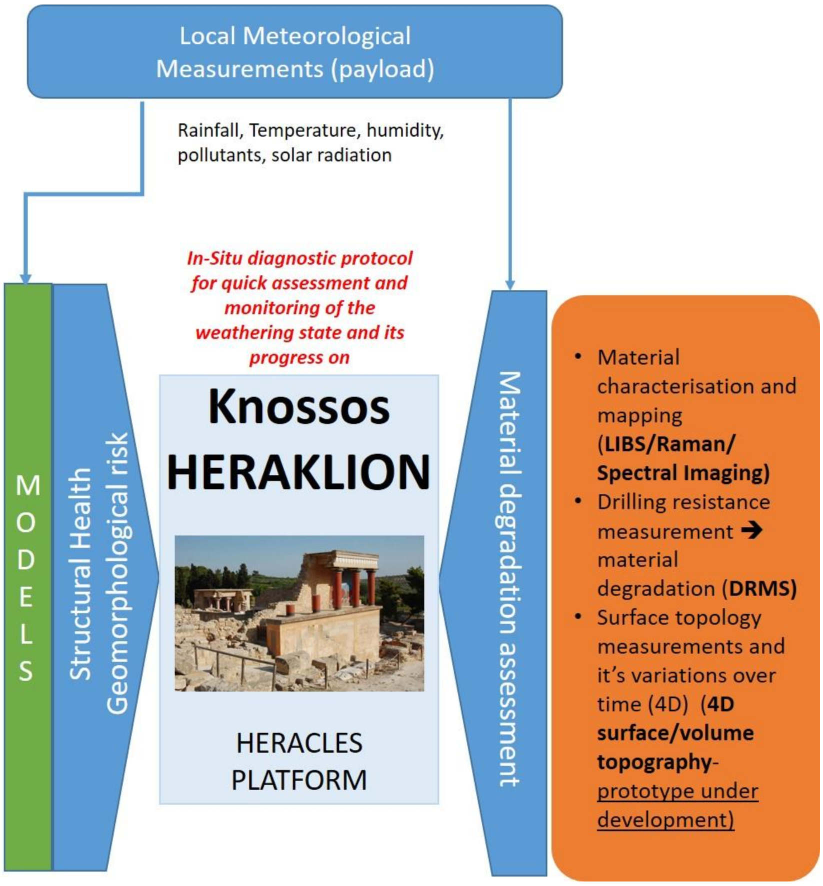


Figure 32: Schematic protocol flow view for Heraklion, archaeological site of Knossos

Both of them also highlight how the in-situ meteorological measurements will be integrated with the other in-situ investigations related to material analysis. Local meteorological data will be correlated with material weathering status. The different investigation present in the protocols can be correlated with the meteorological conditions which trigger the degradation of the materials. On this basis, a possible climatic pattern relating higher risk with material degradation, can be identified.

5 Conclusions

The scope of the present document is to provide protocols related to the in-situ diagnostic and analysis strategies to be adopted in HERACLES with emphasis to the quick assessment and monitoring of the different weathering states and their evolution on the monuments of interest of the project.

To accomplish this task, all the important aspects to be considered, were critically discussed:

- End user requirements related to the HERACLES test beds and specifically those issues that will be approached using in-situ sensors and portable instruments, have been carefully examined.
- Since the Quick Assessment is the object of this deliverable, a focus on QUICK ACTIONS on the MAIN CRITICAL ISSUES affecting the different sites has been considered.
- In-situ sensors for structural survey (geophysical and pointwise), microclimate dynamic monitoring, sea-wave monitoring and portable instrumentation for material analysis, were briefly discussed. Their role in the quick assessment of the structural health, of the environmental conditions and of the weathering state and evolution of the studied test-bed is important, since they allow a screening on-site, being easily transported and/or installed on-site. It can be done permanently or during specific and planned measurement campaigns, in specific time-periods or after extreme CC events which endanger the monuments.
- Finally, suggested actions (protocol) for an effective QA assessment have been proposed and discussed.

In the HERACLES project the in-situ sensors will be used to feed the platform with localized and real-time or periodic data. These sensors in combination with the ex-situ analytical instruments will allow a holistic approach to the test-beds condition and the determination of the factors and mechanisms that contribute to their deterioration. Structural in-situ sensors will provide valuable information about the monuments integrity, while material analysis portable instruments will evaluate the condition of the materials and screen the extent of their pathologies. In addition, in-situ meteorological stations and microclimate sensors will contribute to the definition of the deterioration factors for both structural and materials problems.

Structural and material degradation issues are of primary importance for the HERACLES test-beds. A tailored protocol for each test-bed, with the indication of the suitable sensors and techniques, was provided.

The protocols include remote and close sensing in-situ techniques for the investigation of weathering state and erosion. Ex-situ diagnostic protocols useful for the monument/site overall assessment and monitoring of its weathering state are the main subject of the companion Deliverable D3.1.

Further details for remote and in-situ monitoring will be specifically provided in the deliverable D3.3.

Demonstration activities are the object of WP8, and are in large part still at an initial stage at the time of preparation of the present deliverable. Then, the protocols developed in the present deliverable, can be further assessed and improved at a later stage. More specifically, it is expected that they will be tested and eventually optimised during the demonstration phase. As well, they will be considered in the activities of WP7 regarding "Risk management, Maintenance, Restoration, Adaptation Policies and procedures for end users".

Moreover, they will be critically considered in the phase related to the development of new materials for restoration and remediation purposes (i.e. WP4 activities).

Above all, it has to be underlined that the protocols developed in the present deliverable D3.2, are expected not only to address the needs of the four HERACLES tests-beds, but also to reach a level of maturity which will meet the requirements of a GLOCAL (from LOCAL to GLOBAL) dimension as regards the quick assessment and monitoring of structural conditions and weathering issues of different monuments, against the Climate Change effects.

6 Selected Sources and documents

1. R. Ditommaso F. C. Ponzo G. Auletta, “Damage detection on framed structures: modal curvature evaluation using Stockwell Transform under seismic excitation”, Vol.14, No.2, EARTHQUAKE ENGINEERING AND ENGINEERING VIBRATION (2015) 14: 265-274, DOI: 10.1007/s11803-015-0022-5
2. Grimaz S., Malisan P. and Torres J.; 2015a: “VISUS methodology: a quick assessment for defining safety upgrading strategies of school facilities”. Planet@Risk, 3, 126-136.
3. Daniels D. J., “Ground Penetrating Radar, IET Radar, Sonar, Navigation and Avionics” Series 15, 2nd edition, London: IET, 2004
4. Leone G. and Soldovieri F., “Analysis of the distorted born approximation for subsurface reconstruction: Truncation and uncertainties effect,” IEEE Trans. Geosci. Remote Sens., vol. 41 (1), pp.66–74, Jan. 2003.
5. Solimene, R., Catapano, I., Gennarelli, G., Cuccaro, A., Dell'Aversano, A., Soldovieri, F., "SAR Imaging Algorithms and Some Unconventional Applications: A unified mathematical overview," Signal Processing Magazine, IEEE , vol.31(4), pp.90-98, July 2014.
6. I. Catapano, A. Affinito, G. Gennarelli, A. di Maio, A. Loperte, F. Soldovieri, “Full three-dimensional imaging via ground penetrating radar: assessment in controlled conditions and on field for archaeological prospecting, Applied Physics A, vol. 115 (4), pp. 1415-1422, 2014.
7. H. Liang. “Advances in multispectral and hyperspectral imaging for archaeology and art conservation”. Applied Physics A, 106(2):309{323, 2011.
8. C. Fischer and I. Kakoulli. “Multispectral and hyperspectral imaging technologies in conservation: current research and potential applications”. Studies in conservation, 51(1):3{16, 2006.
9. V. Papadakis, A. Loukaiti, and P. Pouli. “A spectral imaging methodology for determining on-line the optimum cleaning level of stonework”. Journal of Cultural Heritage, 11(3):325{328, 2010.
10. Baker J., Kantarelou V., Karydas A.G., Jones R.E., Siozos P., Anglos D., Derham B., “The height of Denier Tournois minting in Greece (1289-1313) according to new archaeometric data”, Annu. Br. Sch. Athens 2017 In press. DOI: 10.1017/S0068245416000113
11. Papliaka Z.E., Philippidis A., Siozos P., Vakondiou M., Melessanaki K., Anglos D., “A multi-technique approach, based on mobile/portable laser instruments, for the in-situ pigment characterization of stone sculptures on the island of Crete dating from Venetian and Ottoman period”, Herit. Sci., Heritage Science 2016 4(15). DOI: 10.1186/s40494-016-0085-2.
12. Westlake P., Siozos P., Philippidis A., Apostolaki C., Derham B., Terlixi A., Perdikatsis V., Jones R., Anglos D., “Studying pigments on painted plaster in Minoan, Roman and Early Byzantine Crete. A multi-analytical technique approach”. Anal. Bioanal. Chemistry, 2012 402 1413–1432.

13. D. G. Papazoglou, V. Papadakis, and D. Anglos, J. Anal. At. Spectrom. **19**, 483 (2004).
14. V. M. Papadakis, A. Stassinopoulos, D. Anglos, S. H. Anastasiadis, E. P. Giannelis, and D. G. Papazoglou, J. Opt. Soc. Am. B-Optical Phys. **24**, 31 (2007).
15. Y. Arieli, S. Epshtein, I. Yakubov, Y. Weitzman, G. Locketz, and A. Harris, Opt. Express **22**, 15632 (2014).
16. Pamplona M., Cooker M., Snethlage R., Luís Aires B., "Drilling resistance: overview and outlook", Journal of the German Society of Geosciences, Volume 158, Number 3 2007, pp. 665-679 (15).