HERACLES

HEritage Resilience Against CLimate Events on Site

Deliverable D8.1
Description of the site and detailed end-users requirements and definition of the logistics for the monitoring system at HERAKLION

Version: V1.0

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1. Executive Summary

Deliverable D8.1 “Description of the site and detailed end-users requirements and definition of the logistics for the monitoring system at HERAKLION”, refers to the systematic approach of the HERACLES project dealing with the guidelines/procedures for the monitoring, diagnosis and analysis of the monuments/ assets on the basis of their structural issues, materials and weathering states.

The document defines the carrying out of activities according to the following scheme: Define a demonstration planning; Setup experimentation; Conduct experimentation at component/system level.

The protocols outlined in document D3.1 have been developed for the two test-beds in Heraklion for the particular requirements and challenges of HERACLES (Palace of Knossos and the Venetian Fortress - Koules)

The document is organized in separate Sections outlined in the following Introduction (Section 2). The Section 3 presents the overall scheduling of the Heraklion test-beds.

The Sections 4 (#1: Palace of Knossos) and 5 (#2: the Venetian Fortress-Koules) describe the test-bed sites, providing the description of the sites, reminding end-users requirements, degradation problems and risks (already extensively described in D1.2), the position and finally the logistics.

The test-bed activities are scheduled in 3 phases:

1. Sensors Installation: where the logistics of the test-beds is defined and consequently then sensors, wires and connection organisation.
2. Data Collection: where the data from the existing sensors, but also from open data (climate), ordered data (satellite) and on material samples, are collected;
3. Evaluation: where the collected data are analysed and evaluated, giving an output from the different evaluation batches (data model, material analysis, etc) to the platform or to the users.

In the Section 4 and 5 the planning and the demonstration phases are also described. For each test-bed and for each sensor, a description is provided:

- the sensing systems (from the satellite and wide area surveillance up to the in-situ sensors) and several laboratory material characterization methodologies and techniques, which are expected to give relevant information for defining and assessing the weathering state and the degradation processes of the investigated materials.
- the measured parameters;
- the information needed for the installation steps;
- the information needed for the monitoring phases;
- the partners in charge for the installation, data acquisition, data validation activities and in charge to elaborate the model, starting from the collected data.

The already defined protocols (from deliverable D3.1) will be verified during the successive activities of the project (especially the following demonstration phases in WP8), with the aim to assess their efficiency and effectiveness.

The Section 6 explains the modelling systems implemented on the test-beds.

Section 7 presents our conclusions and further developments.

Section 8 lists the literature documents used for D8.2.

2. Introduction

Due to the complexity and the multidisciplinary nature of the problems faced in HERACLES project, info, researches and expertise from different fields are required, such as: user needs assessing, climate events forecasting and modelling, sensing and ICT systems availability and materials weathering state assessment. HERACLES team has been built to cover all these specific requirements according to the very deep skills and expertises of the individual partners.

Some of the general objectives of the HERACLES project are:

- **Objective #3**: Elaboration and integration of forecast climate models and experimental data into the platform as starting-point for the local CH-specific analysis, where implementing the solutions developed during Objective #2.
- **Objective #6**. Demonstration of the effectiveness of HERACLES at **the challenging tests-beds**: objects of the present deliverable will be in Heraklion, the Palce of Knosson (in the tentative list of material UNESCO Heritage) and the Venetian Fortress (*Rocca a Mare*, Koules). In addition, to the historical value, these sites are affected by different kinds of hazards due to climate change effects. They can be generalized to several other areas in Europe and worldwide.

The HERACLES strategic objectives listed above will be pursued by the achievement of **specific technical objectives** to be reached during the projects lifetime, in particular:

1. Improved methodologies and analysis taking into account climatic change impact (at European and proper regional downscaling) for weather forecasting (with emphasis on extreme events frequency of occurrence and intensity) and identification of the relationship between meteo-climatic parameters and environmental risks for CH (in a holistic approach of a coupled air-sea-land interaction).
2. Development of a model for monitoring and mitigating these risks.
3. Design and implementation of an integrated approach, based on remote sensing, in-situ and ex-situ analysis with a minimal or not invasive techniques, able to couple structural long term monitoring and quick damage assessment of the site and of the single structure.
4. Development of methodologies able to integrate monitoring data with structural models for a vulnerability assessment.
5. In-situ and ex-situ physical-chemical characterization of the CH assets, i.e. of the materials constituting the assets and their degradation process and causes.

All these specific technical objectives will be reached starting from the end-user requirements from which a specific monitoring system should be customized and developed.

2.1 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
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	Deliverable D3.2

2.2 Acronyms and abbreviations

2D	Bi-dimensional
3D	Three-dimensional
4D	Fourth-dimensional
AOT	Aerosol Optical Thickness
API	Application Programming Interface
APM	Anthropogenic Pressure Modelling
AR	Assessment Report
CC	Climate Change
CDR	Climate Data Records
CH	Cultural Heritage
CIRIAF	Centro Interuniversitario di Ricerca sull'Inquinamento da Agenti Fisici.
CMIP	Coupled Model Intercomparison Project Phase
CNR	Consiglio Nazionale delle Ricerche
CNR- IREA	Consiglio Nazionale delle Ricerche, Istituto per il Rilevamento Elettromagnetico dell'Ambiente
CNR- ISMN	Consiglio Nazionale delle Ricerche – Istituto per lo Studio dei Materiali Nanostrutturati
COSMO-SkyMed	COnstellation of small Satellites for Mediterranean basin Observation

CSF	Community Structural Funds
DEM	Digital Elevation Model
DInSAR	Differential SAR Interferometry technology
DRMS	Drilling Resistance Measurements System
DSM	Digital Surface Model
EDS	Energy-Dispersive X-ray Spectroscopy
EEPROM	Electrically Erasable Programmable Read-Only
e-geos	electronics-Global Earth Observation Services
FIB	Focused Ion Beam
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
GPR	Ground-Penetrating Radar
GUI	Graphical User Interface
HR	High Resolution
ICOMOS	International Council on Monuments and Sites
ICT	Information and Communications Technology
IFSAR	Interferometric synthetic aperture radar, abbreviated in SAR (or deprecated IFSAR)
IPCC	Intergovernmental Panel for Climate Change
IR	InfraRed
ISCS	International Scientific Committee for Stone
KB	Knowledge Base
LED	
LIBS	Laser Induced Breakdown Spectroscopy
LOD1	Level Of Detail 1
LOS	Line Of Sight
MEPF o MPEF	Multi Excitation Photon Fluorescence
MSI	MultiSpectral Imaging
MTOW	Max Take-Off Weight
NOx	Nitrogen Oxides
NSRF	National Strategic Reference Framework
OGC	Open Geospatial Consortium
OWL	Web Ontology Language
PM	Particulate Matter
PS	Persistent Scatterer
PSP	Persistent Scatterer Interferometry
RCP	Representative Concentration Pathways
RDF	Resource Description Framework
RGB	Red, Green and Blue (colour code)
SAR	Synthetic Aperture Radar Sensors
SHG and THG	Second and Third Harmonic Generation
SEM	Scanning Electron Microscopy
SEM-FIB (EDS)	Scanning Electron Microscopy with Energy Dispersive Spectrometer
SHD	Salt Hydration Distress
SI	Spectral Interferometry
SPARQL	Query Language for RDF

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SRES	Surface Enhanced Raman Spectroscopy
THz	TeraHerz imaging
TLS	Terrestrial Laser Scanning
TMS	Tomographic Sar
UAV	Unmanned Aerial Vehicle
UNINOVA	Universidade NOVA de Lisboa
UniPg/UNIPG	University of Perugia
UoC/UOC	University of Crete
USB	Universal Serial Bus
UV	Ultra Violet
VNI	Visible - Near Infrared
VOC	Volatile Organic Compound
W3C	World Wide Web Consortium
WCS	Web Coverage Service
WG	World Geodetic
WLSI	White Light Scanning Interferometry
WMS	Web Map Service
WP	Work Package
WRF	Weather Research and Forecast
XML	Extensible Markup Language
XRD	X-ray Diffraction
XRF	X-Ray Fluorescence

2.3 *Scope & objectives*

This deliverable has been produced as part of Task 8.1 of WP8, which deals with Demonstrators and results analysis.

The focus of Task 8.1 is on demonstration testing and validation at Case study 1 – Heraklion.

Deliverable 8.1, starting from the end-user requirements and site detailed description (already provided in the deliverables D1.2), from the detailed description of the suitable methodologies (already provided in the deliverable D1.3) and relative protocols developed in deliverables D3.1 and D3.2, aims outlining where the sensors will be installed (focussing on logistics and construction details) and the measurements performed. In particular, more in details:

- D1.1, where guidelines and procedures for CH management have been surveyed;
- D1.2, where the end-users requirements have been traced,
- D1.3, where methodologies for climate change impact and risk and vulnerability analysis have been defined;
- D3.1 where a protocol for each monument/asset of interest in HERACLES based on structural issues and material weathering state, is defined, including natural ageing and hazards due to critical climate events and/or pollution conditions;
- D3.2 where a protocol for the quick assessment and monitoring of the structural condition and of the materials weathering state is outlined, including natural ageing and hazards due to critical climate events and/or pollution conditions.

2.4 Document organization

The 8.1 deliverable is structured around three main blocks that correspond to:

1. The description of the test-beds scenarios and the scheduling and logistics for the HERACLES project experimentation;
2. The detailed description of the site and detailed end-users requirements for the Knossos test-bed;
3. The detailed description of the site and detailed end-users requirements for the Koules test-bed.

The Section 1 is giving an overview of the experimentation schedule according to the end to end scenarios refined from the WP1 and D3.1 needs definition and refinements. It presents the different activities to be set up for a) installation of sensors or techniques, b) the different duration and constraints for collection of data and samples and then c) the validation process schedule and duration for the various HERACLES analysis, monitoring, simulation, maintenance and remediation procedures.

The [section 3], Test-bed site #1-Knossos Palace, is detailing the first Heraklion test-bed site from risks affecting the site and driving the end-users requirements to the logistical requirements for the Knossos demonstration test-bed.

The parallel section [section 4] Test-bed site #2-Venetian Fortress "Rocca a Mare", Koules, is detailing the second Heraklion test-bed site, from the risks affecting the site to the logistical requirements for the Koules demonstration test-bed.

For the logistics requirements, each type of monitoring techniques is described according to:

1- geometrical monitoring techniques;
2- environmental monitoring techniques;
3- structural monitoring techniques.

The complete and foreseen study on both the test-bed sites includes also the study of the constituting materials and their weathering state, carried on using in-situ, as well as ex-situ techniques, that are not typically considered as sensing techniques, and cannot produce immediate or in continuum data: for this reason they are not described in the demonstration scheduling, but in Table 8.

The conclusive part is about the experimentation planning for Heraklion test-beds and sets up the perspectives and the further experimentation steps, linked to the inputs for the D8.3.

2.5 Relation with other deliverables

D1.1 (CNR): Survey of Procedures for the CH management, Report – M6

D1.2 (CNR): Definition of the end-users requirements with emphasis on HERACLES test-beds, Report – M9

D1.3 (FORTH): Definition of methodologies for climate change impact evaluation and risk and vulnerability analysis, Report – M9

D1.4 (FORTH): Survey of the state of art of the technologies of interest for HERACLES, Report-M12

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

D3.1 (FORTH): 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 Report – M12
D3.2 (FORTH): 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, Report – M12
D3.3 (e-geos): Intermediate analysis of the experimental and theoretical aspects underlying the state-of-the-art application of the satellite and airborne sensing technologies, Report- M13
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
D5.1 (FRAU-IOSB): Decentralized system architecture, first draft, Report- M10
D5.3 (FRAU-IOSB): Sensor selection and network management, first draft, Report-M12
D5.6 (FRAU-IOSB): Semantic data integration and knowledge base, Report- M12
D5.7 (FRAU-IOSB): Specification of high-level distributed processing services, Report -M14
D5.8 (THALES): User Interface concepts definition for the HERACLES platform, M11

3. Scheduling

Due to the heterogeneous nature of the sensors involved in this monitoring campaign, it is not possible to concentrate the demonstration in just an event; for this reason a common agenda has been shared on how this activity will be performed and the agenda will be adapted according to the activities needs.

The common activities that are and will be performed are:

- Pre-demo survey
- Actual demonstration
- Post-demo remark.

Details per sensor/model needs are reported in the following sections. In Table 1 and Table 2 the planned activities and the related agreed time-frame are shown for the measuring systems and the material characterization at Knossos Palace and at Koules Fortress, respectively.

Demonstration involving not easily replicable activities (e.g.: use of drones, Laser scanner, etc.) will provide a set of collected data to demonstrate the real fulfilment of the phase.

Table 1 – Measuring Systems Scheduling at testbed#1 - Knossos

TEST BED #1 - KNOSSOS PALACE

2016								2017												2018												2019			
M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36
May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr

			Mesuring Systems	Responsability	Measured parameters	Location	
Measuring systems (sensors)	1.1	Geometrical	Spaceborne radar COSMO-SKYMED	e-GEOS/CNR	Displacements	Sparse natural points exhibiting persistent scattering response in the test bed area, including façades and roofs of the archeological assets.	
	1.2		UAV drone geometrical survey	e-GEOS	Geometry of the structures		
	1.3		Terrestrial Laser Scanner	e-GEOS	Geometry of the structures		
	2.1a	Environmental	Weather monitoring: local station NETWORK	FORTH-IACM	Wind Speed and Direction/Temperature/Humidity/Rainfall/Solar Radiation/UV Index	Location: "Knossos Support Area", Lat.: 35.298904°, Long.: 25.163150°, Alt.: 91 meters	
	2.1b		Weather monitoring: public station NETWORK	SISTEMA	Wind Speed and Direction/Temperature/Rainfal	Knossos, Lat: 35.30075 Lon: 25.16378 Alt: 115 m	
	2.2		Drone measurement of climatic parameters (portable)	UNIPG/CIRIAF	Atmospheric pressure/Relative humidity/Air temperature/Lighting/Global shortwave radiation/CO2 and CO concentration/Air Contaminants concentration	The monitoring path, both from the sky and at pedestrian level, will take place all around the Palace of Knossos' areas of interest within the project (1,2,3,4,5)	
	2.3a		Temperature- Relative Humidity sensor data logging system (portable)	UNIPG/CIRIAF	Air temperature/ Relative humidity	Shaded outdoor location within the case study area	
	2.3b		Temperature- Relative Humidity sensor data logging system (fixed)	FORTH-IESL	Air temperature/ Relative humidity	1. East Wing - "Grand Staircase" - "Hall of Colonnades" 2. "Three Partite Shrine" - "Pillar Crypt"	8 June
	2.4		Infrared Thermography	UNIPG/CIRIAF	Monitoring and detection of specific inner structural diseases and non-homogeneity	The monitoring path will take place all around the Palace of Knossos' areas of interest within the project (1,2,3,4,5)	
	2.5		Multispectral remote sensors	SISTEMA	LST, RH, Air temperature, AOT, SO2, NO2	Knossos, Lat: 35.30075 Lon: 25.16378 Alt: 115 m	
Material Characterization Methodologies	3.1	Material - in situ methodologies	Portable Raman spectroscopy system	FORTH-IESL	Identification of various types of materials, both inorganic and organic	Areas/spots of interest within the project (similar to the sampling areas)	*Samples: HKNI-0101, HKNII-0601, HKNII-0701, HKNII-0401, HKNIII-0801, HKNIV-0201, HKNIV-0301, HKNVI-01A01, HKNVI-01B01, HKNVI-01C01 (The samples were taken for Laboratory analysis to built database for LIBS-Raman)*
	3.2		Portable LIBS	FORTH-IESL	Identification of the elemental composition of materials	Areas/spots of interest within the project (similar to the sampling areas)	
	3.3		Portable Multispectral Imaging system	FORTH-IESL	The stratigraphy of a multi-layered object/surface	East Wing - "Hall of Colonnades": three different areas	8 June
	3.4		4D Surface/ Volume Topography portable prototype	FORTH-IESL	The topology of a surface and its variations over time (4D)	Areas/spots of interest within the project (similar to the sampling areas)	*Cannot yet be detemined, system under development*
	3.5		Drilling Resistance Measurements System (DRMS)	UoC	Penetration force, actual drill position, rotational speed, penetration rate	Gypsum blocks from location 1	

1 - West Magazines [25:9:46,14097E – 35:17:53,4148N]
2 - Tripartite Shrine [25:9:47,02176E – 35:17:52,48463N]
3 - East Wing [25:9:49,06573E – 35:17:51,98847N]
4 - South House [25:9:45,22669E – 35:17:51,18971N]
5 - Giant Pithoi [25:9:49,65482E – 35:17:53,2512N]

Installation
Data collection
One day measurement - No long-term installation required
Data analysis
Sample collection
Ex-situ / Laboratory analysis

Table 2 – Measuring Systems Scheduling at testbed#2 – Koules

TEST BED #2 - VENETIAN FORTRESS 'KOULES'

2016								2017												2018												2019			
M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36
May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr

			Mesuring Systems	Responsability	Measured parameters	Location	
Measuring systems (sensors)	1.1	Geometrical	Spaceborn radar COSMO -SKYMED	e-GEOS/CNR	Displacements.	Sparse natural points exhibiting persistent scattering response from the façades and roof of the Fortress.	
	1.2		UAV/Drone geometrical survey	e-GEOS	Geometry of the structure	S+H7everal areas of the Fortress	
	2.1a	Environmental	Weather monitoring: local station NETWORK	FORTH-IACM	Wind Speed and Direction/Temperature/Humidity/Rainfall/Barometric Pressure/Solar Radiation/UV Index	Location: "Terrace of Koules Monument", Lat.: 35.344482°, Long.: 25.136944°, Alt.: 10,3 meters	
	2.1b		Weather monitoring: public station NETWORK	SISTEMA	Wind Speed and Direction/Temperature/Humidity/Rainfall/	Location: "Heraklion city", Lat.: 35.344482°, Long.: 25.136944°, Alt.: 10,3 meters	
	2.2		Oceanographic sensors	FORTH-IACM	Water level and sea temperature	Two points: 1. ~ 3 m depth Approximately 35°20'41.84"N 25° 8'11.42"E 2. ~10m depth Approximately 35°20'42.79"N 25° 8'10.14"E	
	2.3		Drone measurement of climatic parameters (portable)	UNIPG/CIRIAF	Atmospheric pressure/Relative humidity/Air temperature/Lighting/Global shortwave radiation/CO2 and CO concentration/Air Contaminants concentration	The monitoring path, both from the sky and at pedestrian level, will take place all around the walls of the Venetian fortress	
	2.4a		Temperature- Relative Humidity sensor data logging system (portable)	UNIPG/CIRIAF	Air temperature/ Relative humidity	Shaded outdoor location within the case study area	
	2.4b		Temperature- Relative Humidity sensor data logging system (fixed)	FORTH-IESL	Air temperature/ Relative humidity	1. Room 11-12 (Room of sculptures) 2. Room 24 (Sperone)	9 June
	2.5		Infrared Thermography	UNIPG/CIRIAF	Monitoring and detection of specific inner structural diseases and non-homogeneity	The monitoring path will take place all around the Venetian fortress' areas of interest within the project	
	2.6		Multispectral remote sensors	SISTEMA	LST, RH, Air temperature, AOT, SO2, NO2	Location: "Heraklion city", Lat.: 35.344482°, Long.: 25.136944°, Alt.: 10,3 meters	
Material Characterization Methodologies	3.1	Material - in situ methodologies	Portable Raman spectroscopy system	FORTH-IESL	Identification of various types of materials, both inorganic and organic	Areas/spots of interest within the project (similar to the sampling areas)	*Samples: HKI-0201, HKII-0301, HKII-0401, HKII-1101, HKIII-0101, HKIV-0201 (The samples were taken for Laboratory analysis to built database for LIBS-Raman)*
	3.2		Portable LIBS	FORTH-IESL	Identification of the elemental composition of materials	Areas/spots of interest within the project (similar to the sampling areas)	
	3.3		Portable Multispectral Imaging system	FORTH-IESL	The stratigraphy of a multi-layered object/surface	Room 13 - "Multipurpose Hall", South West wall – Ground floor: three different areas	9 June
	3.4		4D Surface/ Volume Topography portable prototype	FORTH-IESL	The topology of a surface and its variations over time (4D)	Areas/spots of interest within the project (similar to the sampling areas)	*Cannot yet be detemined, system under development*
	3.5		Drilling Resistance Measurements System (DRMS)	UoC	Penetration force, actual drill position, rotational speed, penetration rate	Marly limestones highly affected by salt efflorescence	

- Installation
- Data collection
- One day measurement - No long-term installation required
- Data analysis
- Sample collection
- Ex-situ / Laboratory analysis

4. Test bed site #1 – Palace of Knossos

4.1 Description of the site

The Minoan **Palace of Knossos** bears **unique testimony to the Minoan civilization,** which was arguably considered as the **first centrally organized civilization to flourish in Europe** and amongst the **first civilizations worldwide**. It is also unique because of its continuous habitation from the Neolithic (7000-3000 B.C.) to the Mycenaean Age, while the city of Knossos continued to be an important city-state down to the Hellenistic era, the period of the Roman Empire and the early Byzantine period.

The first palace was built circa 1900 BC. From the few parts of it that survive ("Magazine of the Giant Pithoi"*, etc.*), it seems that its basic layout was set out in sectors around the great "Central Court". The first palace was destroyed around 1700 BC and the new one was erected in its place.

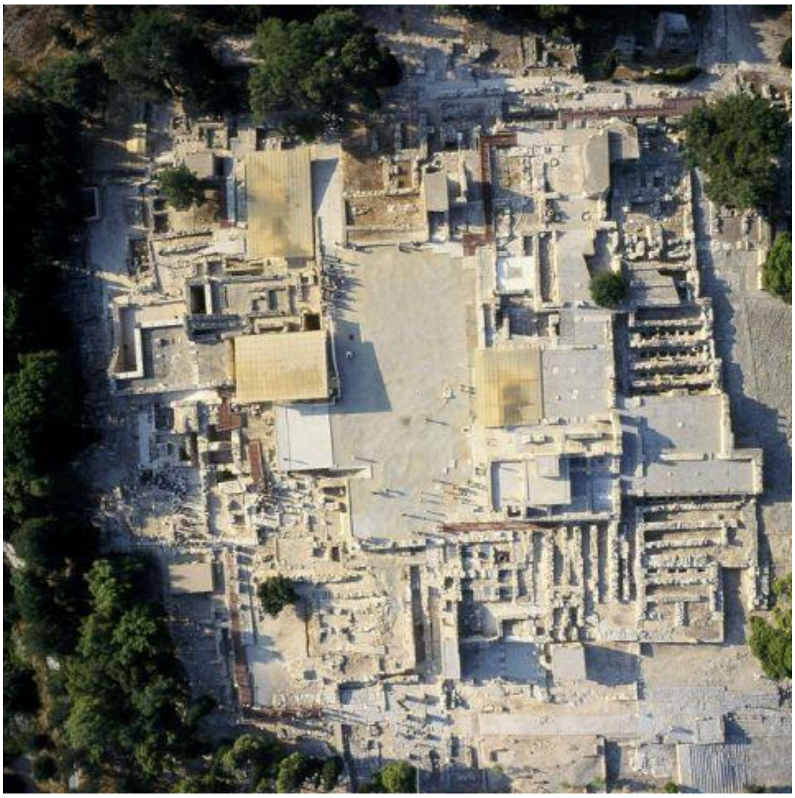

Figure 1: The Palace of Knossos.

The new palace (Figure 1) was constructed according to a specific architectural plan, similar to that of the other palaces, befitting its character and function as the centre of political, economic and religious authority. The main feature remained the Central Court, with monumental buildings rising around it, oriented N-S. There were entrances on every side, the most official being the Southwest and the North Entrance. The West Wing contained shrines, official halls and extensive storage areas, while the East Wing housed the royal apartments. There were also workshops, storerooms and other areas serving a variety of functions to north and south. They feature typical architectural elements of the period, such as polythyra (sets of rooms with multiple pier-and-door partitions on two or three sides) and lustral basins (small, rectangular, semi-underground rooms accessed by a small, L-shaped set of stairs). In the masonry, porous-stone ashlars were used. The floors were paved with slabs of green schist pointed with red plaster. The columns, beams and doorframes were made of wood. Gypsum slabs covered the walls (in the form of marble revetment) and floors, giving the spaces an air of luxury. Gypsum was also used for the bases of columns and jambs, seats, stairs, *etc.* The decoration of the rooms was supplemented by colourful plaster and frescoes.

The Palace of Knossos was the only palace to remain in use after the destruction of 1450 BC, when the Mycenaeans settled Crete. Following the final destruction of 1380 BC, large parts of it were reoccupied and remodelled.

The first excavations at Knossos were carried out in 1878 by a merchant and antiquarian from Heraklion, Minos Kalokairinos, who discovered part of the West Wing of the Palace.

Systematic excavations began in March 1900 under Sir Arthur Evans, then Curator of the Ashmolean Museum in Oxford. Two years later, the excavation of the Palace was almost complete. Over the following years there were supplementary excavations, which were completed in 1930-31 [1].

4.1.1 Previous and recent restorations

The necessity of restoring the Palace was evident from the first years of the excavation. The fragile building materials proved extremely sensitive to weathering. During the first phase of their restoration efforts, in 1905, Evans and his colleagues restricted themselves to protecting the ruins. After 1925, however, Evans attempted a reconstruction of the monument, with large-scale use of reinforced concrete. Upper storeys and architectural elements were reconstructed. The timber frames and wooden Minoan columns were made of concrete and painted. The frescoes were restored and copies placed in different parts of the Palace (Figure 2).

Today, Evans's reconstruction of the Palace of Knossos forms an integral part of the monument and its history.

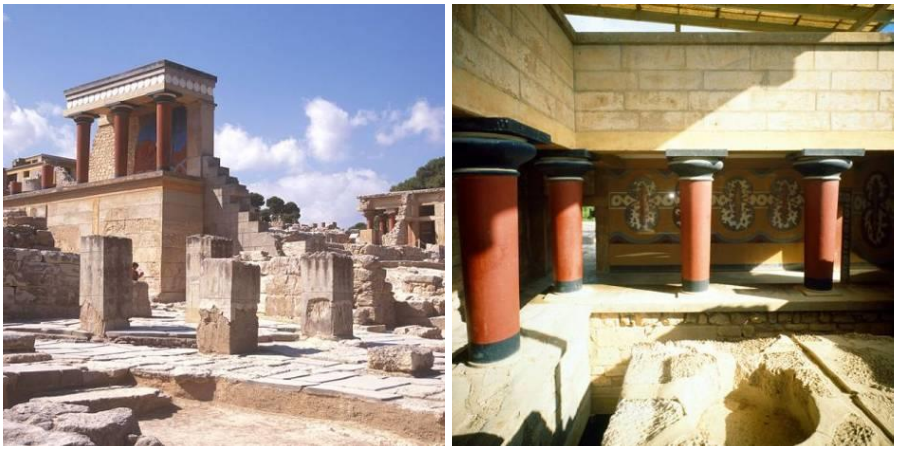

Figure 2: The Palace of Knossos after Evans's reconstruction.

After the Second World War, extensive restoration work was carried out on the Palace by the Directors of the Heraklion Archaeological Museum N. Platon and S. Alexiou. This work was limited to the conservation of the ancient masonry, the restoration of the floors and the protection of certain areas with roofing [1]. In the 1990s, under the authority of the Ministry of Culture and the Ephorate of Antiquities, a significant part of the concrete slabs of Evans' restoration of the Palace was conserved.

In the 3rd CSF (Community Structural Funds) a conservation project of the Palace was included in 2000 – 2008. A NSRF (National Strategic Reference Framework) Project begun in 2010 and finished 2015, concerning the restoration and conservation of the monument. Indeed, a complete programme of conservation and promotion of the site was launched concerning the conservation of masonry, gypsum stones and limestones, ancient coatings and plaster (Figure 3), copies of frescoes, columns and wood imitations, the Minoan pithoi, and replacement of Evans's lightly-arched roofs [2].

Figure 3: Palace of Knossos. Conservation of gypsum stones (selenite), ancient plaster of the Minoan masonry.

4.2 *End - User Detailed requirements*

The Palace of Knossos presents several degradation problems, which should be thoroughly investigated. The areas of interest that will be studied within HERACLES are shown in Figures 4 and 5. Their geographical coordinates are given in Table 3.

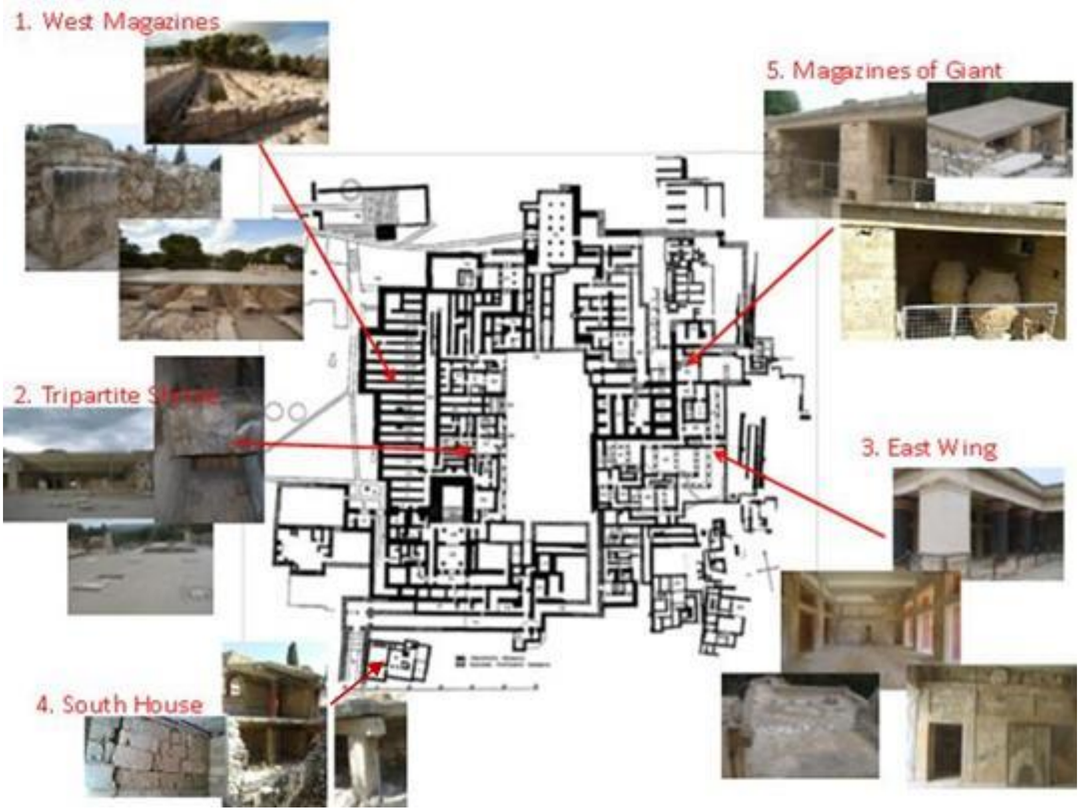

Figure 4: Knossos site map

Table 3 – Knossos Test-bed areas

Areas	Coordinates
1. "West Magazines"	25:9:46,29638E – 35:17:53,34951N - 127.3149077010364
2. "Tripartite Shrine "	25:9:46,82077E – 35:17:52,47386N – 142.52081761301514
3. "East Wing"	25:9:45,66213E – 35:17:51,84548N - 118.33789681962192
4. "South House"	25:9:45,0426 E – 35:17:50,31995N – 116.42006691798187
5. "Giant Pithoi"	25:9:49,4798 E – 35:17:53,33482N – 119.66484077448038

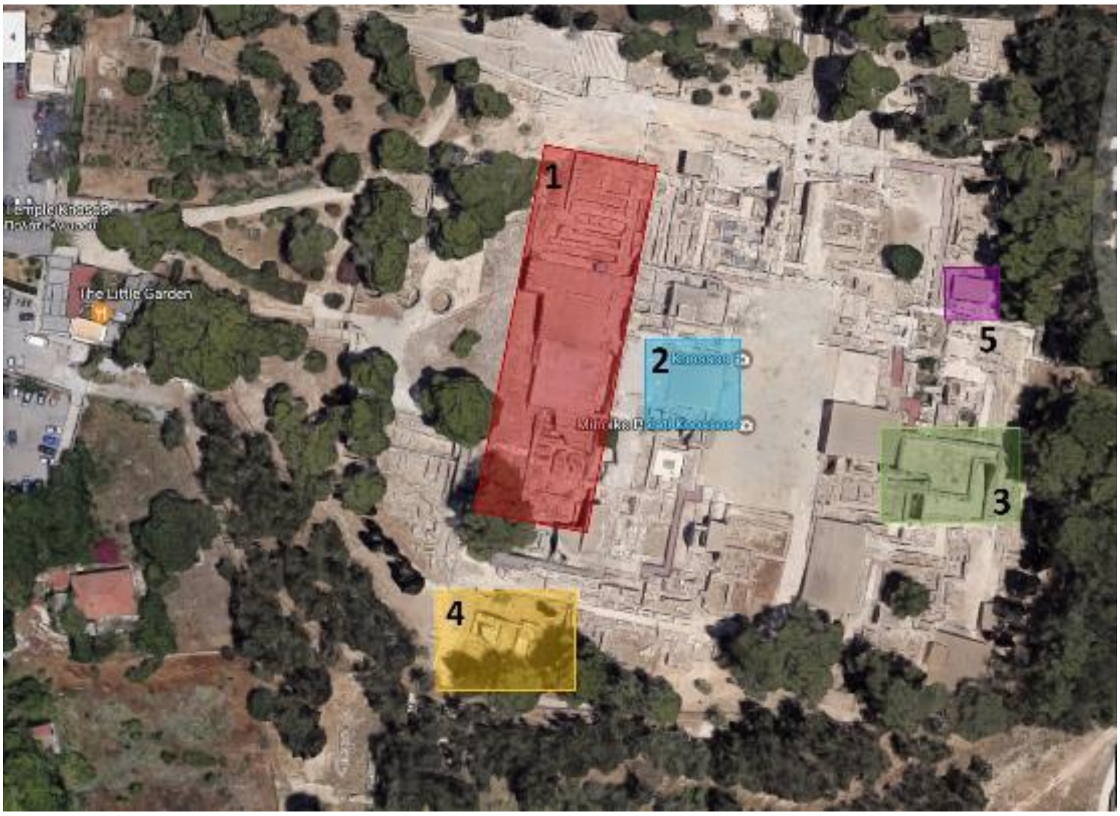

Figure 5: Knossos site map. Areas in the Palace of Knossos to be studied in HERACLES are: 1. West Magazines, 2. Tripartite Shrine, 3. East Wing, 4. South House. 5. Magazine of Giant Pithoi

1. The complex of the eighteen **"West Magazines"** in the West Wing of the Palace is the main storage area and one of the most important parts of the monument. In 1929 Evans and his colleagues decided to roof the "Magazines VIII-XII" complex with reinforced concrete, in order to preserve *in-situ* and to protect the gypsum floors, the door jambs and the pithoi. On the contrary, "Magazines III-VII and XIII-XVIII" remained unroofed, essentially free of any large-scale interventions, providing visitors with the true picture of the Palace following its excavation.
Consequently, it is a partly sheltered area, exposed in the west site of the Palace from North to South, with intense temperature variations between day and night. The area has a large number of selenite blocks, exposed to the weather [2].
2. Bordering the Central Court of the Palace of Knossos on the west is an area of great importance for its history and interpretation: the **Tripartite Shrine**, or **Central Palace Sanctuary**, with the Pillar Crypts and Temple Repositories. Today it is a sheltered area, partly with a shelter and partly with reinforced concrete, with dominant presence of moisture. Moisture penetrates through from the roof of the *Piano Nobile* (through openings at the contact points between selenite and the reinforced concrete), towards the lower rooms in the Pillar Crypts. The same minoan selenite pillars area is subjected to weathering due to the humidity, while other crusts (i.e. efflorescence) are also identified [3].
3. The **East Wing** is one of the most interesting parts of the palace because two storeys are preserved below the level of the Central Court. Today, a large part of it has been reconstructed in concrete. The restored and sheltered area presents

weathering problems concerning its materials, due to the moisture through the reinforced concrete roof. Creeping effects and crack patterns are significant.

4. In the **South House,** as reconstructed by Evans with three storeys, many of the architectural and decorative features of the Palace are repeated ("lustral basin", pillar crypt, widespread use of gypsum, *etc.*). This part of the monument presents a significant number of structural and material problems of interest to HERACLES: intense moisture, soil movement, static problems, collapses, cracks and delamination of concrete due to the movement of soil, falling of trees due to the presence of groundwater.

5. The **Magazine of Giant Pithoi** is a store room restored with reinforced concrete in the NE area of the Palace, which presents static problems and cracks (Figure 4, Figure 5) [3, 4].

4.2.1 Degradation problems and risks at Knossos Palace

4.2.1.1 The ancient and restored masonries

In most parts of the Palace the Minoan masonry was set, without foundations, on the marly limestone (kouskouras), or on Neolithic layers. The Minoan walls were built with rough and carved limestone and gypsum stones, the joints were filled with mortar of clay and they were coated with clay and lime plaster, in order to create a surface for the fresco decorations.

Figure 6: Minoan walls before and after the conservation works.

During Evans's restoration (1900-1930) and later during several conservation works (1950-1970, 1980s), after World War II, different cement mortars had been used for filler of the ancient walls. Since 2000, a complete conservation program of the Minoan walls and of the Evans's restoration has been launched. The cement mortar, used in earlier interventions, was removed in order to conserve the stone walls. The joints were cleaned, consolidated and filled with new, compatible material (Figure 6, Figure 7).

Figure 7: Minoan walls built with rough and carved limestone and gypsum stones.

Generally, the damage to the monument is associated with external factors connected to the environmental conditions of the area and to the history of the Palace, as well as to endogenous factors arising from the structure of the foundations and the characteristics of the building material themselves. Significant degradation effects for the masonries are concerned with the cracks affecting both the ancient and the restored masonry (Figure 8).

Figure 8: Cracking in restored and ancient wall.

4.2.1.2 Reinforced concrete

The necessity of restoring the Palace was evident from the first years of the excavation. The fragile building materials proved extremely sensitive to weathering. In 1905, during the first phase of their restoration efforts, Evans and his colleagues restricted themselves to protecting the ruins. After 1925, however, Evans attempted a reconstruction of the monument, with large-scale use of reinforced concrete. Upper storeys and architectural elements were reconstructed. The timber frames and wooden Minoan columns were made of concrete and painted. The frescoes were restored and copies placed in different parts of the Palace.
Today, Evans's reconstruction of the Palace of Knossos forms an integral part of the monument and its history (Figure 9).

Figure 9: Minoan walls and Evans's reconstruction.

Corrosion of the iron gilders used in Evans reconstruction, cracking, degradation, deformation of reinforced concrete elements, humidity in excess of indoor environments, represent one of the major threats to the monument. A control of the structural stability of the monument is necessary in view of possible static reinforcement interventions (Figure 10).

Figure 10: Corrosion of the iron girders used in Evans's reconstruction.

Figure 11: Corrosion of the iron reinforce used in Evans's reconstruction, degradation, deformation of reinforced concrete elements.

The rising of groundwater and the general presence of moisture affect the monument. The different origins of moisture may dictate the rehabilitation behaviour, depending on the season. The effects to be accounted for, are: Moisture affecting the jointing mortar; Absorption of moisture from the mortar and transfer inside the masonry; Moisture in excess of indoor environments; Efflorescence salts on the ancient and the restored masonry and on the restored roofs. Lack of cohesion between different materials (reinforced concrete, ancient architectural, gypsum stones) promotes infiltration of the moisture through the interface between the materials and the cracks. The same applies to the contact points between the insulating material of the roof and the masonry (Figure 11, Figure 12) [2].

Figure 12: Deformation of reinforced concrete elements of Evans's reconstruction, efflorescence salts on the ancient and the restored masonry.

4.2.1.3 Mineral Gypsum Decay and Degradation

Gypsum and limestone are the main building materials used throughout the Palace. The gypsum is an extremely sensitive material and has been severely eroded, due to its relatively high solubility in water and the subsequent deterioration of its mechanical properties [5]. Based on the International Council on Monuments and Sites (ICOMOS) International Scientific Committee for Stone (ISCS): Illustrated glossary on stone deterioration patterns [6], the decay of mineral gypsum (primary and recrystallized) can be summarized in the following categories:

- Crack & Deformation
- Detachment
- Features induced by material loss
- Discoloration & deposit

Crack and deformation

Definition: Individual fissure, clearly visible by the naked eye, resulting from separation of one part from another (shown in Figures 13 and 14).

HORIZON 2020

Figure 13: Secondary mineral gypsum from the Palace of Knossos showing a network of thin cracks.

Figure 14: Fractures: Cracks due to mechanical stress. "North Entrance", Palace of Knossos.

Detachment

Detachment process affecting laminated stones (most of sedimentary rocks, some metamorphic rocks). It corresponds to a physical separation into one or several layers following the stone laminate. The thickness and the shape of the layers are variable. The layers may be oriented in any direction with regard to the stone surface (Figure 15).

Exfoliation: detachment of multiple thin stone layers (cm scale) that are sub-parallel to the stone surface. The layers may bend, twist in a similar way as book pages (Figure 16).

Figure 15: Secondary gypsum block located at the East Wing of the Palace of Knossos.

Figure 16: Exfoliation of microcrystalline mineral gypsum slab, Palace of Knossos.

Disintegration

Disintegration: Detachment of single grains or aggregates of grains.

Crumbling: Detachment of aggregates of grains from the substrate. These aggregates are generally limited in size (less than 2 cm). This size depends on the nature of the stone and its environment. The effects are shown in Figures 17 and 18.

Figure 17: Loss of cohesion between gypsum crystal aggregates leading to crumbling. Selenite block located near the west magazines, Palace of Knossos.

Figure 18: Loss of cohesion between gypsum (selenite) crystal aggregates leading to crumbling.

Erosion

Erosion: Loss of original surface, leading to smoothed shapes.
Microkarst: Network of small interconnected depressions of millimetre to centrimetre scale, sometimes looking like hydrographical network, clearly linked to a dissolution process (Figures 19 and 20).

Figure 19: Typical formation of microkarst cavities on the surface of secondary gypsum from Knossos. Dissolution pits, grooves and runnels, collectively called karren.

Figure 20: Microkarst runnels on the surface of a building element located near the west magazines, Palace of Knossos.

Encrustation

Definition: Generally coherent accumulation of materials on the surface. Compact, hard, mineral outer layer adhering to the stone. Surface morphology and colour are usually different from those of the stone (Figures 21-24).

Figure 21: Deposition of dissolved and recrystallized gypsum on the surface of a marly limestone from the West Court, Palace of Knossos.

Figure 22: Recrystallized gypsum accumulations on the surface of selenite. Coarse crystalline gypsum (selenite) from the West Court, Palace of Knossos.

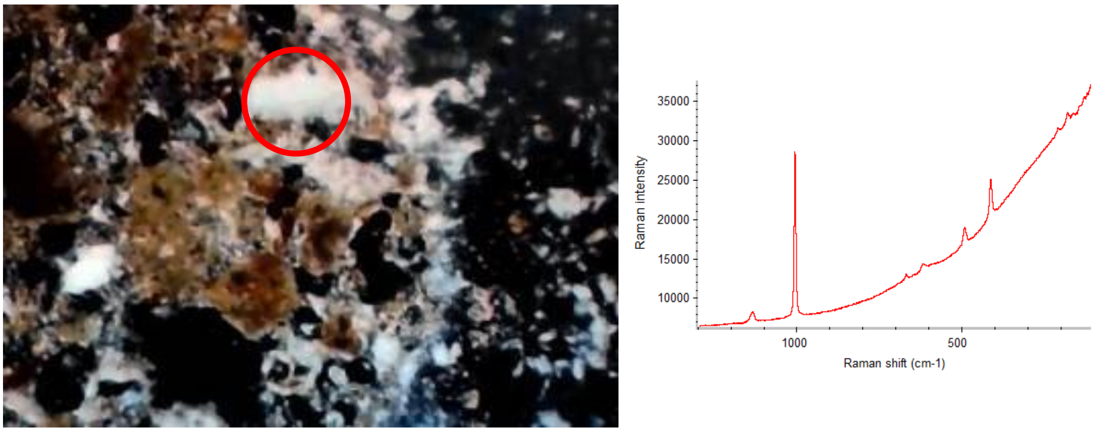

Figure 23: Encrustation thin section (x30, parallel Nicols). Source: primary gypsum. μRaman spectrum acquisition area is denoted by the red circle. Typical spectrum of gypsum ($CaSO_4x2H_2O$) other constituents of the encrustation include iron oxides and magnesium/aluminum silicate minerals.

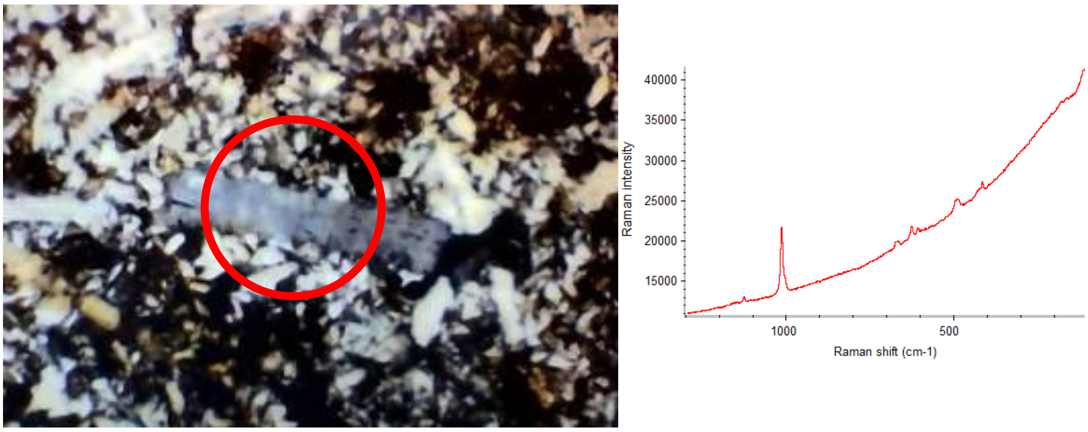

Figure 24: Encrustation thin section (x50, parallel Nicols). Source: secondary (burned) gypsum. μRaman spectrum acquisition area is denoted by the red circle. Typical spectrum of anhydrite ($CaSO_4$) acquired from the prismatic crystal. Other constituents of the encrustation include iron oxides and magnesium/aluminum silicate minerals.

Note: The examination results of the Knossian gypsum encrustations via μRaman spectroscopy presented here are part of the manuscript Grammatikakis E.I & Demadis D.K., Investigation of gypsum encrustations from the Minoan Palace of Knossos. A multianalytical approach, Journal of Cultural Herritage, Elsevier (under review).

Water – Gypsum system

The effect of humidity on the deterioration of stone monuments is one of the most extensively studied topics in conservation science. Massari in his introductory report at the 'Conference on the problems of moisture in historic buildings' states that "at the origin of almost all types of degeneration affecting individual materials is to be found one common factor: water. It is the presence of water which gives rise to the majority of the processes of decay, and water is the parent of all the organic and chemical processes which destroy monuments and works of art" [7].
Indeed, there are hardly any deterioration processes in which water is not involved. Chemical, mechanical and biological deterioration processes are all largely depended on the availability of water, which acts as an activator [8]. The majority of the decay phenomena regarding the preservation of mineral gypsum of the Palace of Knossos, are related to the presence of water. The dominant effects are the

disintegration and the erosion both leading to the loss of original material and the formation of secondary accumulations of gypsum.

In order to describe the mechanisms and results of the aforementioned phenomena, as regards to the environmental parameters of the monument the term of karst is introduced. Karst is a mass-transfer process applicable to soluble rocks with increased permeability, dominated by interconnected conduits. These structures occur mainly due to dissolution and facilitate the circulation of fluid in the downgradient direction wherein the permeability structure evolved as a consequence of dissolution by the fluid.

Within this concept, the fundamental chemical property of the material under study is solubility and even though it is constant (therefore cannot be not affected by external factors) the dissolution rate varies. The fluctuations, especially within the concept of a natural environment, are dependent upon the physical properties of the system (temperature, pressure, flow velocity) and chemical characteristics of the solvent (concentration). The dependency of gypsum dissolution upon the aforementioned parameters has been thoroughly studied both as a theoretical model as well as experimentally [9]. It has been demonstrated that the most critical determining factor with respect to the dissolution of gypsum, is connected to the qualitative and quantitative composition of the solvent.

The erosion of mineral gypsum and consequent loss of original material, especially in the cases where in contact with other architectural elements, leads to the uncontrolled channeling of the rain water.

Different effects produced on the monument by water are visible in Figures 25- 29.

Figure 25: Eroded (dissolved) gypsum slabs from the “King’s Megaron”, Palace of Knossos.

Figure 26: The dissolved gypsum elements are preserved in a lower level comparing to the cement mortar that was initially used for the fixation of the gypsum fragments, "King's Megaron", Palace of Knossos.

Figure 27: Rain water is channelled through the discontinuities to the substrate on which the gypsum elements are founded. The water flow contributes to the worsening of erosion effect and loss of material of the original parts of the monument, "King's Megaron", Palace of Knossos.

Figure 28: The results of the uncontrolled rain water drainage can be summarized as: erosion of the iron rebar, further degradation of the concrete building and ornamental elements, salt efflorescence, "Pillar Crypts", Palace of Knossos.

Figure 29: Salt efflorescence, of higher plantation growth and rain water accumulation, (after the rainfall on the 31st of October 2016), "Pillar Crypts", Palace of Knossos.

A working hypothesis based on the state of preservation of the gypsum building and of the ornamental elements of the Knossos palace as well as on the fact that the rain water concentration in the Knossos area might affect the dissolution rate of gypsum, can be considered as a basis for further research.

4.2.1.4 Pollution sources

The contribution of possible pollutant sources such as the steam electric power station, the city of Heraklion and the sea front, has to be taken into account. Furthermore, in the case of the north coast of the island of Crete on a yearly basis, the N/NW accounts for about 61%, the W for 13%, the S/SW for 18% and the others for the remaining 8% of the wind events [10] (Figures 30, 31).

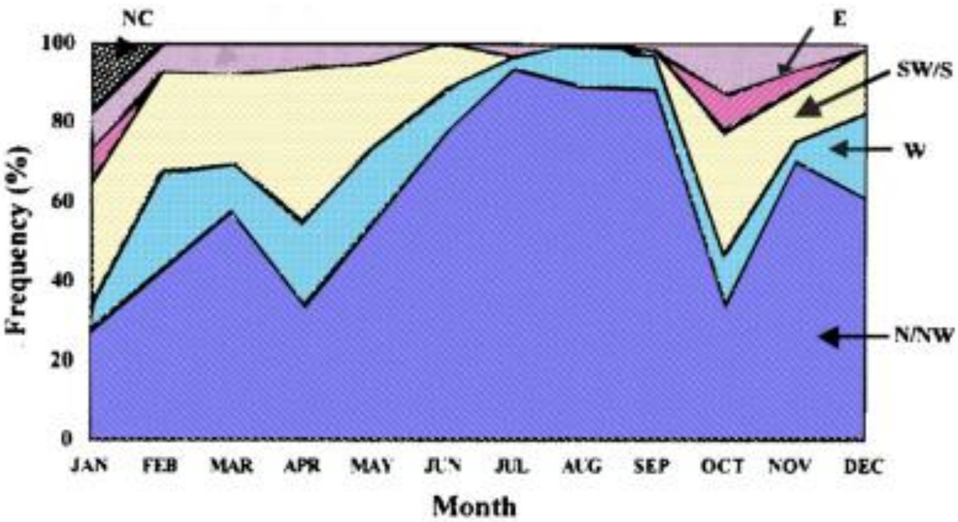

Figure 30: Contribution of each sector to the origin of the air masses after Michalopoulos et al., 1997 [10].

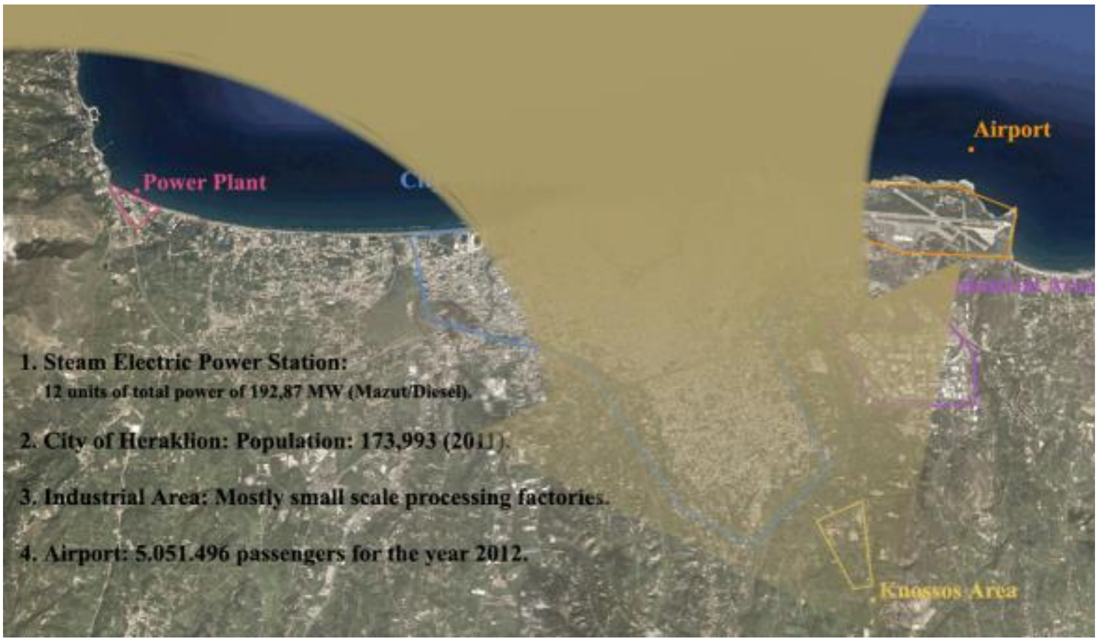

Figure 31: Air masses above Heraklion

4.3 Demonstration activity on test bed #1 - Knossos Palace

In the previous sections all the criticalities affecting the Knossos Palace have been reported. In the following picture (Figure 32) a summary of the systematic protocol proposed for the Knossos Palace is presented. It was the outcome of the work done in D3.1, where the methodologies suitable to study this CH asset have been considered. Here is reported to guide the demonstration activities.
The aim is to provide a clear and easy visualization of all the phases/actions necessary to assess the current situation of the Knossos Palace.

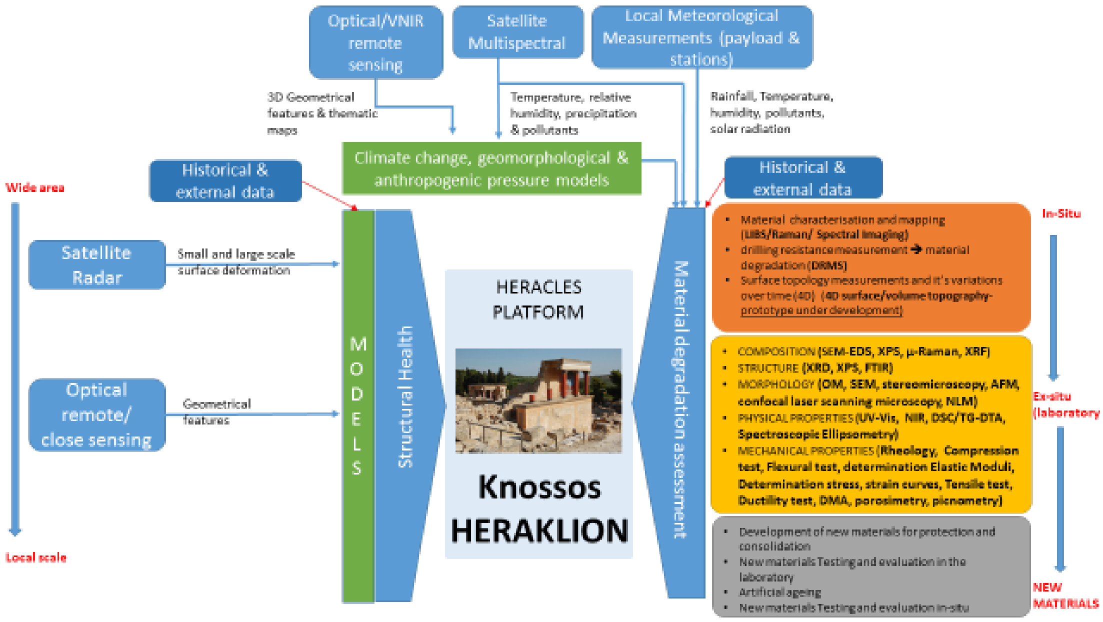

Figure 32: Systematic and complete protocol flow-view for Knossos Palace test-bed

4.3.1 Availability of historical information

1 DEM from official topographic maps (1:5000) from 1978, and 1 DEM from official topographic maps (1:20000) from 2000, are available. Also, there are aerial photos available (1945, 1998, 2009), one satellite image worldview 2 from 2009, and geological maps.
Meteo-climatic parameters since 2007 (from http://stratus.meteo.noa.gr/front; http://weather.uwyo.edu/cgi-bin/wyowx.fcgi?TYPE=metar&UNITS=M&STATION=LGIR).

4.3.2 Measuring systems to be installed/or already installed

According to the protocols developed in WP3 (D3.1 and D3.2), the test/measuring systems that will be installed or used at Knossos Palace consist of the following sensors:

1. Geometrical
   - #1.1 Spaceborne radar COSMO-SKYMED [e-GEOS/CNR]
   - #1.2 UAV-Drone geometrical survey - [e-GEOS]
   - #1.3 Terrestrial Laser Scanner - [e-GEOS]
2. Environmental

- #2.1a Weather monitoring: local station NETWORK - [FORTH-IACM]
- #2.1b Weather monitoring: public station NETWORK – [SISTEMA]
- #2.2 Drone measurement of climatic parameters (portable environmental payload device for the monitoring of local microclimate variables) - [UNIPG/CIRIAF]
- #2.3a Temperature-Relative Humidity (RH) sensor data logging system (portable) - [UNIPG/CIRIAF]
- #2.3b Temperature-Relative Humidity (RH) sensor data logging system (fixed) - [FORTH-IESL]
- #2.4 Infrared Thermography - [UNIPG/CIRIAF]
- #2.5 Multispectral remote sensors [SISTEMA]

4.3.3 Material Characterization Methodologies

The methodologies that will be used for the characterizations of Knossos Palace materials are the following:

3. Material – in-situ methodologies
    - #3.1 Portable Raman spectroscopy system - [FORTH-IESL]
    - #3.2 Portable LIBS - [FORTH-IESL]
    - #3.3 Portable Multispectral Imaging system - [FORTH-IESL]
    - #3.4 4D Surface/ Volume Topography portable prototype - [FORTH-IESL]
    - #3.5 Drilling Resistance Measurements System (DRMS) - [UoC]
4. Material – ex-situ methodologies
    - #4.1 Drilling Resistance Measurements System (DRMS) - [UoC]
    - #4.2a SEM-FIB (with EDS) - Scanning Electron Microscopy - [UNINOVA]
    - #4.2b SEM-EDS Scanning Electron Microscopy - [UoC]
    - #4.3 X-ray Diffraction (also micro) (XRD) - [UoC]
    - #4.4 Non-linear microscopy - [FORTH-IESL]
    - #4.5 Raman Spectroscopy [UoC]
    - #4.6 Fourier transform infrared spectroscopy (FTIR) [UoC]

Moreover, discussion and contacts, as well exchange of sample are on-going, among Consortium Partners in order to enlarge and complete the material characterization activity.

4.3.4 Logistics

Figure 33: Knossos maps and access view

In Figure 33 a map of Knossos and the access view are reported.

- **Access:** cars can reach the site up to the Central Court
- **Power supply:** at the "West Magazines", the "Tripartite Shrine" and the "East Wing" a three phase current is provided.
- **Internet:** No internet access (to be installed soon)
- **Safe deposition of instruments:** yes

4.3.5 Knossos Palace - Test bed sensor #1.1: Spaceborne radar COSMO-SKYMED

4.3.5.1 Description

The Knossos Palace, as the other test sites of HERACLES project, will be made object of an IFSAR analysis aimed to detect the relative displacements of the relative scattered points [11, 12]. This methodology is carried on starting from HR SAR data from COSMO SKY-MED constellation. The IFSAR analysis help to monitor instability phenomena affecting the interested structures and their surrounds and gives back subsidence maps, whose information, combined with the susceptibility maps coming from the geomorphological analysis, give an exhaustive overview of the criticism related to the stability of the asset and of its surrounding elements.
This methodology allows to detect terrain displacements with millimetre/centimeter accuracy.

The IFSAR analysis uses the remote sensing SAR data. The fundamental principle is that the phase difference between two SAR images acquired at different times and with slightly different view angles is related to the topography of the observed scene as well as to its terrain/structure displacements.

4.3.5.2 Measured Parameters

The interferometric technique is able to measure the projection of the displacement along the line of sight (LOS) of the sensor (see Figure 34).

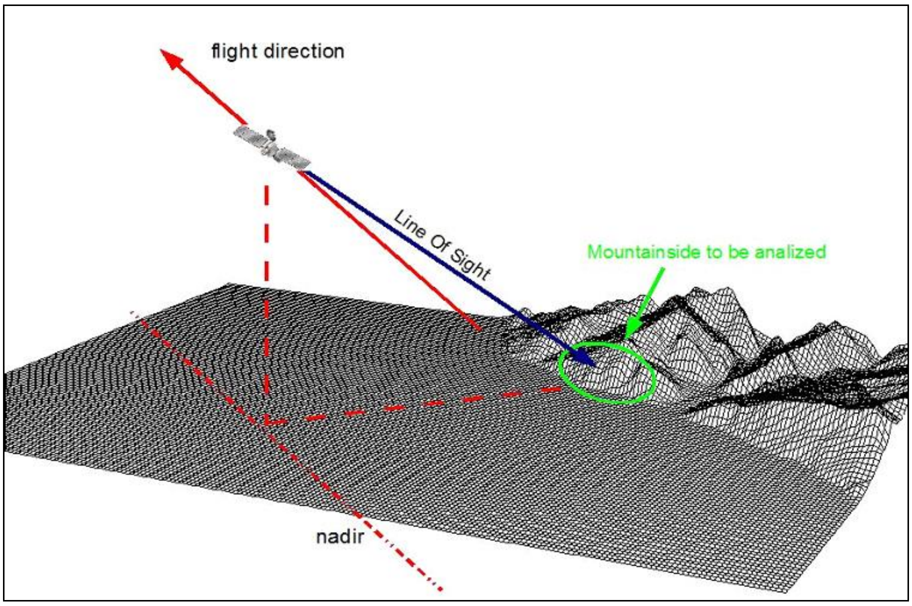

Figure 34 Line of sight direction

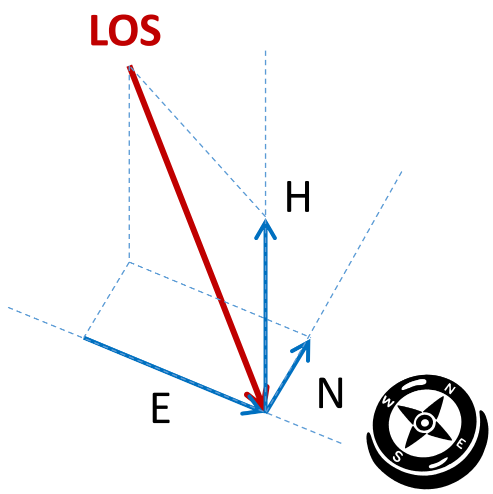

Figure 35 Line of sight direction decomposition

The line of sight direction in general can be decomposed into three components: northward, eastward, vertical (Figure 35).

With currently available satellite systems, it is possible to perform interferometric analysis with two complementary geometries (ascending/descending or left/right), and it is possible to discriminate between the eastward (E) and vertical component

(H) of the displacement, whereas the system is blind with respect to northward (N) component. For each observation geometry the three direction cosine are provided. To better understand the meaning of interferometric measurements, an example relative to a landslide in presence of terrain slope is shown in Figure 36 and Figure 37.

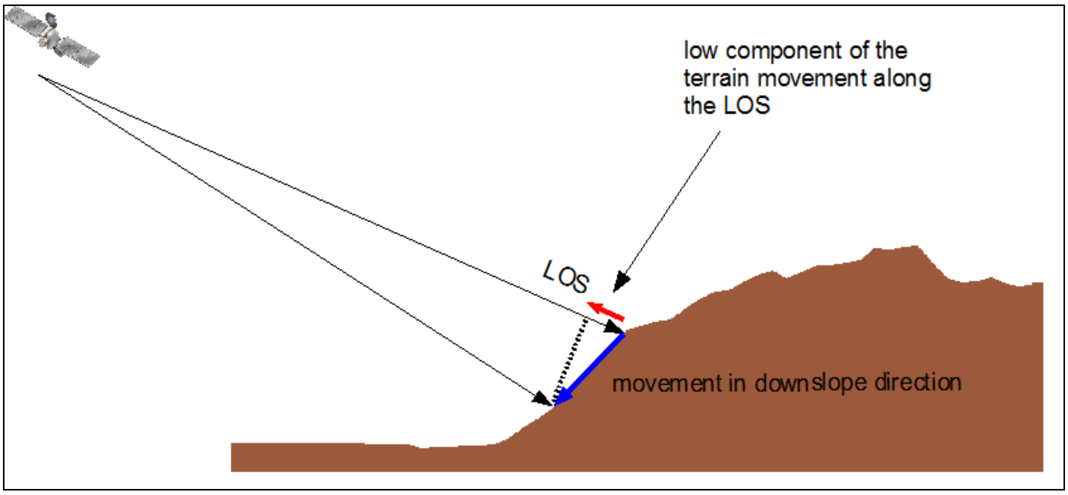

Figure 36: The red line represents the component of the terrain displacement measured by the SAR interferometry technique in the case of ascending acquisition geometry.

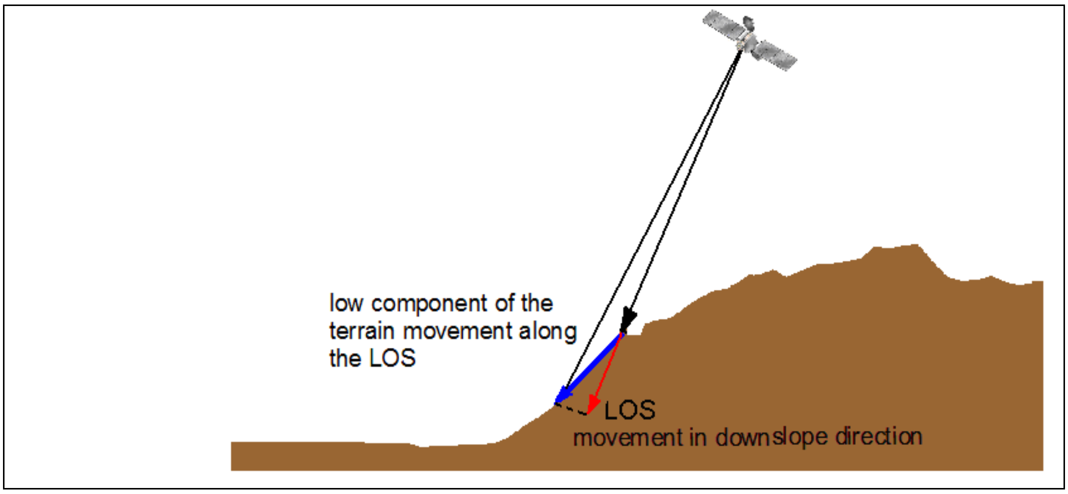

Figure 37: The red line represents the component of the terrain displacement measured by the SAR interferometry technique in the case of descending acquisition geometry.

The examples reported on the previous figures shows the same landslide (blue arrow) measured with two different geometries ascending and descending. In Figure 36, the component of the terrain movement along the LOS (red arrow) indicates that the measurement point moves to the sensor: in this case the displacement is considered positive. In Figure 37, instead, the component of the terrain movement along the LOS (red arrow) indicates that the measurement point moves away from the sensor: in this case the displacement is considered negative. The combination of the two set of measurements allows reconstructing the horizontal (eastward) and vertical component of the displacement.

In case of vertical movements, as for subsidence phenomena, only one observation geometry is sufficient to reconstruct the displacement vector.

e-GEOS developed an end-to-end processing chain for SAR interferometry processing, named PSP, which is able to identify either point-like or distributed scatterers [11]. The PSP method is able to reconstruct at full resolution the displacement (and the 3D position) without explicit need of adaptive spatial averages. Exploiting the relative properties (arcs) between neighbouring points the technique allows extracting information in correspondence of weak area signal (distributed scatterers), and the robust finite difference integration method allows reconstructing the value on each point using redundant integration path minimizing the impact of the noise, preserving the information at full resolution.
CNR developed an approach framed in the context of tomography that extends the classical interferometric approaches, referred to as Tomographic SAR (TMS) [12], particularly suitable for the localization and monitoring of PS located over the built environment.
For each detected measurement point (PS), the following information, is provided by both PSP and TMS methods (see Figure 38):

- PS Position, measured position of the PS point (geographic coordinates and heights)
- PS mean velocity, measured PS mean velocity in the period between the first and the last SAR acquisition dates
- PS temporal evolution, measured PS displacement at each acquisition date in the analysed period.

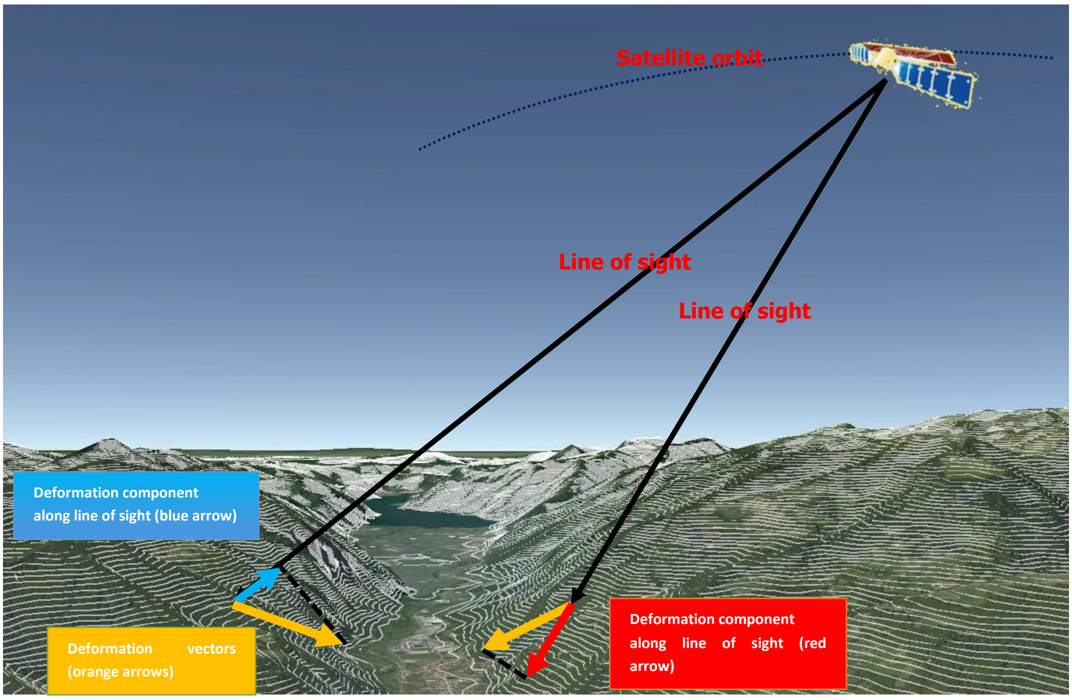

Figure 38: Acquisition of PS

The maps of displacements obtained through the IFSAR analysis consist in a series of scattered points (PS) having three dimensions (X,Y,Z) each and representing the relative displacements of the PD in the analysed period (from SAR image t° to image t°+n). In the next Figure 39, an example of IFSAR maps and of the derived displacements graphics obtained in Gubbio-Consoli Palace (other HERACLKES test-bed), is shown.

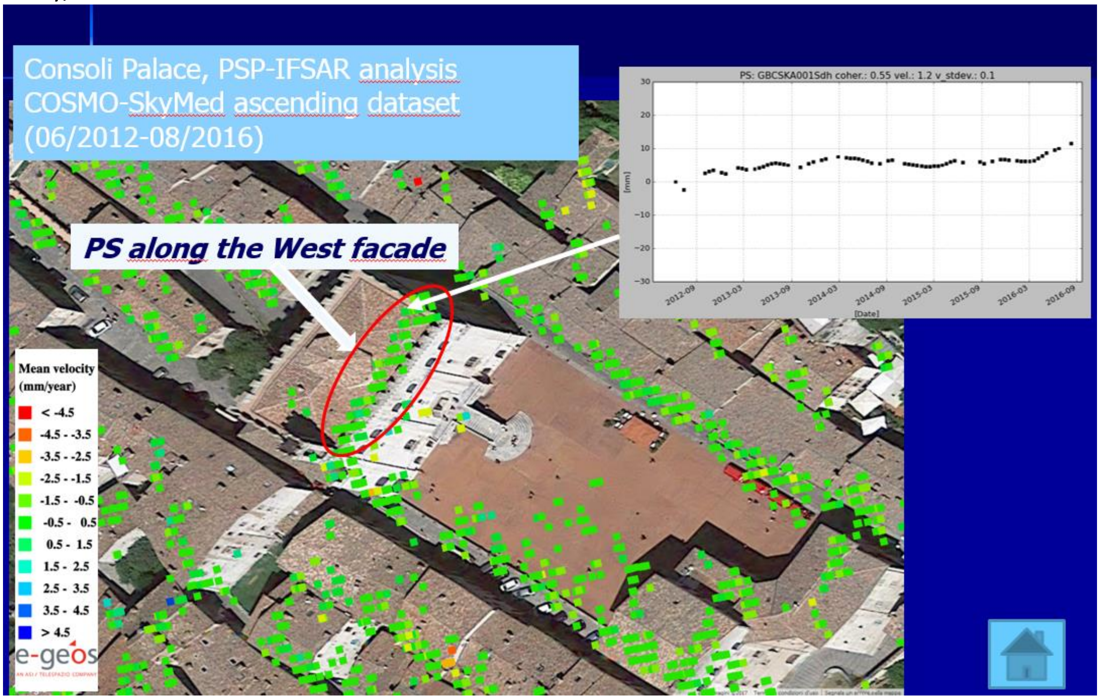

Figure 39: IFSAR analysis on Consoli Palace in Gubbio

The IFSAR stability analysis on the Knossos Palace will be performed in order to detect instability ground phenomena and displacements due to the soil movements. The same analysis will be able to even detect the phenomena of displacements due to the erosion of atmospheric agents (wind and rain) on the exposed structures.
Similarly to the Gubbio test bed, the Knossos Palace data will be analysed also by means for the Tomographic SAR (TMS) technique, which is particularly suitable for the monitoring of buildings and infrastructures.

4.3.5.3 Installation

Sensing Technique	IFSAR
Sensor location	Not applicable
Where to fix the sensor (post, tripod, etc)	Not applicable
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	Not applicable
Give a description of the installation procedure.	Not applicable
Time required to install the sensor	Not applicable

Possible constraints for the installation (authorizations – announcement in advance, *etc.*)	Not applicable

4.3.5.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	Not applicable
How many measurements are planned to be done	An initial analysis will be performed during WP2 activities and an update of the data is foreseen during the demonstration phase
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Not applicable
Dimension of the sensor system (sensor + any electronic control or computer)	Not applicable
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	Not applicable
The instrument requires an Ethernet connection during the experiment.	Not applicable
Time required to perform a preliminary signal processing to ensure the measurement reliability	Not applicable
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	No other technique affects the SAR measurements
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	Meteorological conditions, acquisition geometry, land cover.

4.3.5.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	Not applicable
Partner in charge for data acquisition	e-GEOS
Partner in charge for data validation	e-GEOS/CNR-IREA
Partner in charge for processing/ modelling	e-GEOS/ CNR-IREA/UniPG

4.3.6 Knossos Palace - Test bed sensor #1.2: UAV-Drone geometrical survey

4.3.6.1 Description

UAV is the acronym for Aerial Unmanned Vehicles, best known as drones. UAV surveys will be used on Knossos Palace in order to realize a quick and complete optical survey of the whole archaeological settlement. The results of the survey will be used, together with the laser scanner survey results, to produce a detailed 3D representation of the archaeological area at the scale of the single building. The two surveys (UAV and terrestrial laser scanner) will be integrated by optical remote sensing information, thanks to the exploitation of archives of digital aerial ortophotos and, if necessary, by VHR optical satellite images.

4.3.6.2 Measured Parameters

The drone, equipped with an optical high precision camera, will be manned in order to obtain both a nadiral and oblique survey (Figure 40) of the interested area, having the following features:

- Final resolution of the images = 1 cm
- Optical camera with minimum 20 Megapixels
- Suitable calibration of the camera
- If necessary, the aerial survey has to be integrated by pictures made on site by ground.

The oblique survey will allow the 3D reconstruction of the observed structures with particular attention to the areas of degradation and collapse.

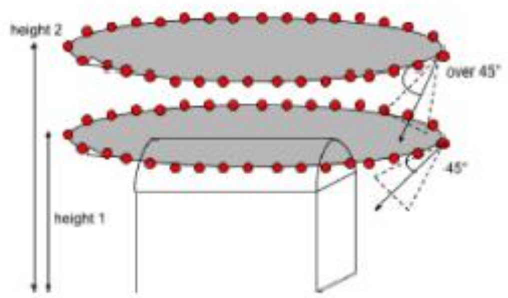

Figure 40: UAV oblique survey

In the oblique survey (Figure 40):

- the camera will be positioned at an angle of about 45° towards the nadir
- the path of the survey will be completed by the GPS coordinates

The following Table 4 reports the main outputs of the UAV survey:

Table 4: UAV survey main outputs

ID	ITEM	Type	FORMAT
1.	Flight plan	ASCII	PDF, kml
2.	Cameras calibration Report	Metadata	XML, CSV
3.	Oriented images (initial EO)	RASTER 2D	JPG o TIF (geotagged)
4.	Final orientation (final EO)	ASCII	txt,csv,dat
5.	Control points (GCP e markers) and report bundle adjustment	ASCII	txt,csv,dat
6.	Flight graphic	Vector	DXF; SHP
7.	Sparse points cloud	Point Cloud	las (xyzrgb)
8.	TLS Raw data (mosaicated)	Point Cloud	las (xyzrgb)
9.	TLS Ancillary data	Metadati	XML
10	Report on the georeferenced points cloud	ASCII	txt, csv, dat

It is important to point out that each aerial survey, UAV included, needs specific authorization by the local authorities. E-GEOS will take care to obtain the necessary licences.

4.3.6.3 Installation

Sensing Technique	UAV survey, close range photogrammetry
Sensor location	Over the chosen area
Where to fix the sensor (post, tripod, etc)	Not applicable
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	Not applicable
Give a description of the installation procedure.	Not applicable
Time required to install the sensor	Not applicable
Possible constraints for the installation (authorizations – announcement in advance, *etc.*)	Flight permission by local authorities

4.3.6.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	2 days
How many measurements are planned to be done	1 survey
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	YES
Dimension of the sensor system (sensor + any electronic control or computer)	Under 2.5 kg MTOW
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	NO
The instrument requires an Ethernet connection during the experiment.	NO
Time required to perform a preliminary signal processing to ensure the measurement reliability	Not applicable
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	YES
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	Meteo conditions, illumination

4.3.6.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	Not applicable
Partner in charge for data acquisition	e-GEOS
Partner in charge for data validation	e-GEOS
Partner in charge for processing/ modelling	e-GEOS

4.3.7 Knossos Palace - Test bed sensor #1.3: Terrestrial Laser Scanner @ zones 1-2-3-4-5

4.3.7.1 Description

Terrestrial Laser Scanning (TLS) is an imaging technique that performs distance measure at nearly equidistant sampling steps along vertical and horizontal directions.

4.3.7.2 Measured Parameters

The laser scanner acquisition produces cloud of 3D points, whose density on the Knossos Palace will be of 10.000 points per sqm. The clouds of 3D points will be completed by radiometric information RGB. The survey will be applied to all the buildings of the archaeological area (an example is shown in Figure 41).
Together with the TLS survey, it will be realized a UAV nadir-oblique photogrammetric survey of the whole area, in order to integrate the 3D reconstruction of the survey obtained by the combination of aerial and TLS surveys.

Figure 41: example of a TLS relief and of a points cloud

4.3.7.3 Installation

Sensing Technique	TLS survey
Sensor location	Itinerant sensor
Where to fix the sensor (post, tripod, …)	Not applicable
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	NO
Give a description of the installation procedure.	No installation is foreseen
Which is the time required to install the sensor	Not applicable
Possible constraints for the installation (authorizations – announcement in advance*, etc.*)	Not applicable

4.3.7.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	2 days
How many measurements are planned to be done	between 4-8 laser scanner stations, included two station "indoor"
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery operated
Dimension of the sensor system (sensor + any electronic control or computer)	Not applicable
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	NO
The instrument requires an Ethernet connection during the experiment.	NO
Time required to perform a preliminary signal processing to ensure the measurement reliability	Not applicable
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	YES
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	Meteo conditions, illumination

4.3.7.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	Not applicable
Partner in charge for data acquisition	e-GEOS
Partner in charge for data validation	e-GEOS
Partner in charge for processing/modelling	e-GEOS

4.3.8 Knossos Palace - Test bed sensor #2.1a: Weather monitoring - local station NETWORK

4.3.8.1 Description

Fixed installation of a 3m mast meteorological station for measuring Wind Speed and Direction, Temperature, Humidity, Rainfall, Solar Radiation and UV Index, is required.

4.3.8.2 Measured parameters

The monitoring parameters are summarised in the following Table 5.

Table 5: Monitoring parameters at different zones of Knossos Palace

N	Zones	Position	Parameters
1	"West Magazines"	25:9:46,29638E – 35:17:53,34951N - 127.3149077010364	SO_2, NO_2, CO, O_3, PM10, PM2.5 Wind, Atmospheric Pressure, temperature, Relative Humidity, Solar radiation
2	"Tripartite Shrine "	25:9:46,82077E – 35:17:52,47386N – 142.52081761301514	SO_2, NO_2, CO, O_3, PM10, PM2.5 Wind, Atmospheric Pressure, temperature, Relative Humidity, Solar radiation, stability
3	"East Wing"	25:9:45,66213E – 35:17:51,84548N - 118.33789681962192	SO_2, NO_2, CO, O_3, PM10, PM2.5 Wind, Atmospheric Pressure, temperature, Relative Humidity, Solar radiation, soil creeping, stability
4	"South House"	25:9:45,0426 E – 35:17:50,31995N – 116.42006691798187	SO_2, NO_2, CO, O_3, PM10, PM2.5 Wind, Atmospheric Pressure, temperature, Relative Humidity, Solar radiation, soil creeping, stability
5	"Giant Pithoi"	25:9:49,4798 E – 35:17:53,33482N – 119.66484077448038	SO_2, NO_2, CO, O_3, PM10, PM2.5 Wind, Atmospheric Pressure, temperature, Relative Humidity, Solar radiation, stability, soil creeping

4.3.8.3 Installation

Sensing Technique	Microclimate monitoring sensors
Sensor location	Knossos Palace
Where to fix the sensor (post, tripod, etc)	On a 3m Mast
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	No
Give a description of the installation procedure.	A metal cylindrical mast is anchored on a base to the ground and the Meteorological Station is fastened on

	the top of the mast.
Time required to install the sensor	4 hours approximately
Possible constraints for the installation (authorizations – announcement in advance*, etc.*)	The Ephorate has already authorized the necessary procedures

4.3.8.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	The measurements are taken continuously
How many measurements are planned to be done	Continuous measurements till the end of the program
The system is battery operated or requires electric energy necessities (Voltage, Power, ets)	The station is powered by a small PV panel and data storage and relay equipment is powered by a PV panel connected to a 50AH battery.
Dimension of the sensor system (sensor + any electronic control or computer)	Met Station dimensions: 279 mm x 238 mm x 533 mm
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	Yes
The instrument requires an Ethernet connection during the experiment.	Yes
Time required to perform a preliminary signal processing to ensure the measurement reliability	1 Hour
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Yes
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	No

4.3.8.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	FORTH IACM
Partner in charge for data acquisition	FORTH IACM
Partner in charge for data validation	FORTH IACM
Partner in charge for processing/modelling	ARIA

4.3.9 Knossos Palace - Test bed sensor #2.1b: Weather monitoring – public station NETWORK

4.3.9.1 Description

Weather stations belonging to the public meteorological office of Greece around HERAKLION area have been selected both as complementary local weather data source in addition to the data collected from the weather station installed and managed by FORTH and for the collection of local Climate Data Records (CDR) that can be used to identify climate change trends and climate patterns affecting Koules and Knossos Palace.

4.3.9.2 Measured parameters

The parameters collected from local public weather stations are Temperature, Precipitation and Wind.

4.3.9.3 Installation

Sensing Technique	Microclimate monitoring sensors
Sensor location	Not applicable
Where to fix the sensor (post, tripod, …)	Not applicable
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	Not applicable
Give a description of the installation procedure.	Not applicable
Time required to install the sensor	Not applicable
Possible constraints for the installation (authorizations – announcement in advance etc.)	Not applicable

4.3.9.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc)	The data collection of the parameters listed above deals with both archive data and near real time data. Depending on the operational time range of the sensor, some data collections are available since 2006.
How many measurements are planned to be done	The amount of data depends by the operational time range of each single station. In general, it is foreseen to have daily measurements for almost all the

	sensors until the end of the project.
The system is battery operated or requires electric energy necessities (Voltage, Power…)	Not applicable
Dimension of the sensor system (sensor + any electronic control or computer)	Not applicable
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	Not applicable
The instrument requires an Ethernet connection during the experiment.	Not applicable
Time required to perform a preliminary signal processing to ensure the measurement reliability	Not applicable
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique ?)	Yes
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc.)	No

4.3.9.5 Data acquisition-Validation and processing/modelling

Partner in charge for installation	Not applicable
Partner in charge for data acquisition	SISTEMA
Partner in charge for data validation	SISTEMA
Partner in charge for processing/modeling	SISTEMA

4.3.10 Knossos Palace - Test bed sensor #2.2: Drone measurement of climatic parameters (portable environmental payload device for the monitoring of local microclimate variables)

4.3.10.1 Description

The monitoring of microclimate parameters (i.e. dry bulb temperature [°C], relative humidity [%], surface temperature [°C], air quality in terms of CO_2, CO, and VOC [ppm], wind speed [m/s] and direction [°], global radiation [W/m^2], and lighting [lux]) in time and space will be carried out by means of a dedicated newly developed geo-referenced payload consisting of miniaturized environmental sensors (Figure

42). The system is also equipped with visible and infrared cameras to detect superficial temperature [°C] of the surrounding environment.

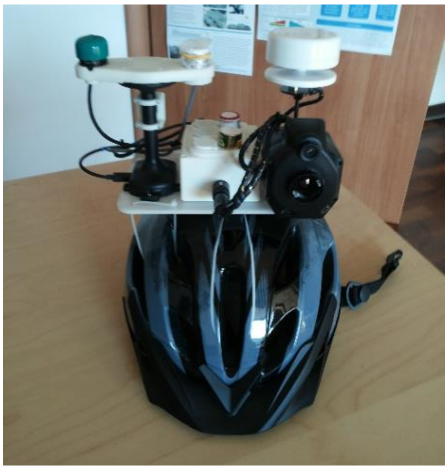

Figure 42: Miniaturized environmental payload mounted over a helmet.

These monitoring campaigns will be carried on both at sky, by means of drone, and at the ground (i.e. at pedestrian level). The monitoring campaign took place on July from 3rd to 6th, 2017.

4.3.10.2 Measured parameters

The sensors composing the environmental payload and the monitored parameters are summarised in the following Table 6.

Table 6 – payload and the monitored parameters Test-bed sensors #2.2 and #2.3

Sensors	Parameters
BME280	Atmospheric pressure [Pa], relative humidity [%] and air temperature [°C]
Eko ML-020S-O	Lighting [lux]
SP-110	Global shortwave radiation [W/m²]
TDS0037	Carbon Dioxide concentration [ppm]
GS+4CO	Carbon Monoxide concentration [ppm]
TGS 8100	Air Contaminants concentration [ppm]

4.3.10.3 Installation

Sensing Technique	Microclimate monitoring sensors
Sensor location	The payload device will be used to perform continuous measurement in space and time; therefore it will not be positioned in a specific location. The monitoring path, both from the sky and at pedestrian level, will take place all

	around the Palace of Knossos areas selected for the project, namely: West Magazines, Tripartite Shrine, East Wing, South House, and Magazine of Giant Pithoi.
Where to fix the sensor (post, tripod, etc)	No mechanical supports are needed
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	No actions that could modify the structures are necessary
Give a description of the installation procedure.	The payload device will be installed on a drone and on a helmet
Time required to install the sensor	-
Possible constraints for the installation (authorizations – announcement in advance*, etc.*)	Drone flights will take place during the closing hours of the touristic site.

4.3.10.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	3 days measurement (from July 3rd to 6th, 2017)
How many measurements are planned to be done	At least one measurement from the sky, by means of drone, and one at pedestrian level, by means of the helmet, will be performed.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery operated. Battery operation time = 3 hours Battery charging time = 8 hours
Dimension of the sensor system (sensor + any electronic control or computer)	Height: 10 cm Width: 20 cm Depth: 15 cm
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	No
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	The sensors constituting the monitoring system are already calibrated so the measurement reliability is guaranteed. The data analysis and post-processing will require a few months.
Compatibility or not with the other sensing techniques (what are the other	Compatible with all the other measures

techniques that can be used without affecting the measurement of the specific technique?)	
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc.)	-

4.3.10.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	UNIPG/CIRIAF
Partner in charge for data acquisition	UNIPG/CIRIAF
Partner in charge for data validation	UNIPG/CIRIAF
Partner in charge for processing/modelling	UNIPG/CIRIAF

4.3.11 Knossos Palace - Test bed sensor #2.3.a: Temperature - Relative Humidity (RH) sensor data logging system (portable)

4.3.11.1 Description

The punctual monitoring of the main environmental parameters, i.e. air temperature [°C] and relative humidity [%], will be carried out by means of a TGP-4500 device. Such device is a rugged, waterproof temperature and relative humidity logger with built-in sensors, able to monitor temperatures within -25 and +85°C and all the spectra of relative humidity (i.e. 0-100%). Moreover, the device has an internal memory which guarantees data collection of 113 days of continuous monitoring. The data collected by this system, coupled with the data acquired by the weather station installed on site, will be used to validate the numerical microclimate model of the area. Therefore, the thermal-humidity sensor will be located within the area of interest for the project.

4.3.11.2 Measured parameters

Parameters monitored by TGP-4500 sensor are: (i) air temperature and (ii) relative humidity. The operative ranges of the devices are -25 ÷ +85°C and 0 ÷ 100% for temperature and relative humidity respectively.

4.3.11.3 Installation

Sensing Technique	Microclimate monitoring sensors
Sensor location	Shaded outdoor location within the case studied area
Where to fix the sensor (post, tripod, etc)	No mechanical supports are needed
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	No actions that could modify the structure are necessary

Give a description of the installation procedure.	The sensor can be simply put or clamped on available supports already present in the area
Time required to install the sensor	Just few minutes to find the optimal location for the sensor
Possible constraints for the installation (authorizations – announcement in advance, *etc.*)	Authorizations from Ephorate are necessary

4.3.11.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	Continuous monitoring. Due to internal memory space, the data must be downloaded every 113 days of monitoring
How many measurements are planned to be done	UNIPG/CIRIAF will provide this sensor during the continuous monitoring carried out by payload (3^{rd}-6^{th}July 2017). Afterwards, the FORTH/Ephorate will provide their own sensors.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery operated, no power supply is needed
Dimension of the sensor system (sensor + any electronic control or computer)	Height: 34 mm Width: 57 mm Depth: 80 mm
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	To be consistent with the Gubbio case study, one year of monitoring is recommended
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	-
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Compatible with all the other measures
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	Direct insulation and rainfall can affect measurement of the device

4.3.11.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	UNIPG-CIRIAF/FORTH
Partner in charge for data acquisition	UNIPG-CIRIAF/FORTH
Partner in charge for data validation	UNIPG-CIRIAF/FORTH
Partner in charge for processing/modelling	UNIPG-CIRIAF

4.3.12 Knossos Palace: Test bed sensor #2.3b: Temperature - Relative Humidity (RH) sensor data logging system (fixed)

4.3.12.1 Description

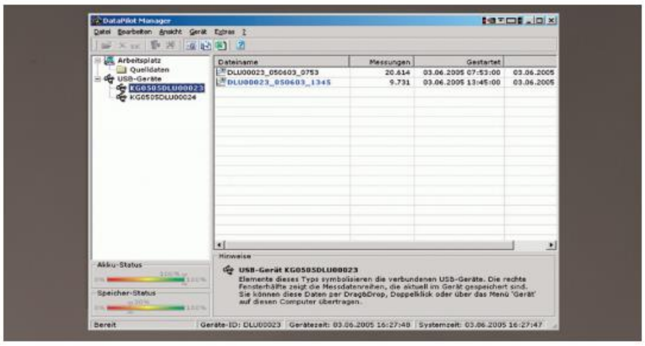

Figure 43: a) The data logger with corresponding accessories (cable, installation cd) and b) The dedicated software for data downloading and acquisition scheduling.

The Temperature and Relative Humidity loggers (Figure 43) are compact sized sensors, integrating a battery and a built-in memory. In such a way, they can autonomously operate and periodically store data. The loggers provide a USB2.0 connection allowing users to download data acquired by the loggers and schedule the measurements. The whole process is performed via dedicated software (Figure 43).

The main specifications of the sensors are reported in the following Table 7:

Table 7 – Main specifications of the sensors

HARDWARE	
Power supply	Li-ion battery 3.7 VDC / 1000 mA
Charging voltage	+5 V DC
Current consumption	Charge current max.500 mA Measuring mode <1 mA
SENSOR	
Relative humidity	0 to 100% ± 2% RH
Temperature	-40 ° C to + 85 ° C ± 0.3 ° C
Dimensions (l x b x h)	67 x 40 x 16 mm
Weight approx.	95 g
Protection class	IP41

Resolution	12 bits RH / 14 Sit Tomp
Communication	USB 2.0 (1 MBit / sec)
Storage capacity	approx. 2 million measured values
Memory type	non-volatile flash EEPROM
Drift d. Real-time clock	<2 sec / week
Max. Recording time	> 1 year
Functional check	2-color LED
ACCESSORIES AND SPECIAL EQUIPMENT	
Measuring case with software and manual	
Self-charging to USB interface	
Charging indicator light	
2-color function control light	
Recording interval selectable from 1 sec to 12 h	
Programmable measuring programs - Single start / stop - Continuous measurement - Daily repetition - Weekly measuring programs	
Backup with Flash-Imaging	
SYSTEM REQUIREMENTS	
Software	DataPilot Manager 3.0
Computer type	IBM or compatible
Operating system	Microsoft Windows2000 / XP
CPU speed	> 300 MHz
Memory	> 64 MB
Free hard disk space	> 24 MB
Interfaces USB	1.1 / 2.0

4.3.12.2 Measured parameters

The parameters monitored by the sensor are relative humidity and air temperature. The operative ranges of the device are 0 to 100% (± 2% RH) and -40 °C to + 85 ° C (± 0.3° C) for relative humidity and temperature, respectively.

4.3.12.3 Installation

Sensing Technique	Temperature and Humidity data loggers
Sensor location	At various locations of the monument
Where to fix the sensor (post, tripod, etc)	The sensor will be fixed 3-4 meters from the ground at a robust point via a string-location according to Ephorate
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	Yes
Give a description of the installation	The sensor will be fixed 3-4 meters from

procedure.	the ground at a robust point via a string.
Time required to install the sensor	30 minutes
Possible constraints for the installation (authorizations – announcement in advance, *etc.*)	Authorization by Ephorate needs

4.3.12.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	Continuous recording
How many measurements are planned to be done	Long term measurements (1-2 years)
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery operated
Dimension of the sensor system (sensor + any electronic control or computer)	67 x 40 x 16 mm
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	Yes
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	Data download time. Requires unfixing of the logger. Approx 30 minutes
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Performs independently
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc.)	Environmental conditions can affect data

4.3.12.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	FORTH-Ephorate
Partner in charge for data acquisition	FORTH-Ephorate
Partner in charge for data validation	FORTH (IACM)
Partner in charge for processing/modelling	FORTH (IACM)

4.3.13 Knossos Palace - Test bed sensor #2.4: Infrared Thermography

4.3.13.1 Description

The infrared thermography will be performed by means of a dedicated thermographic camera available at UNIPG/CIRIAF laboratories. The aim of this monitoring is to detect specific inner structural diseases and non-homogeneities.
A first campaign already took place on November 6th-9th 2016. The second one took place in the first week of July 2017 (i.e. from 3rd to 6th).

4.3.13.2 Measured parameters

The infrared thermographic camera detects the infrared energy emitted by bodies and so their superficial temperature [°C], which is converted in electronic signal and then elaborated to produce images as the one reported below (Figure 44). The superficial temperature of the object is therefore determined.

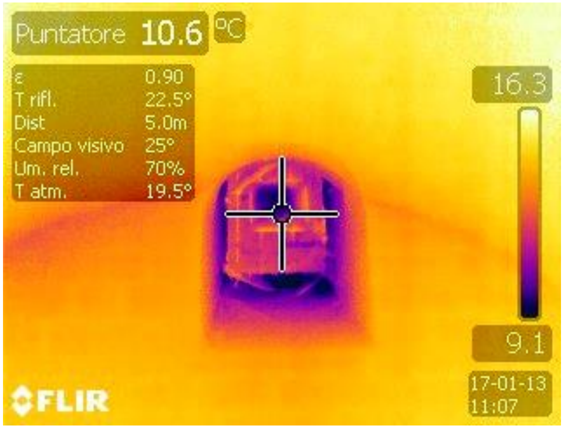

Figure 44: Example of infrared thermography result.

4.3.13.3 Installation

Sensing Technique	Thermographic IR camera
Sensor location	The camera is carried around by hands as a traditional camera
Where to fix the sensor (post, tripod, …)	Not applicable
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	No sensor installation is needed
Give a description of the installation procedure.	-
Time required to install the sensor	-
Possible constraints for the installation (authorizations – announcement in advance, *etc.*)	None

4.3.13.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	One-day measurement
How many measurements are planned to be done	At present, two monitoring campaigns were scheduled. Both already took place during November 6-9th 2016, and July 2017.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery operated
Dimension of the sensor system (sensor + any electronic control or computer)	Portable camera (about 20x10x10 cm)
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	No
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	No time is required
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Compatible with all the other sensing techniques
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	-

4.3.13.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	UNIPG/CIRIAF
Partner in charge for data acquisition	UNIPG/CIRIAF
Partner in charge for data validation	UNIPG/CIRIAF
Partner in charge for processing/modelling	UNIPG/CIRIAF

4.3.14 Knossos Palace - Test bed sensor #2.5: Multispectral remote sensors

4.3.14.1 Description

Multispectral remote sensing is defined as the collection of reflected, emitted, or backscattered energy from an object or area of interest in multiple bands of the electromagnetic spectrum.

By means of the combination of spatial and temporal resolution features, multispectral sensors give a relevant contribution to Cultural Heritage monitoring by providing meteo-climatic and air quality measurements for the characterization of local scale meteorological conditions and climate change effects that have a potential impact on the conservation of historical and archaeological structures.

The multispectral data are collected over both the test sites in Heraklion.

4.3.14.2 Measured parameters

The multispectral sensors identified for HERACLES allow the measurements of those parameters that affect directly or indirectly the historical buildings and structures.

The meteo parameters are: precipitation, air temperature, relative humidity and land surface temperature.

The air quality parameters are: Aerosol Optical Thickness (AOT), SO_2 and NO_2 concentrations.

4.3.14.3 Installation

This section does not apply to satellite multispectral sensors.

4.3.14.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	The data collection of the parameters listed above deals with both archive data and real time data. Depending on the operational time range of the sensor, some data collection is available since 2000.
How many measurements are planned to be done	The amount of data depends by the operational time range and the revisiting time of the sensor. In general, it is foreseen to have daily measurements for almost all the sensors, apart from the precipitation data that are acquired on hourly basis.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Not applicable
Dimension of the sensor system (sensor + any electronic control or computer)	Not applicable
It is planned to leave the sensor instrumentation on the test-bed location	Not applicable

during all the experiment period to perform a several days monitoring.	
The instrument requires an Ethernet connection during the experiment.	Not applicable
Time required to perform a preliminary signal processing to ensure the measurement reliability	Not applicable
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Not applicable
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc.)	Not applicable

4.3.14.5 Data acquisition – Validation and processing/modelling

Partner in charge for installation	Not applicable
Partner in charge for data acquisition	SISTEMA
Partner in charge for data validation	SISTEMA
Partner in charge for processing/modelling	SISTEMA

4.3.15 Knossos Palace - Test bed methodology #3.1: Portable Raman spectroscopy system

4.3.15.1 Description

The Raman process represents inelastic scattering of light by matter. Light in the visible, near-IR or near-UV, typically from a laser source, interacts with molecules by depositing part of its energy to chemical bonds that vibrate at characteristic resonance frequencies. Raman spectroscopy provides an accurate look into chemical bonding, thereby enabling identification of various types of materials, both inorganic and organic [13].

4.3.15.2 Measured parameters

Spectral analysis of the inelastically scattered light yields the Raman spectrum, which is a plot of the intensity of scattered light as a function of the frequency difference between the incident and scattered radiation. The frequency difference $\Delta\nu$, is called the Raman shift, expressed in wavenumbers (cm^{-1}). The spectral bands in the spectrum correspond to characteristic bond vibration in the molecule [14].

4.3.15.3 Installation

Sensing Technique	Raman spectroscopy
Sensor location	Against the area under examination (mm

	distance from the surface). Different areas/spots will be examined
Where to fix the sensor (post, tripod, etc)	Usually, a pair of tripods is employed to fix/stabilize the sensor to the desired position of examination.
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	Raman spectroscopy is a non-invasive and non-destructive technique.
Give a description of the installation procedure.	The instrument probe head needs to be positioned close to the surface under examination, and this is achieved by mounting it on a custom-made platform that enables lateral movement of the head along a length of 1 m. This platform arrangement, supported on a pair of tripods, permits measurements to be performed from a minimum height of 60 cm up to a maximum of 2 m. The other parts of the system (spectrograph, detector, power supply units) are all attached firmly onto a light-weight aluminium frame (at a distance from the object under analysis).
Time required to install the sensor	Typical installation time is approximately 30 minutes (not including transportation of the equipment to the site)
Possible constraints for the installation (authorizations – announcement in advance, *etc.*)	Raman spectroscopy is a non-destructive technique, therefore no special authorization is needed. Still an advance announcement to the stakeholder/end-user is mandatory.

4.3.15.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	Raman is a spot size measurement. An average time for recording a Raman spectrum is approximately 30 sec.
How many measurements are planned to be done	Measurements will be done at several areas/spots of interest on-site.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The system operates with 230V AC.
Dimension of the sensor system (sensor + any electronic control or computer)	The size of the whole set-up is such that it can be mounted on a mobile support (60 x 40 x 80 cm^3 approximately,

	considering the control computer).
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	No. An operator is required for running the sensor. If a several days experiment is necessary, the system must be in a safe place of the location (a locked room) during the time that no measurements were performed (overnight).
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	The system reliability and repeatability are achieved with the use of standard samples, before analysing the real object. An approximately time for performing this test is 15 minutes. During the experiment the stability/reliability of system are also checked by analysing standard samples.
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	LIBS technique can be used simultaneously at the area examined with Raman.
Factors affecting the measurement (sun insulation, temperature, meteorological conditions,etc)	The system cannot perform under rainfall (due to the ADC supply) and high temperature (due to the system detector).

4.3.15.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	IESL-FORTH
Partner in charge for data acquisition	IESL-FORTH
Partner in charge for data validation	IESL-FORTH
Partner in charge for processing/modelling	IESL-FORTH

4.3.16 Knossos Palace - Test bed methodology #3.2: Portable LIBS

4.3.16.1 Description

Laser-induced breakdown spectroscopy provides information about the elemental composition of materials. Briefly, focusing a pulse from a nanosecond laser onto the surface of an object, under analysis, a transient micro-plasma is generated, which emits light upon relaxation [13, 15].

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4.3.16.2 Measured parameters

Recording the plasma emission on a spectrometer produces the LIBS spectrum, which features sharp atomic emission peaks leading to the identification of the elements contained in the sample. The peak intensity or the integrated intensity of the atomic emission peaks is related to the number density of each emitting species in the plume and this, in turn, with the concentration of specific elements in the ablated material [14].

4.3.16.3 Installation

Sensing Technique	Laser Induced Breakdown Spectrosopy (LIBS)
Sensor location	Over the area under examination, multiple areas will be tested
Where to fix the sensor (post, tripod, etc)	Usually, standard tripods or a monopod are required
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	The experimental equipment needed for LIBS is both simple and versatile. LIBS analysis can be applied in-situ, eliminating the need for sample removal and/or sample preparation.
Give a description of the installation procedure.	The sensor is positioned against the surface under examination, (approximately 7.5 cm distance), and this is achieved either by supporting the optical head on a standard tripod or by mounting it on a custom-made platform that enables lateral movement of the head along a length of 1 m. This platform arrangement supported on a pair of tripods permits measurements to be performed from a minimum height of 60 cm up to a maximum of 2 m. In cases that the object (or spot to be analysed) is over 2 m above floor level, the LIBS sensor is mounted on a monopod. The other parts of the system (spectrometer, power supply) are positioned at 1 m distance away from the object.
Time required to install the sensor	Typical installation time is approximately 20 minutes (not including transportation of the equipment to the site).
Possible constraints for the installation (authorizations – announcement in advance, *etc.*)	Considering that laser ablation is involved in a LIBS measurement, removal of a minute amount of material from the sample surface takes place with

	each laser pulse (mass removal on the order of a few nanograms), and so the technique is termed as micro-destructive. The diameter of the laser spot is in the range of 150–300 μm. Hence, the trace left on the object surface is hardly visible by the naked eye. However, an advance announcement to the stakeholder/end-user is mandatory.

4.3.16.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	The measurement time, at a single area, is a few seconds
How many measurements are planned to be done	Measurements will be done at several areas of interest on-site. Periodic repetition of the measurement is also scheduled.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The system operates with 230V AC.
Dimension of the sensor system (sensor + any electronic control or computer)	The sensor fits in a compact case (dimensions of 46 × 33 × 17 cm^3) and weigth less than 9 kg. The sensor is directly connected to a laptop. Instrument operation and spectra acquisition are fully controlled via a custom-made software.
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	No. An operator is required for running the sensor. If a several days experiment is necessary, the system must be in a safe place of the location (a locked room) during the time that no measurements were performed. (overnight)
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	Approximately 5 minutes
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the	LIBS instrument can operate well in parallel with Raman spectroscopy system on an arrangement that permits simultaneous analysis with both

specific technique?)	techniques over the surface of an object.
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	The sensor cannot perform under rainfall or high humidity. This is mainly due to the ADC supply. Moreover, high temperatures and sunlight are avoided.

4.3.16.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	IESL-FORTH
Partner in charge for data acquisition	IESL-FORTH
Partner in charge for data validation	IESL-FORTH
Partner in charge for processing/monitoring	IESL-FORTH

4.3.17 Knossos Palace - Test bed methodology #3.3: Portable Multispectral Imaging system

4.3.17.1 Description

Multi-Spectral Imaging (MSI) combines a monochromator with an imaging sensor in order to depict the object under study in a series of images acquired at consecutive narrow spectral images. This series of images, also known as "spectral cube", allows the extraction of useful information on the materials of the object under study [16].

4.3.17.2 Measured parameters

The post-processing of spectral cube data provides information related to:

- The stratigraphy of a multi-layered object/surface. This is feasible because light of different wavelengths is differentially absorbed by various materials/layers and thus allows the visualization of discrete materials/layers [17].
- Material discrimination based on their discrete optical properties. Such information derives from the intensity of a pixel or an area of pixels along the spectral cube resulting into a spectrum of intensities, which is characteristic for individual materials [18].

4.3.17.3 Installation

Sensing Technique	MultiSpectral Imaging (MSI)
Sensor location	Against the area under examination. Multiple areas will be examined
Where to fix the sensor (post, tripod, etc)	Usually, a tripod is employed to fix/stabilize the sensor to the desired position of examination.
The sensor installation require to drill,	This imaging technique performs

glue, paint or other action that could change the state or the aspect of the structure	remotely and is non-invasive and non-destructive.
Give a description of the installation procedure.	The sensor is positioned against the area under examination. The distance between the sensor and the studied area depends on the size of the area. The sensor is connected to a laptop computer, which controls the system and acquires data. Two illumination sources are also placed at the sides of the sensor at an angle approximately of 45 degrees between the area and the source. In this way, uniform illumination of the studied area is achieved. In most cases 2-3 different illumination sources are used in order to ensure efficient illumination of the area at the various spectral bands. The sources are placed on special tripods and powered from an electric box, custom made, to interconnect all the illumination sources types.
Time required to install the sensor	Typical time is approximately 30 minutes (not including transportation of the equipment to the site)
Possible constraints for the installation (authorizations – announcement in advance*, etc.*)	MSI has limitations similar to common photography. Since it is non-destructive no special authorization is needed. Still an advance announcement to the stakeholder/end-user is mandatory.

4.3.17.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	The average time for a measurement at a single area is approximately 45 minutes.
How many measurements are planned to be done	Measurements will be done at several areas of interest on-site. Periodic repetition of the measurement is also scheduled.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The system operates with 230V AC.
Dimension of the sensor system (sensor + any electronic control or computer)	The MSI sensor is approximately 21 x 16 x 6.5 cm. The sensor is directly

	connected to a laptop. No other electronics are connected to the sensor.
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	No. An operator is required for running the sensor.
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	First results (spectral cube visual study) can be performed immediately after acquisition. Further processing will require at least one hour.
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Other techniques cannot run simultaneously at the area examined with MSI.
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	The sensor cannot perform under rainfall or high humidity. This is mainly due to the ADC supply.

4.3.17.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	IESL-FORTH
Partner in charge for data acquisition	IESL-FORTH
Partner in charge for data validation	IESL-FORTH
Partner in charge for processing/modelling	IESL-FORTH

4.3.18 Knossos Palace - Test bed methodology #3.4: 4D Surface/Volume Topography portable prototype

4.3.18.1 Description

4D surface/volume topography measures the topology of a surface and its variations over time (4D) using two complementary optical techniques, Spectral Interferometry (SI) and White Light Scanning Interferometry (WLSI). Both techniques use low coherence white light, they are non-invasive and non-destructive, with a capability of being portable [19]. This technique is novel and prototype, the instrument being developed for the first time within HERACLES and will be tested initially, in the laboratory, before the testing onsite

4.3.18.2 Measured parameters

The post-processing of data provides information related to:

- In SI, spectral fringes are captured using an imaging sensor, with each frame corresponding to a complete measurement of the surface profile along a line. Since no moving parts are present, it is possible to carry out high repetition rate measurements (>100 Hz) with sub-wavelength precision (<λ/70). There is a maximum height difference that can be measured (typically ~ 200 λ).

In WLSI, a series of interferograms of varying path delay are captured using an imaging sensor. The 2D surface topology is retrieved by analysing, pixel by pixel, the intensity variation of these images. The WLSI technique is optimal for in depth, sub-wavelength precision (<λ/50) measurements of the surface topology without practical limits on the surface height.

4.3.18.3 Installation

Sensing Technique	Spectral interferometry (SI) and White Light Scanning Interferometry (WLSI)
Sensor location	Against the area under examination. Multiple areas will be examined
Where to fix the sensor (post, tripod, etc)	Typically, a tripod is employed to fix/stabilize the sensor to the desired position of examination.
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	This imaging technique performs remotely and is non-invasive and non-destructive.
Give a description of the installation procedure.	The sensor positioned against the area under examination. The distance between the sensor and the studied area depends on the size of the area. The sensor connected to a computer, which controls the system and acquires data. Illumination sources are integrated with the sensors.
Time required to install the sensor	Typical time is approximately 15 minutes (not including transportation of the equipment to the site)
Possible constraints for the installation (authorizations – announcement in advance*, etc.*)	SI and WLSI have limitations similar to common photography. Since it is non-destructive, no special authorization needed. Still an advance announcement to the stakeholder/end-user is mandatory.

4.3.18.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	The average time for a measurement is approximately 1 minute for WLSI and less than 100 ms for SI.
How many measurements are planned to be done	Measurements will be done at several areas of interest on-site. Periodic repetition of the measurement is also scheduled.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The system operates with 230V AC
Dimension of the sensor system (sensor + any electronic control or computer)	Both SI and WLSI devices are approximately 25 x 20 x 10 cm, with the prospect to make the devices smaller. The sensor is directly connected to a computer. No other electronics are connected to the sensor for the SI, while for the WLSI a piezo-driver is needed.
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	No
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	First results (spectral fringes) can be performed immediately after acquisition. Further processing will require several minutes.
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Other imaging techniques can in principle run simultaneously at the area examined with SI and WLSI.
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	The sensor cannot perform under rainfall or high humidity.

4.3.18.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	IESL-FORTH
Partner in charge for data acquisition	IESL-FORTH
Partner in charge for data validation	IESL-FORTH
Partner in charge for processing/modelling	IESL-FORTH

4.3.19 Knossos Palace - Test bed methodology #3.5: Drilling Resistance Measurements System (DRMS) (in-situ)

4.3.19.1 Description

The application of the drilling resistance measuring will be focused on two distinct targets: i) the evaluation of the stone current state preservation of the building and architectural elements of the Knossos Palace and ii) the sampling of the drilling residue (dust) from distinct interval depths for further physicochemical analyses of selected stones, highly affected by salt efflorescence, in Knossos Palace. The materials will be tested and evaluated in-situ.

4.3.19.2 Measured parameters

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

4.3.19.3 Installation

Sensing Technique	DRMS
Sensor location	Gypsum surfaces with evident degradation
Where to fix the sensor (post, tripod, …)	No
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	Drilling (6mm in diameter, 10cm max depth) is required in order to estimate the state of preservation and to collect the drilling residue.
Give a description of the installation procedure.	Drilling on the surface of the architectural/building elements of the monument.
Time required to install the sensor	Approximately 30 minutes for each spot.
Possible constraints for the installation (authorizations – announcement in advance*, etc.*)	Drilling permission, sample collection permission.

4.3.19.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	30 minutes
How many measurements are planned to be done	4 per stone. Total 8 measurements

The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery operated
Dimension of the sensor system (sensor + any electronic control or computer)	30x20x20 cm
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	No
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	-
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Yes, the specimens collected will be examined with several other ex-situ analytical techniques (SEM-EDS, XRD, XPS, etc)
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	Humidity in the stone might affect drilling resistance results

4.3.19.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	UoC
Partner in charge for data acquisition	UoC
Partner in charge for data validation	UoC
Partner in charge for processing/modelling	UoC

4.3.20 Knossos Palace – Test-bed analytical techniques #4.1: Stone, mortar, weathering crusts and concrete samples analysis

4.3.20.1 Description

The suggested analysis strategy for the Knossos materials refers to the monitoring and analysis of the original materials as well as those ones used for reconstruction. Furthermore, crusts and accumulations due to pollution and climate change combined effects will be object of this study. Particular attention will be given to:

a. the unique feature of selenite, which is particularly sensitive to a number of factors, humidity being the most important.

b. the mortars, ancient as well as historical ones (from the Evans reconstruction works and more recent ones), with the aim to evaluate their performance against weathering and other effects of climate change

c. efflorescence salts in sheltered areas due to incompatibility of adjacent materials that have been applied in different periods and conditions

d. concrete (used by Evans and more recent ones)

As already stated in previous document (D3.1), the suggested strategy will assess the status of materials, looking for the reasons producing these degradation phenomena, with the aim to monitor their progresses and trying to prevent them. The above studies will always be based on the correlation of the increasing pollution and extreme weather conditions data.

4.3.20.2 Measured parameters

This activity refers to ex-situ characterization and analytical methods applied to Heraklion test-beds materials. This approach is valid for both Heraklion test-beds (Knossos Palace and Koules Fortress). As well, the techniques used for the material characterization are valid for both sites. The analytical and diagnostic strategy for the materials will include techniques for the physical, chemical, morphological, mechanical and thermo-physical characterization of gypsum, concrete, mortars, stones and weathering crusts (i.e. black deposits, efflorescence etc). The mechanical and thermo-physical characterizations allow to verify the state of the preservation and the resistance to the chemical, mechanical and thermal stresses of the materials. The physico-chemical characterization will provide information on the chemical compounds constituting the materials object of the study and other compounds present on their surfaces. Also, through the analysis and the characterization of the degradation products, it will be made possible to acquire a better understanding of the erosion mechanisms and the environmental factors that trigger them. After sampling campaigns on the selected areas of the monuments, the characterization of the weathering state of the materials started and the techniques that are used, as well the measured parameters related to each technique are detailed in Table 8. Any sampling campaign requires the authorization from Hellenic Ministry of Culture, Heraklion Ephorate of Antiquities.

The principal workflow steps are:

- **sampling phase:** this phase included and includes the identification of the most significant areas to be studied and sampled, as well the indication of the sample dimension. The sampling campaigns have required the authorization from Hellenic Ministry of Culture.
- **measurements/characterization phase in the lab (ex-situ)**
- **elaboration of the experimental data** using reference data, database etc.
- **comparison of the results with others coming from different and complementary techniques** to have a complete view of the problem and to better define the elemental composition, the phases, the morphology and so on.
- **development of a methodology for the in-situ analysis** using the portable instruments available in HERACLES on the basis of the measurements/data collected from the various ex-situ techniques and their assessment and cross-processing for the different analytical instruments.

For a detailed description of the analytical techniques, including references, refer to deliverable D3.1.

4.3.20.3 Data acquisition - Validation and processing/modelling

Partner in charge for sampling	Ephorate/FORTH/UoC
Partner in charge for data acquisition	FORTH/UoC/UNINOVA/CNR-ISMN/ CVR-INSTM
Partner in charge for data validation	FORTH/UoC/UNINOVA/CNR-ISMN/ CVR-INSTM
Partner in charge for processing/modelling	FORTH/UoC/UNINOVA/CNR-ISMN/ CVR-INSTM

Table 8: Characterization methods applied to the HERACLES test-bed materials, and their duration

Method	Incident radiation or item	Detection	Information	Analyzed depth	Depth resolution	Lateral resolution	Sample dimension	Analysis Time	HERACLES partner
SEM-FIB (with EDS) - Scanning Electron Microscopy not portable	e^-	e^-, X-ray	Microstructural and microchemical characterization (up to the nanoscale)	µm	µm	100 nm (structure), µm (analysis)	mg-µg	Few minutes to some hours	UNINOVA UoC
X-ray Diffraction (also micro) XRD not portable	X-ray	x-ray	Mineralogical analysis	> 10 µm	µm	mm to µm	mg-µg	Few minutes to some hours	UNINOVA UoC CNR-ISMN
X-ray Fluorescence (also micro) XRF not portable	x-ray	x-ray	Chemical analysis	> 10 µm	> 10 µm	mm to µm	mg-µg	Few minutes to some hours	UNINOVA
TG-DTA and DSC Thermogravimetry, Differential Thermal Analysis and Differential Scanning Calorimetry, not portable	heat	Heat, mass changes	Transformation temperatures, enthalpy and mass changes with heating	µg			mg-µg	Few minutes to some hours	UNINOVA UoC
micro Raman, not portable	light	Raman emission	Molecular fingerprint	µm	µm	mm to µm	mg-µg	Few minutes to some hours	UNINOVA UoC
Laser Scanning Microscopy, not portable	laser	light	Confocal Laser Scanning microscopy 3D surface image	µm	µm	0.1 µm	Up to cm	Few minutes to some hours	UNINOVA
Stereo microscopy, not portable	light	light	Optical spectroscopy Surface image	µm	µm	µm	Up to cm	Few minutes to some hours	UNINOVA UoC
FTIR - Fourier Transform Infrared Spectroscopy, not portable	Infrared	Infrared	Composition of materials	µm	µm	mm to µm	Up to cm	Few minutes to some hours	UNINOVA, INSTM, UoC

Ellipsometry, not portable	light	Dispersed light	Dielectric function modulation of materials	nm	Å to µm	µm	Up to cm	Few minutes to some hours	UNINOVA
AFM - Atomic Force Microscopy, not portable	Micro-tip	height	surface analysis technique, producing an actual three-dimensional profile of the surface	First layer	<nm	<nm	Up to cm	Few minutes to some hours	UNINOVA, UoC CNR-ISMN
Spectrophotometry (UV-Vis-NIR)	Light	light	Transmittance and reflectance measurements	First layer	First layer	µm	mg-µg	Few minutes to some hours	UNINOVA, UoC
Porosimetry (Archimedes) and helium picnometry			Open porosity and density measurements Pore size distribution curves				mg-µg	Few minutes to some hours	UNINOVA, INSTM
X-ray photoelectron spectroscopy (XPS)	x-ray	Secondary e^-	elemental composition, empirical formula, oxidation and electronic state of the elements	<μm^3	<10nm	mm to µm	mg-µg	Few minutes to some hours	CNR-ISMN
Laser Induced Breakdown Spectroscopy (LIBS)-laboratory and portable	laser	Plasma emission	Determination of elemental composition of materials	point analysis/extremely high spectral resolution	10-50µm	150-200µm	any	Few minutes to some hours	FORTH-IESL
Multispectral Imaging- laboratory and portable	UV-VIS-NIR Illumination	Diffuse light	Stratigraphic analysis, materials differentiation, monitoring of alterations (eg chemical)	extremely high (5MP, versatile imaging lenses can modify FOV)/moderate spectral	≈1 mm	Depends on magnification	any	Few minutes to some hours	FORTH-IESL

				resolution					
4D surface volume topography	White light illumination	Backscattered light	Artworks and monuments for structural and surface assessment/ diagnosis (technique first time developed for HERACLES)	extremely high (versatile imaging system)	To be determined	To be determined	any	Few minutes to some hours	FORTH-IESL
Non-linear Microscopy laboratory instrument	fs laser	Non-linear phenomena emitted from the sample	laser scanning microscopy to detect interfaces, non-centrosymmetric molecules and fluorescence. Initially tested on selenite, where background is available.	~500µm in transparent samples	2µm	500nm	Limitations related to the sample's size. Scanning region ~ 200 x 200 µm	Few minutes to some hours	FORTH-IESL
Raman spectroscopy - laboratory and portable	laser	Raman emission	Determination of molecular composition of materials	point analysis/extremely high spectral resolution	Max 100µm	≈20µm	any	Few minutes to some hours	FORTH-IESL
Drilling Resistance Measurements System (DRMS)	Drill bit	Drilling resistance	Drilling resistance by depth/sampling	Drilling resistance: F/Nt, Drilling depth: L/µm	10 cm	High resolution	any		UoC
DSC Differential Scanning Calorimetry, not portable	heat	Heat, mass changes	Transformation temperatures, enthalpy and mass changes with heating	µg			mg-µg	Few minutes to some hours	INSTM, UoC

5. Test bed site #2 – Venetian Fortress "Rocca a Mare", "Koules"

5.1 Description of the site

The fortified enclosure of the Venetian Candia (today Heraklion) of the 15th century, which is still preserved today, is one of the most significant monuments of its kind in the whole Mediterranean basin. Another important monument of the period is the imposing fortress of "Koules" which is dominating at the edge of the Venetian NW breakwater of the old harbour (orange circle in Figure 45).

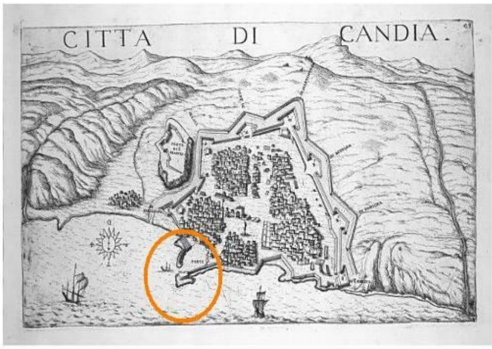

Figure 45: (left) Marco Boschini: *Il regno tutto di Candia. Delineato a parte, Venezia* 1651, (right) Candia, during the last siege from the Ottomans, (1648-1669). Marciana Library, Venice.

It was built by the Venetians before the construction of the new Venetian fortification, in order to protect the pier and the port (Figure 46). It took its last shape in the years 1523-1540, replacing another construction destroyed by an earthquake. The violent waves of the sea have been constantly causing damages to its stonework and foundation, thus it has been continuously repaired.

Figure 46: Aerial photo of Heraklion port and Koules fortress.

On the ground floor, to the left of the main corridor, there are barrel-vaulted rooms, 26 in number, which hosted barracks, warehouses, prison cells and water-tanks. Light and air came to the rooms through the roof. All around the building there were openings for the cannons. A staircase and a ramp for the cannons lead to the upper terrace, around which there were more cannon-openings, barracks, a mill and a beacon. The surrounding walls ended up in a straight parapet, protecting the inner corridor. The battlements were added during the period of the Ottoman occupation

[20]. A scketch of the external façade and grond plan are shown in Figure 47.

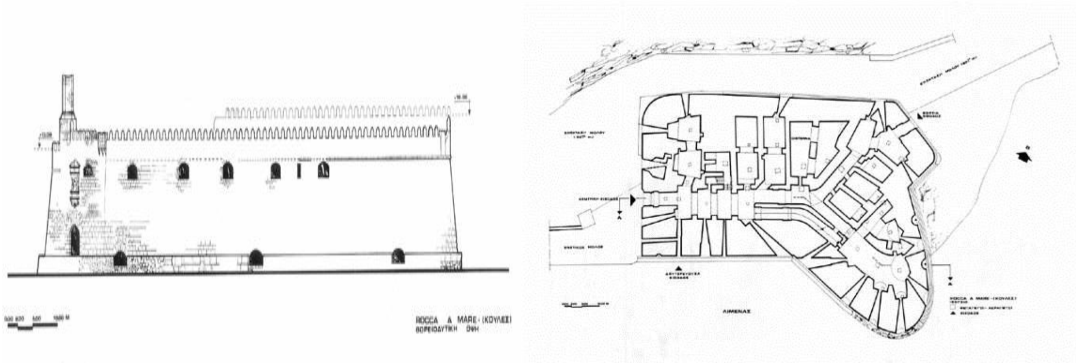

Figure 46: N Side view and ground plan of Rocca a mare, Koules- Ministry of Culture

5.1.1 Previous and recent restorations

The first attempts of restoration started in 1959 by the curator of antiquities Stylianos Alexiou. Further works have been done by M. Borboudakis during the period 1972-75, according to the approved study suggested by A. Lampakis in order to make the fortress accessible for tourists.

During the first decade of 2000, the Greek Ministry of Culture, anticipating the problems that the monument was facing, decided to take new measures for its protection and safeguarding. Under the direction of the Ephorate of Antiquities a National Strategic Reference Framework Project concerning the Restoration and Conservation of the Venetian Fortress (Koules) took place (2011-2016).

In the conservation program the main concern was related to the static and reinforcement aspects of the monument. In order to achieve the desired result, previous interventions to masonries both indoors and outdoors, were removed, the lions reliefs were consolidated and preserved and the old frames of the cannon openings at the ground floor were replaced with stainless ones. Restoration works aimed to was to the cleaning and protection of the stone surfaces from hard salt crusts and biodeterioration signs, where it was possible, without losses of materials. In addition, the three lions emblems at the façades of the monument were cleaned and consolidated in order to achieve compactness (see Figures 48 - 51).

Figure 48: Before cleaning the surface of the lion (SE side

Figure 49: After cleaning.

Figure 50: Black-brown hard crust on lion's surface (SE side).

Figure 51: After cleaning.

It has to be mentioned that during the restoration program (2009), the School of Mineral Resources Engineering of Technical University of Crete had performed analysis of stone masonry carrots, identifying the following types of sedimentary stones:

a) brecciated fossiliferous limestones;
b) microbrecciated limestone;
c) calcarenites sandstones;
d) bioclastic/biomicritic fossiliferous limestone

In 2008, the Ephorate assigned a geophysical study (prospecting by georadar method) to a private technical company to investigate possible decays, erosions and cracks in the walls and pavements of the monument. The geophysical study included georadar lines on the internal, external walls and the pavements of the monument as well (see Figure 52).

Figure 52: An attempt to show the GPR activities (vaulted constructions, fractures, existence of moisture) on the plan.

5.2 End-user detailed requirements

Koules fortress is representing all the coastal monuments present in Europe that face the risk of hazards from climatic changes, such as significant impact from the sea (as sea level is rising, increasing intensity of extreme weather phenomena combined with the air and land associated hazards, raised salinity accelerating corrosion and deterioration of materials and structures, *etc.*). Such hazards affect the monument integrity through time, leaving signs, unfortunately irreversible.

Due to its severe preservation state, hazards and risks have been considered, and its weathering state will be studied through HERACLES project, in order to increase its resilience against degradation factors.

Although different weathering patterns concerning constituting materials are present all over the monument, specific areas are selected to demonstrate and depict the present situation.

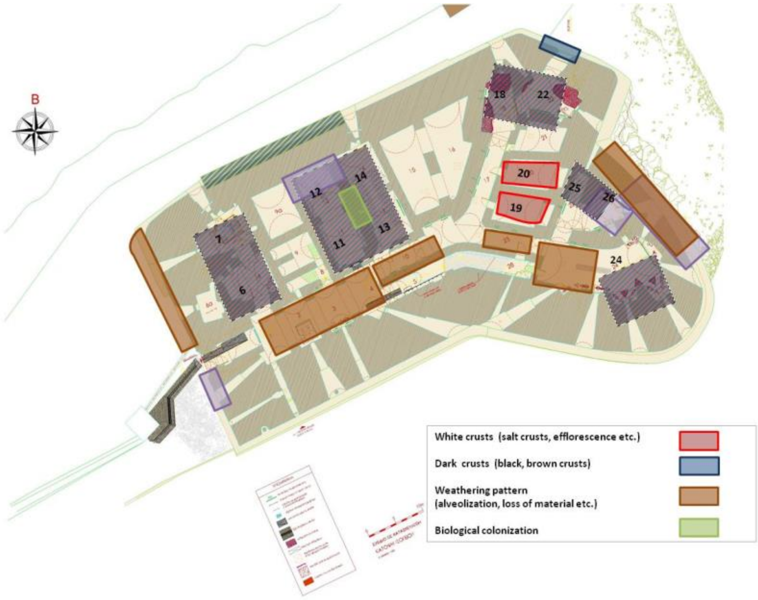

Figure 53: Ground floor plan of the Fortress of Koules. Selected areas with the major hazards.

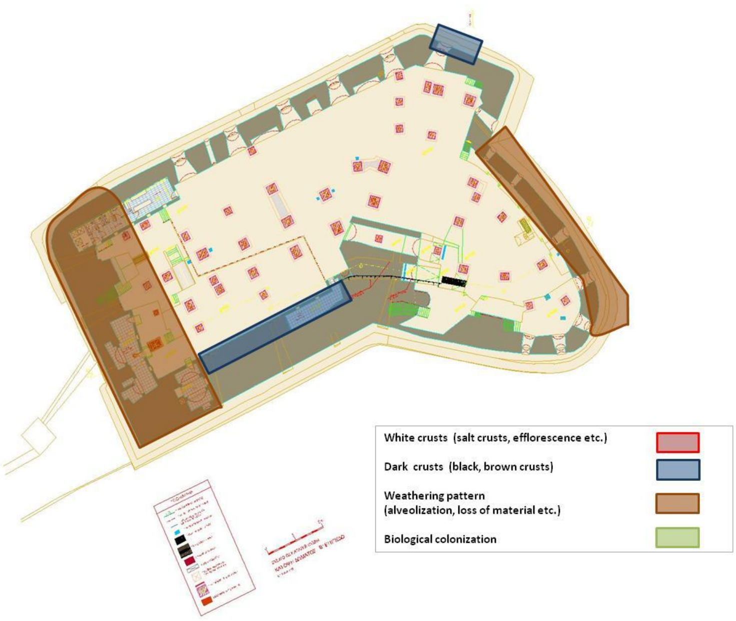

Figure 54: First Floor plan with areas of interest.

The selected areas are shown in Figures 53 and 54. On the ground floor, at rooms 6-7, 11-12, 13-14, humidity is a dominant risk. Especially, at rooms 11-12, during warm days, it appears in an abundant way, deriving mainly from the top and provoking acceleration of decay material mechanism.

Dark colour crusts in combination with white crusts/depositions are covering a large part of the room surface. Some of them are quite hard and adherent to the substrate.

White accumulations, in a form of stalactites, are very common as well, but not as much as efflorescence salts. At room 12, a gap is observed at the contact point of the north vertical wall and the vaulted ceiling. At rooms 18 and 22, where the ancient shipwrecks are exhibited, the same patterns of stone weathering are observed. Among the dark coloured crusts, different typology are observed, at least from an optical inspection. Analytical techniques in the frame of HERACLES project will offer the opportunity to clarify their origins (biological colonization or aggressive agents derived from air pollution).

Rooms 19, 20 (former prisons during the Ottoman occupation) present several white crusts (either efflorescence, or white hard encrustation).

Rooms 24 (sperone), 25 and 26 present all the aforementioned decay patterns and also some structural issues which were faced during restoration works taken place from 2011 to 2016. The cracks were filled with mortar and small stones, both indoors as well outdoors. A similar fracture was observed and restored on the left side of the main entrance.

First floor walls present the same weathering patterns of the areas inside the monument. Degradation of materials depends on the exposure of surfaces to extreme climatic conditions, accelerating their decay mechanism. On the south wall at the terrace, a quite expanded area with black crust is present. Other types of weathering refer to the material loss of stone.

The continuous exposure to marine aerosol of the fortress has produced severe weathering of the building stone (biocalcarenite), which is a porous material susceptible to the action of soluble salts and environmental conditions. The same issue concerns the new materials used for restoration works.

5.2.1 Degradation problems and risks/hazards at the Fortress of Koules

5.2.1.1 Material degradation and structural issues

According to the ICOMOS-ISCS "Illustrated glossary on stone deterioration patterns" 2008 [6], considering the weathering/degradation of materials that the monument is consisted by, the decay factors can categorised to the following deterioration patterns I) Crack and deformation II) Detachment, III) Features induced by material loss, IV) Discoloration and deposit and V) Biological colonization.

In the following figure (Figure 55), some examples of weathering patterns are shown.

Category III) Differential erosion: erosion succeeds irregularly, following the veins of the marble

Category III) Alveolization: formation on the stone surface of cavities

Category IV) Crust: coherent accumulation materials on the surface. Here, black crust and white salt crust

Figure 55: Examples of weathering patterns, according to the ICOMOS glossary [6]

At the Koules sea-fortress the material analysis strategy refers to the monitoring and analysis of the crusts and accumulations, which are present on the monument due to pollution and climatic change effects as previously discussed. Emphasis is given on:

a. **the black deposits** accumulated on the surfaces and due to intense environmental pollution;
b. **bio-degradation** due to the biological activity on the surface, linked to the increasing levels of moisture, the air pollution and the temperature cycle variations;
c. **efflorescence salts** (already extensively described);
d. **white salt accumulations**, probably due to water infiltration through the masonry.

Scientific study and analysis will probably elucidate the presence of the high level of moisture and probably its evolution mapping.

The effects of sea wave impact on the fortress is going to be observed and monitored, considering structural and weathering materials issues.

The cumulative effect of the weathering factor at the monument is unambiguous, since it has been acting for more than five centuries.

Concerning the structural integrity and stability issues, existed fractures at the west and east side of the monument were faced already, during the restoration project launched in 2011, under the direction of the Ephorate.

5.2.1.2 Risks/hazards and climate/monument interaction

Nowadays, the monument presents several degradation problems due to weathering factors provoking its current preservation state. Climate change effects (like heavy rainfall events, temperature cycle variations) in combination with the

increasing pollution levels are also responsible for the present monument degradation.
The consequences of climate change impact in Figures 56 and 57, are clearly shown, where photos taken at the beginning of 20th century and today, are reported: testifying the weathering state evolution.

Figure 56: Lion relief-Main entrance – 1905 [20]

Figure 57: Same relief- Present situation.

5.2.1.2.1 Coastal flooding/wave impact

The Koules fortress, as aforementioned, is located at the entrance of the Venetian port of Heraklion, facing the Cretan sea (Figure 58). Its immediate contact to the sea, makes it vulnerable to sea flooding, waves and salty northern winds, which several times become very severe, reaching the scale of 9 to 10 or even 11 in the Beaufort climax/scale.

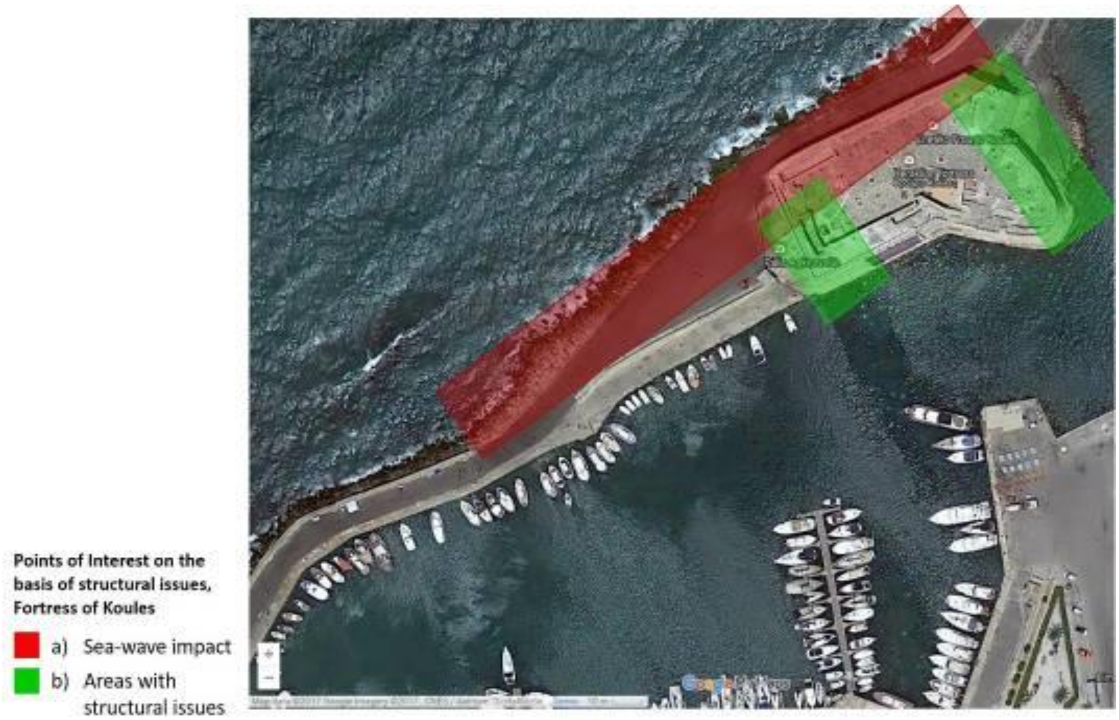

Figure 58: Zone affected by wave impact and zones with structural issues.

Especially during winter season high waves are literally covering it (as shown in Figure 59). That means that waves during rough sea may cause the displacement of breakwater blocks (in red circle of Figure 59) with the consequent damage to the monument surface. In addition to the blocks, sand is transferred out from sea and upon the fortress masonry provoking a sandblasting effect. Furthermore, sea water is a mean of dispersion of soluble salts (mainly chlorides, secondary sulphates) producing an increased and well-known effect on construction material decay (Figure 59)

In addition, sea water flooding (containing dissolved sea salts) penetrates into the pores of the stones, leading to the crystallization of salts within stones and mortars.

Figure 59 (left and right): February 2015. Wind speed reaching the scale of 10 in the Beaufort climax. Waves height can reach approximately up to 20 m.

5.2.1.2.2 Moisture/temperature fluctuations and salt encrustations

Moisture or humidity act as a mean of salt particles transportation from the sea to the monument. The stone deterioration begins with the detachment of the grain aggregates and it proceeds to selective pitting resulting in the formation of deep interconnected cavities. The stone appears to have suffered an irregular loss of material, which follows the alveolar weathering pattern. The final result includes mass loss, colour and texture alterations and structural failure.

Salts crusts, salt efflorescence combined with the existence of a high level of moisture and rising temperature create the conditions for “salt hydration distress” (SHD) occurring in stones. As already mentioned in D 3.1, this term, suggested by the University of Crete to best describe the process, is related to the repeated reconversions of a salt between its anhydrous and hydrated forms.

5.2.1.2.3 Rain, Wind speed/direction

Entire stones or parts of them exposed to rain present surface recession and mass loss by erosion-dissolution in the parts exposed to the rain.

Air humidity associated with marine aerosols (sea spray) favours biological colonisation (lichens, mosses, algae).

Wind is responsible for the transportation of extraneous materials on the monument surfaces. When north winds prevail, aqueous solutions of sodium chlorides (and not only) penetrate into the materials pores, resulting the weathering of stones following the aforementioned phenomena.

When south strong winds occur, sand transported from North Africa deserts creates an unbearable situation for the area exposed to it (Figure 60).

Figure 60: March 2016-Sand transferred from the Sahara desert.

5.2.1.2.4 Air pollution sources

Air pollution (from industries, traffic, domestic heating, etc) often results in the formation of gypseous black crusts and soiling the stone surfaces of the monuments. The intensification of rainfalls including acid rains, in combination with the local extreme winds, results into the weathering of the carbonaceous stones that have been used as construction materials. Moreover, the high concentration of pollution levels is responsible for the accumulation of salt encrustations/deposits on the exposed surfaces of the monument, thus inducing problems that highly affect its preservation state.

The pollution sources affecting the integrity of the fortress are the Nikos Kazantzakis Airport at the East, the chimneys stacks from Public Power Corporation Installations at the West and the Industrial Area of the city of Heraklion at the South East. Furthermore, the smokestacks of the ships constitute an additional source of air pollutants. Minor, but not negligible is considered the pollution coming from domestic heating and vehicle circulation. A map is shown in Figure 61.

Figure 61: Map of the region pointing the main pollution sources of Heraklion city.

5.3 *Demonstration activity on test bed #2 - Venetian Fortress "Rocca a Mare", "Koules"*

In the following picture (Figure 62) a summary of the systematic protocol proposed for the Venetian Fortress is presented. It was the result of the work done in WP3 (D3.1 and D3.2) and here is reported to guide the demonstration activities.
The aim is to provide a clear and easy visualization of all the phases/actions necessary to assess the current situation of the Venetian Fortress.

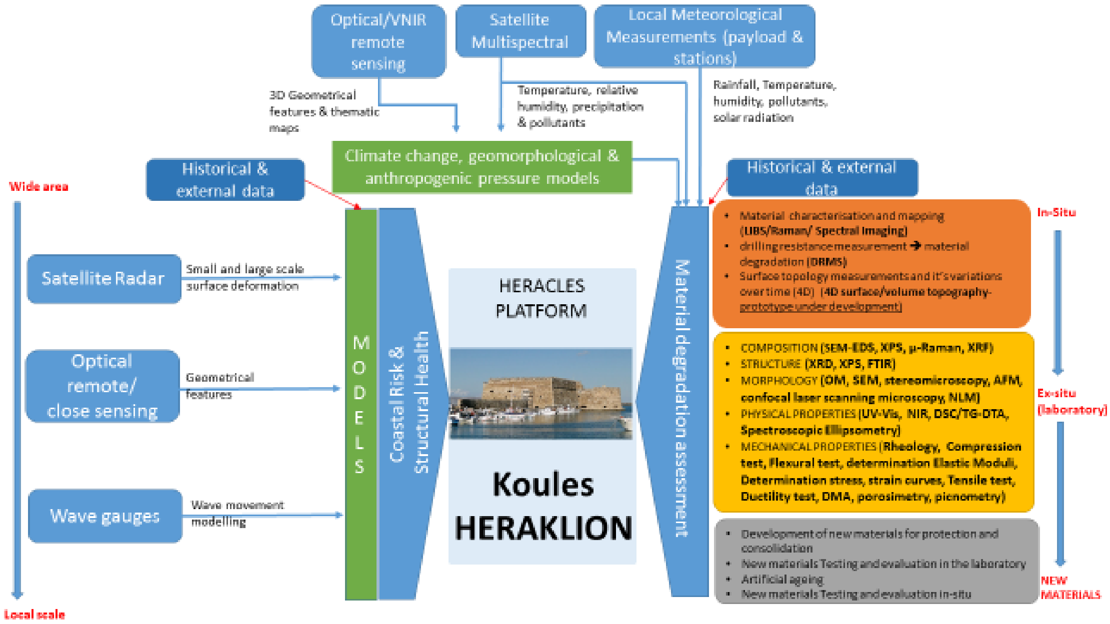

Figure 62: Systematic and complete protocol flow-view for the Venetian Fortress-Koules

5.3.1 Availability of historical information

One DEM from official topographic maps (1:5000) since 1978, and one DEM from official topographic maps (1:20000) since 2000, are available. Also, aerial photos (1945, 1998, 2009), one satellite image worldview 2 from 2009, and geological maps are available. Related to Wave data, Historical wave data from 1980-2007, sea level data from 1957, and wind data time series from 1957 until now, are available.
With specific reference to the Fortress, data are available for the bathymetry and include the Official bathymetric data (10x10m resolution) and two sets of bathymetric data (1mX1m resolution) from previous surveys made by Coastal Research Lab of FORTH-IACM. Also one set of side scan sonar data is available. Related to topographic data there are available one DEM from stereoscopic images 1mX1m resolution, one DEM from D-GPS for Rocca a Mare site.
The situation for the air monitoring parameters is summarised in Table 9.
Meteo-climatic parameters since 2007 (from http://stratus.meteo.noa.gr/front; http://weather.uwyo.edu/cgi-bin/wyowx.fcgi?TYPE=metar&UNITS=M&STATION=LGIR).

HORIZON 2020

Table 9 –Air monitoring parameters

DATA	KOULES		KNOSSOS	
	EXISTING	TO BE ACQUIRED DURING HERACLES PROJECT	EXISTING	TO BE ACQUIRED DURING HERACLES PROJECT
Barometric Pressure	Since 27/04/2007	Timeseries	Since 04/04/2006	Timeseries
Dewpoint (calculated)	Since 27/04/2007	Timeseries	Since 04/04/2006	Timeseries
Evapotranspiration (calculated)	NA	Timeseries	NA	Timeseries
Heat Index (calculated)	Since 27/04/2007	Timeseries	Since 04/04/2006	Timeseries
Humidity	Since 27/04/2007	Timeseries	Since 04/04/2006	Timeseries
Rainfall	Since 27/04/2007	Timeseries	Since 04/04/2006	Timeseries
Rain Rate	Since 27/04/2007	Timeseries	Since 04/04/2006	Timeseries
Solar Radiation	NA	Timeseries	NA	Timeseries
Temperature	Since 27/04/2007	Timeseries	Since 04/04/2006	Timeseries
Temperature Humidity Sun Wind Index	Since 27/04/2007	Timeseries	Since 04/04/2006	Timeseries
Ultra Violet (UV) Radiation Dose	NA	Timeseries	NA	Timeseries
Ultra Violet (UV) Radiation Index	NA	Timeseries	NA	Timeseries
Wind Speed and Direction	Since 27/04/2007	Timeseries	Since 04/04/2006	Timeseries

5.3.2 Measuring Systems to be installed or already installed:

1. Geometrical
   - #1.1 Spaceborne radar COSMO-SKYMED [e-GEOS/CNR]
   - #1.2 UAV-Drone geometrical survey - [e-GEOS]
   - #1.3 Terrestrial Laser Scanner - [e-GEOS]
2. Environmental
   - #2.1a Weather monitoring: local station NETWORK - [FORTH-IACM]
   - #2.1b Weather monitoring: public station NETWORK - [SISTEMA]
   - #2.2 Oceanographic sensors - [FORTH-IACM]
   - #2.3 Drone measurement of climatic parameters (portable environmental payload device for the monitoring of local microclimate variables) – [UNIPG-CIRIAF]
   - #2.4a Temperature-Relative Humidity (RH) sensor data logging system (portable) - [UNIPG-CIRIAF]
   - #2.4b Temperature-Relative Humidity (RH) sensor data logging system (fixed) - [FORTH-IESL]
   - #2.5 Infrared Thermography - [UNIPG-CIRIAF]
   - #2.6 Multispectral remote sensors - [SISTEMA]

5.3.3 Material Characterisation Methodologies

The methodologies that will be used for the characterizations of Venetian Fortress ‘KOULES’ materials are the following:

3. Material - in situ methodologies
   - #3.1 Portable Raman spectroscopy system - [FORTH-IESL]
   - #3.2 Portable LIBS - [FORTH-IESL]
   - #3.3 Portable Multispectral Imaging system - [FORTH-IESL]
   - #3.4 4D Surface/ Volume Topography portable prototype - [FORTH-IESL]
   - #3.5 Drilling Resistance Measurements System (DRMS) - [UoC]
4. Material - Ex situ methodologies
   - #4.1a SEM-FIB (with EDS) - Scanning Electron Microscopy - [UNINOVA]
   - #4.1b SEM-EDS Scanning Electron Microscopy - [UoC]
   - #4.2 X-ray Diffraction (also micro) XRD - [UoC]
   - #4.3 Raman Spectroscopy [UoC]
   - #4.4 Fourier transform infrared spectroscopy (FTIR) [UoC]
   - #4.5 Thermogravimetric Analysis (TGA) – [UoC]

5.3.4 Logistics

- **Access:** via the breakwater until the main entrance or through a wooden ramp (see Figure 63)

Figure 63: Koules entrance

- **Power supply:** A central electrical panel exists in the room near the main entrance. Each room has its own one, providing three phases current (Figure 64).

Figure 64: Koules Power supply

- **Internet**: Internet provided (24 MbPS)
- **Safe deposition of instruments**: yes

5.3.5 VENETIAN FORTRESS 'KOULES' - Test bed sensor #1.1: Spaceborne radar COSMO-SKYMED

5.3.5.1 Description

For the general principles of IFSAR methodology and description of the capability of this technique, refer to section 4.3.5.

In the case of the Koules Fortress, the IFSAR analysis will be carried on to detect displacements of the exposed structures and of the immediate surroundings due to the main environmental factors to which they are exposed, with particular attention to hydrodynamic factors, such as the sea waves action. This result will be correlated to the study of the material degradation, since this phenomenon often involves a significant erosion of the structures and their dimensional change (e.g. lowering of the scattered PS points). The IFSAR analysis uses the remote sensing SAR data.

Both approaches, PSP and TMS, will be used similarly to the Knossos Palace test bed to provide useful information for the qualitative assessment of the stability state of the Fortress and as well as of possible deformation affecting the surrounding area. A preliminary result is shown in Figure 65.

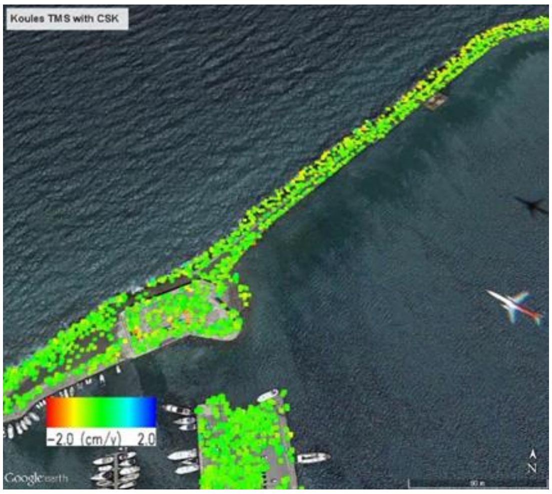

Figure 65: TMS preliminary results on Koules achieved by descending CSK passes

5.3.5.2 Measured parameters

The measured parameters are the same already provided in section 4.3.5.2

5.3.5.3 Installation

Sensing Technique	IFSAR
Sensor location	Not applicable
Where to fix the sensor (post, tripod, etc)	Not applicable
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	Not applicable

Give a description of the installation procedure.	Not applicable
Time required to install the sensor	Not applicable
Possible constraints for the installation (authorizations – announcement in advance, *etc.*)	Not applicable

5.3.5.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	Not applicable
How many measurements are planned to be done	An initial analysis will be performed during WP2 and WP3 activities and an update of the data is foreseen during the demonstration phase
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Not applicable
Dimension of the sensor system (sensor + any electronic control or computer)	Not applicable
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	Not applicable
The instrument requires an Ethernet connection during the experiment.	Not applicable
Time required to perform a preliminary signal processing to ensure the measurement reliability	Not applicable
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Not applicable
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	None

5.3.5.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	Not applicable
Partner in charge for data acquisition	e-GEOS
Partner in charge for data validation	e-GEOS
Partner in charge for processing/modelling	e-GEOS/CNR-IREA/UniPG

5.3.6 VENETIAN FORTRESS 'KOULES' - Test bed sensor #1.2: UAV-Drone geometrical survey

5.3.6.1 Description

UAV is the acronym for Aerial Unmanned Vehicles, best known as drones. UAV surveys will be used on Koules Fortress in order to realize a quick and complete optical survey of the building. The results of the survey will be used, together with the laser scanner survey results, to produce a detailed 3D representation of the structure. The two surveys (UAV and terrestrial laser scanner) will be integrated by optical remote sensing information, thanks to the exploitation of archives of digital aerial ortophotos and, if necessary, by VHR optical satellite images.
The UAV survey is very effective in case of isolated buildings such as Koules Fortress, having some sides not reachable by the ground.

5.3.6.2 Measured Parameters

The drone, equipped with an optical high precision camera, will be manned in order to obtain both a nadiral and oblique survey (Figure 40) of the interested area, having the following features:

- Final resolution of the images = 1 cm
- Optical camera with minimum 20 Megapixels
- Suitable calibration of the camera

The oblique survey will allow the 3D reconstruction of the observed structures with particular attention to the areas of degradation.
In the oblique survey (Figure 40):

- the camera will be positioned at an angle of about 45° towards the nadir
- the path of the survey will be completed by the GPS coordinates

The main outputs of the UAV survey, were already reported in section 4.3.6.2, table 4.
It is important to point out that each aerial survey, UAV included, needs specific authorization by the local authorities. E-GEOS will take care to obtain the necessary licences.

5.3.6.3 Installation

Sensing Technique	UAV survey
Sensor location	Not applicable
Where to fix the sensor (post, tripod, etc)	Not applicable
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	Not applicable
Give a description of the installation procedure.	Not applicable

Time required to install the sensor	Not applicable
Possible constraints for the installation (authorizations – announcement in advance*, etc.*)	Flight permission by local authorities

5.3.6.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	2 days
How many measurements are planned to be done	1 survey
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	NO
Dimension of the sensor system (sensor + any electronic control or computer)	Not applicable
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	Not applicable
The instrument requires an Ethernet connection during the experiment.	Not applicable
Time required to perform a preliminary signal processing to ensure the measurement reliability	Not applicable
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Not applicable
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc.)	Meteo conditions, illumination

5.3.6.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	Not applicable
Partner in charge for data acquisition	e-GEOS
Partner in charge for data validation	e-GEOS
Partner in charge for processing/modelling	e-GEOS

5.3.7 VENETIAN FORTRESS 'KOULES' - Test bed sensor #1.3: Terrestrial Laser Scanner

5.3.7.1 Description

Terrestrial Laser Scanning (TLS) is an imaging technique that performs distance measure at nearly equidistant sampling steps along vertical and horizontal directions.

5.3.7.2 Measured Parameters

The laser scanner acquisition produces cloud of 3D points, whose density on the Venetian Fortress will be of 10.000 points per sqm. The clouds of points will be completed by radiometric information RGB. The survey will be applied to the Koules Fortress. This relief will be very effective in order to detect the entity of the degradation of the material exposed to the waves impact.
Together with the TLS survey, a UAV zenith photogrammetric survey of the whole area will be realized, in order to integrate the 3D reconstruction of the relief obtained by the combination of aerial, with the TLS surveys.
In Figure 66, an example of a TLS relief is given.

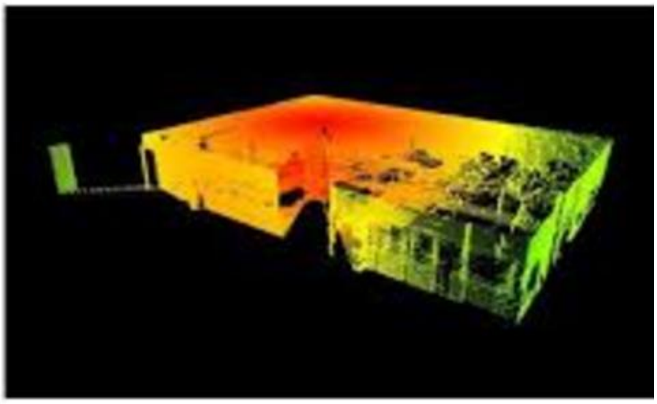

Figure 66: example of a TLS relief and of a points cloud

5.3.7.3 Installation

Sensing Technique	TLS survey
Sensor location	Itinerant sensor
Where to fix the sensor (post, tripod, …)	Not applicable
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	Not applicable
Give a description of the installation procedure.	No installation is foreseen
Time required to install the sensor	Not applicable
Possible constraints for the installation (authorizations – announcement in	Not applicable

advance, *etc.*)	

5.3.7.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	1 day
How many measurements are planned to be done	1 survey
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	battery operated
Dimension of the sensor system (sensor + any electronic control or computer)	Not applicable
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	Not applicable
The instrument requires an Ethernet connection during the experiment.	Not applicable
Time required to perform a preliminary signal processing to ensure the measurement reliability	Not applicable
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Not applicable
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc.)	Meteo conditions, illumination

5.3.7.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	Not applicable
Partner in charge for data acquisition	e-GEOS
Partner in charge for data validation	e-GEOS
Partner in charge for processing/modelling	e-GEOS

5.3.8 VENETIAN FORTRESS 'KOULES' - Test bed sensor #2.1a: Weather monitoring - local station NETWORK

5.3.8.1 Description

The information provided by the Hellenic National Meteorological Service for the surrounding area and the local weather station near the airport will be worked out and used in order to correct the mesoscale data with the aim to minimize the computational error and provide a good estimate of the local current climatic conditions. In addition, a 3m metal mast with a sensor will provide raw data (time series of wind speed and direction, temperature, humidity, rainfall, barometric pressure, solar radiation and UV Index), as well as graphical plots of the measurements (see Figure 67 and Table 10). The provided meteorological data are point data, focusing only on the location of the installed meteorological stations. The data will be made available from the moment the two meteorological stations are in-place and the uplink to the HERACLES database has been established. The sampling frequency of the measured data is 0.4Hz (1 / 2.5sec). The data are averaged on mean minute values.

Table 10: position of the meteorological sensors on Koules terrace.

Name	Longitude (dec. deg)	Latitude (dec. deg)	Elevation (m asl)	Photo Orientation (deg)
Koules_4	35°20'40.14"N	25° 8'13.00"E	6.5	332.82

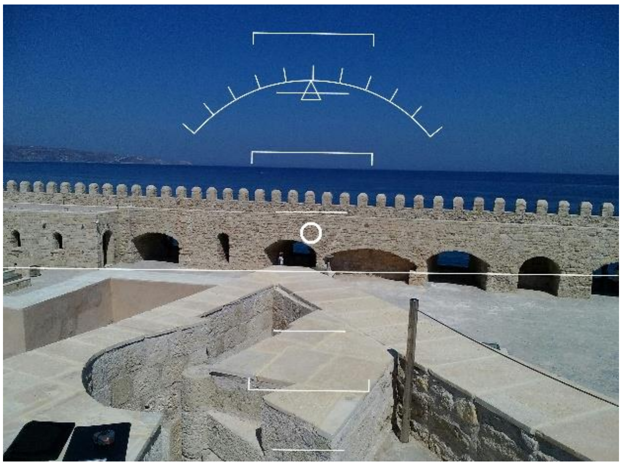


Figure 67: Position of the meteo station mast at the terrace of Koules.

5.3.8.2 Measured parameters

The parameters measured by the microclimate station are summarised in the following table 11:

Table 11: Monitoring parameters at different zones of Koules Fortress

1.	METEOROLOGICAL SENSOR ON KOULES TERRACE	35°20'40.14"N, 25° 8'13.00"E – 6.5m	Wind, Atmospheric Pressure, temperature, Relative Humidity, Solar radiation
2.	Temperature and	Room 11, 12 (see fig. 52, D8.1)	Temperature, Relative Humidity

	humidity microsensor		
3.	Temperature and humidity microsensor	Room 24 (see fig. 52, D8.1)	Temperature, Relative Humidity

5.3.8.3 Installation

Sensing Technique	Point Measurements
Sensor location	Terrace of Koules monument with two additional microsensors in rooms 11, 12, and room 24 (for room location see map Figure 53)
Where to fix the sensor (post, tripod, etc)	On a 3m mast for the meteo station on the terrace. The microsensors in rooms 11, 12 and 24 are hanging from the ceiling.
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	A metal cylindrical mast is anchored on a base to the terrace of the Koules monument with metal screws. The microsensors are hanging from the skylight windows with attached wires, approx. 3 meters from the ground.
Give a description of the installation procedure.	For the meteo station on the terrace, a metal cylindrical mast is anchored on a base to the terrace of the Koules monument with metal screws and the meteorological station is fastened on the top of the mast. In the rooms, the microsensors are fastened firmly with wires on the bars of the skylight windows on the ceiling room and lowered approx. 3 meters above ground level.
Time required to install the sensor	4 hours approximately
Possible constraints for the installation (authorizations – announcement in advance*, etc.*)	The Ephorate has already authorized the necessary procedures

5.3.8.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	The measurements are taken continuously
How many measurements are planned to be done	Continuous measurements till the end of the program

The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The station is powered by a small PV panel and data storage and relay equipment is powered by a regular 220V supply. The microsensors are self-powered by batteries which will last for two years with the current configuration.
Dimension of the sensor system (sensor + any electronic control or computer)	Meteo Station dimension: 279 mm x 238 mm x 533 mm
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	Yes
The instrument requires an Ethernet connection during the experiment.	Yes
Time required to perform a preliminary signal processing to ensure the measurement reliability	1 Hour
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Yes
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	Not applicable

5.3.8.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	FORTH-IACM
Partner in charge for data acquisition	FORTH-IACM
Partner in charge for data validation	FORTH-IACM
Partner in charge for processing/modelling	ARIA

5.3.9 VENETIAN FORTRESS 'KOULES' - Test bed sensor #2.1b: Weather monitoring - public local station NETWORK

5.3.9.1 Description

Weather stations belonging to the public meteorological office of Greece around HERAKLION area have been selected both as complementary local weather data source in addition to the data collected from the weather station installed and managed by FORTH and for the collection of local Climate Data Records (CDR) that can be used to identify climate change trends and climate patterns affecting Koules and Knossos Palace.

5.3.9.2 Measured parameters

The parameters collected from local public weather stations are Temperature, Precipitation and Wind.

5.3.9.3 Installation

This section does not apply to local public weather stations. See also section 4.3.9.3

5.3.9.4 Monitoring

The monitoring system is the same already object of Section 4.3.9.4, and details were already provided in that section.

5.3.9.5 Data Acquisition – Validation and processing/modelling

Partner in charge for installation	Not applicable
Partner in charge for data acquisition	SISTEMA
Partner in charge for data validation	SISTEMA
Partner in charge for processing/modeling	SISTEMA

5.3.10 VENETIAN FORTRESS 'KOULES' - Test bed sensor #2.2: Oceanographic sensors

5.3.10.1 Description

The RBRduet T.D. (Figure 68) wave gauges measuring water level and sea temperature will be deployed in the sea bottom in front of the test-bed of Koules. Their small compact size allows to be installed in a base near the sea bottom. The RBRduet has two channels submersible temperature and depth logger that will allow long term deployments.

Figure 68: RBRduet sensor (left) and example of an installation base.

5.3.10.2 Measured parameters

The wave gauges will provide raw data (time series of sea level and temperature). All data will be available online, and accessible via the HERACLES web page after acquisition and processing. All parameters will be recorded at 2Hz intervals. The raw data will be stored and processed locally and the processed data will be transferred to the database via ftp protocol and stored there. The RBRduet is calibrated to an accuracy of ±0.002°C (ITS-90 and NIST traceable standards) and accuracy of 0.05% full scale for pressure (between -5°C and 35°C). The standard thermistor has a time constant of approximately 1.0 second. The RBRduet T.D. has a measurement range of -5°C to +35°C in its standard calibration.

5.3.10.3 Installation

Sensing Technique	Point Measurements
Sensor location	Two points first ~ 3 m depth, approximately 35°20'41.84"N 25° 8'11.42"E and at ~10m depth, approximately 35°20'42.79"N 25° 8'10.14"E
Where to fix the sensor (post, tripod, …)	A customized cement or sand filled base is needed.
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	No
Give a description of the installation procedure.	The units are submerged in specific depth and fixed into position to provide continues data acquisition
Time required to install the sensor	1 Hour
Possible constraints for the installation (authorizations – announcement in advance*, etc.*)	Large sea waves >2m

5.3.10.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	The measurements are taken continuously
How many measurements are planned to be done	Continuous measurements till the end of the program
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The units are battery powered
Dimension of the sensor system (sensor	Diameter: 63.25mm

+ any electronic control or computer)	Length: 395mm
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	Yes
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	1 h
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Not applicable
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	None

5.3.10.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	FORTH-IACM
Partner in charge for data acquisition	FORTH-IACM
Partner in charge for data validation	FORTH-IACM
Partner in charge for processing/modelling	FORTH-IACM

5.3.11 VENETIAN FORTRESS 'KOULES' - Test bed sensor #2.3: Drone measurement of climatic parameters (portable environmental payload device for the monitoring of local microclimate variables)

5.3.11.1 Description

The description for this sensor was already provided in section 4.3.10.1, since it is referred to the same system that is used in both the Heraklion test-beds (Figure 42). The monitoring campaign took place from July 3rd to 6th, 2017.

5.3.11.2 Measured parameters

The sensors composing the environmental payload and the monitored parameters are summarised in previous table 6, section 4.3.10.2.

5.3.11.3 Installation

Sensing Technique	Microclimate monitoring sensors
Sensor location	The payload device will be used to perform continuous measurement in space and time; therefore it will not be positioned in a specific location. The monitoring path, both from the sky and at pedestrian level, will take place all around the external walls of the Venetian fortress
Where to fix the sensor (post, tripod, etc)	No mechanical supports are needed
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	No actions that could modify the structure are necessary
Give a description of the installation procedure.	The payload device will be installed on a drone and on a helmet
Time required to install the sensor	-
Possible constraints for the installation (authorizations – announcement in advance, *etc.*)	Drone flights will take place during the closing hours of the tourist site.

5.3.11.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	From July 3rd to 6th, 2017
How many measurements are planned to be done	At least one measurement from the sky, by means of drone, and one at pedestrian level, by means of the helmet, will be performed.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery operated. Battery operation time = 3 hours Battery charging time = 8 hours
Dimension of the sensor system (sensor + any electronic control or computer)	Height: 10 cm Width: 20 cm Depth: 15 cm
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	No
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary	The sensors constituting the monitoring

signal processing to ensure the measurement reliability	system are already calibrated so the measurement reliability is guaranteed. The data analysis and post-processing will require a few months.
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Compatible with all the other measures
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	-

5.3.11.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	UNIPG/CIRIAF
Partner in charge for data acquisition	UNIPG/CIRIAF
Partner in charge for data validation	UNIPG/CIRIAF
Partner in charge for processing/modelling	UNIPG/CIRIAF

5.3.12 VENETIAN FORTRESS 'KOULES' - Test bed sensor #2.4a: Temperature-Relative Humidity (RH) sensor data logging system (portable)

5.3.12.1 Description

The description for this sensor was already provided in section 4.3.11.1, since it is referred to the same system that is used in both the Heraklion test-beds. The thermal-humidity sensor will be located in shaded areas.

5.3.12.2 Measured parameters

Parameters monitored by TGP-4500 sensor are (i) air temperature and (ii) relative humidity. The operative ranges of the devices are -25 ÷ +85°C and 0 ÷ 100% for temperature and relative humidity respectively.

5.3.12.3 Installation

Sensing Technique	Microclimate monitoring sensors
Sensor location	Shaded place in the proximity of the fortress or on its top
Where to fix the sensor (post, tripod, etc)	No mechanical supports are needed
The sensor installation require to drill,	No actions that could modify the

glue, paint or other action that could change the state or the aspect of the structure	structure are necessary
Give a description of the installation procedure.	The sensor can be simply put or clamped on available supports already present in the area
Time required to install the sensor	Just few minutes to find the optimal location for the sensor
Possible constraints for the installation (authorizations – announcement in advance, *etc.*)	Authorizations from Ephorate are necessary

5.3.12.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	Continuous monitoring. Due to internal memory space, the data must be downloaded every 113 days of monitoring
How many measurements are planned to be done	UNIPG/CIRIAF will provide this sensor during the continuous monitoring carried on by payload (3rd-6thJuly). Afterwards, the Ephorate will provide their own sensor
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery operated, no power supply is needed
Dimension of the sensor system (sensor + any electronic control or computer)	Height: 34 mm Width: 57 mm Depth: 80mm
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	To be consistent with the Gubbio case study, one year of monitoring is recommended
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	-
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Compatible with all the other measures
Factors affecting the measurement (sun insulation, temperature, meteorological	Direct insulation and rainfall can affect measurement of the device

conditions, etc)	

5.3.12.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	UNIPG/CIRIAF
Partner in charge for data acquisition	UNIPG/CIRIAF
Partner in charge for data validation	UNIPG/CIRIAF
Partner in charge for processing/modelling	UNIPG/CIRIAF

5.3.13 VENETIAN FORTRESS 'KOULES' - Test bed sensor #2.4b: Temperature - Relative Humidity (RH) sensors data logging system (fixed)

5.3.13.1 Description

The Temperature and Relative Humidity loggers (Figure 43 - section 4.3.12.1) are compact sized sensors integrating a battery and a built-in memory. This way they can autonomously operate and periodically store data. The loggers provide a USB 2.0 connection allowing users to download data acquired by the loggers and schedule the measurements. The whole process is performed via dedicated software.
The main specifications of the sensors were already given in Table 7- section 4.3.12.1

5.3.13.2 Measured parameters

Parameters monitored by the sensor are relative humidity and air temperature. The operative ranges of the device are 0 to 100% (± 2% RH) and -40 ° C to + 85 ° C (± 0.3° C) for relative humidity and temperature respectively.

5.3.13.3 Installation

Sensing Technique	Temperature and Humidity data loggers
Sensor location	At various locations of the monument (Rooms 11-12, 24) Figure 66
Where to fix the sensor (post, tripod, etc)	No
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	No
Give a description of the installation procedure.	The sensor will be fixed 3-4 meters from ground at a robust point via a string.
Time required to install the sensor	30 minutes
Possible constraints for the installation (authorizations – announcement in advance, *etc.*)	Announcement to the Ephorate


Figure 69: Data loggers for measuring RH and temperature, installed by FORT/IESL in rooms 11-12 and 24 (Sperone) at Koules fortress.

5.3.13.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	Continuous recording
How many measurements are planned to be done	Long term measurements (1-2 years)
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery operated
Dimension of the sensor system (sensor + any electronic control or computer)	67 x 40 x 16 mm
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	Yes
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	Data download time. Requires unfixing of the logger. Approx 30 minutes
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Performs independently
Factors affecting the measurement (sun insulation, temperature, meteorological	Environmental conditions affect data

conditions, etc)	

5.3.13.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	FORTH-Ephorate
Partner in charge for data acquisition	FORTH-Ephorate
Partner in charge for data validation	FORTH (IACM)
Partner in charge for processing/modelling	FORTH (IACM)

5.3.14 VENETIAN FORTRESS 'KOULES' - Test bed sensor #2.5 Infrared Thermography

5.3.14.1 Description

The description for this sensor was already provided in section 4.3.13.1, since it is referred to the same system that is used in both the Heraklion test-beds.
A first campaign already took place on November 6-9th, 2016. The second one took place in the first week of July 2017 (i.e. from 3rd to 6th).

5.3.14.2 Measured parameters

The infrared thermographic camera detects the infrared energy emitted by bodies and so their superficial temperature [°C] which is converted in electronic signal and then elaborated to produce images as the one reported in Figure 44, section 4.3.13.2. The superficial temperature of the object is therefore determined.

5.3.14.3 Installation

The installation details were already given in section 4.3.13.3

5.3.14.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	One-day measurement
How many measurements are planned to be done	At present, two monitoring campaigns were scheduled. Both already took place during November 6-9th 2016 and July 2017.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery operated
Dimension of the sensor system (sensor + any electronic control or computer)	Portable camera (about 20x10x10 cm)
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to	No

perform a several days monitoring.	
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	No time is required
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	Compatible with all the other sensing techniques
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc.)	-

5.3.14.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	UNIPG/CIRIAF
Partner in charge for data acquisition	UNIPG/CIRIAF
Partner in charge for data validation	UNIPG/CIRIAF
Partner in charge for processing/modelling	UNIPG/CIRIAF

5.3.15 VENETIAN FORTRESS 'KOULES' - Test bed sensor #2.6: Multispectral remote sensors

5.3.15.1 Description

Multispectral remote sensing description was already provided in section 4.3.14.1. The multispectral data are collected over both the test sites in Heraklion .

5.3.15.2 Measured parameters

The multispectral sensors identified for HERACLES allows the measurements of those parameters that affect directly or indirectly the historical buildings and structures. Other details were already provided in section 4.3.14.2.

5.3.15.3 Installation

This section does not apply to satellite multispectral sensors.

5.3.15.4 Monitoring

Monitoring details are the same already given in section 4.3.14.4.

5.3.15.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	Not applicable
Partner in charge for data acquisition	SISTEMA

Partner in charge for data validation	SISTEMA
Partner in charge for processing/modelling	SISTEMA

5.3.16 VENETIAN FORTRESS 'KOULES' – Test-bed methodology #3.1: Portable Raman Spectroscopy System

5.3.16.1 Description

The description for this methodology was already provided in section 4.3.15.1, since it is referred to the same system that is used in both the Heraklion test-beds.

5.3.16.2 Measured parameters

The measured parameters were already described in section 4.3.15.2

5.3.16.3 Installation

The installation details were already given in section 4.3.15.3

5.3.16.4 Monitoring

The monitoring details were already given in section 4.3.15.4

5.3.16.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	IESL-FORTH
Partner in charge for data acquisition	IESL-FORTH
Partner in charge for data validation	IESL-FORTH
Partner in charge for processing/modelling	IESL-FORTH

5.3.17 VENETIAN FORTRESS 'KOULES' - Test bed methodology #3.2: Portable LIBS

5.3.17.1 Description

The description for this methodology was already provided in section 4.3.16.1, since it is referred to the same system that is used in both the Heraklion test-beds.

5.3.17.2 Measured parameters

The measured parameters were already described in section 4.3.16.2

5.3.17.3 Installation

The installation details were already given in section 4.3.16.3

5.3.17.4 Monitoring

The monitoring details were already given in section 4.3.16.4

5.3.17.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	IESL-FORTH
Partner in charge for data acquisition	IESL-FORTH
Partner in charge for data validation	IESL-FORTH
Partner in charge for processing/modelling	IESL-FORTH

5.3.18 VENETIAN FORTRESS 'KOULES' - Test bed methodology #3.3: Portable Multispectral Imaging system

5.3.18.1 Description

The description for this methodology was already provided in section 4.3.17.1, since it is referred to the same system that is used in both the Heraklion test-beds.

5.3.18.2 Measured parameters

The measured parameters were already described in section 4.3.17.2

5.3.18.3 Installation

The installation details were already given in section 4.3.17.3

5.3.18.4 Monitoring

The monitoring details were already given in section 4.3.17.4

5.3.18.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	IESL-FORTH
Partner in charge for data acquisition	IESL-FORTH
Partner in charge for data validation	IESL-FORTH
Partner in charge for processing/modelling	IESL-FORTH

5.3.19 VENETIAN FORTRESS 'KOULES' - Test bed methodology #3.4: 4D Surface/Volume Topography portable prototype

5.3.19.1 Description

The description for this methodology was already provided in section 4.3.18.1, since it is referred to the same system that is used in both the Heraklion test-beds.

5.3.19.2 Measured parameters

The measured parameters were already described in section 4.3.18.2

5.3.19.3 Installation

The installation details were already given in section 4.3.18.3

5.3.19.4 Monitoring

The monitoring details were already given in section 4.3.18.4

5.3.19.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	IESL-FORTH
Partner in charge for data acquisition	IESL-FORTH
Partner in charge for data validation	IESL-FORTH
Partner in charge for processing/modelling	IESL-FORTH

5.3.20 VENETIAN FORTRESS 'KOULES' - Test bed methodology #3.5: Drilling Resistance Measurements System (DRMS)(in-situ)

5.3.20.1 Description

The description of this methodology was already provided in Section 4.3.19.1.

5.3.20.2 Measured parameters

The measured parameters were already described in Section 4.3.19.2.

5.3.20.3 Installation

Sensing Technique	DRMS
Sensor location	Marly limestones and sandstones highly affected by salt efflorescence.
Where to fix the sensor (post, tripod, etc)	No
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	Drilling (6mm in diameter, 10cm max depth) is required in order to estimate the state of preservation and to collect the drilling residue.
Give a description of the installation procedure.	Drilling on the surface of the architectural/building elements of the monument.
Time required to install the sensor	Approximately 30 minutes for each spot.
Possible constraints for the installation (authorizations – announcement in advance, *etc.*)	Drilling permission, sample collection permission.

5.3.20.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, *etc.*)	30 minutes
How many measurements are planned to be done	4 per stone. Up to 160 measurements
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery operated

Dimension of the sensor system (sensor + any electronic control or computer)	30x20x20 cm
It is planned to leave the sensor instrumentation on the test bed location during all the experiment period to perform a several days monitoring.	No
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	-
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without affecting the measurement of the specific technique?)	XRD, Spectroscopies, Electronic Microscopy
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc.)	Humidity in the stone

5.3.20.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	UoC
Partner in charge for data acquisition	UoC
Partner in charge for data validation	UoC
Partner in charge for processing/modelling	UoC

5.3.21 VENETIAN FORTRESS 'KOULES' – Test-bed analytical techniques #4.1: Stone, mortar and weathering crusts samples analysis

5.3.21.1 Description

At the Koules sea fortress the material analysis strategy refers to the monitoring and analysis of stones, mortars and weathering crusts, which are present on the monument due to pollution and climatic change effects as previously discussed. Emphasis is given to:

a. the features of construction stones, which are particularly sensitive to a number of factors, humidity and salt deposits being the most important.

b. the historical mortars as well as recent ones, with the aim to evaluate their performance against weathering and other effects of climate change

c. weathering crusts (i.e. black deposits, bio-degradation accumulations, efflorescence salts etc.) accumulated on the surfaces and due to intense environmental agents.

As already discussed in previous document (D3.1), our strategy will focus not only on the characterization of the degraded materials but also on the understanding of the degradation mechanisms, as well as, on how these processes evolve in correlation with the pollution and extreme weather conditions.

5.3.21.2 Measured parameters

All the considerations already made in Section 4.3.20.2 are appropriate for the present discussion, too. The investigation approach is similar to the one chosen for the Knossos Palace, described in the previous section 4.3.20.2. As reported before, the diagnostic strategy for the materials will include the use of techniques for physical, chemical, morphological, mineralogical, mechanical and thermo-physical characterization of the materials and weathering products characterizing Koules.
To characterize the impact of atmospheric pollutants it is necessary to collect as much information as possible from different analytical techniques, to obtain a complete and detailed overview of the building conservation state.
After sampling campaigns on the selected areas of the monument, the characterization of the weathering state of the materials started and the techniques used have been reported and briefly described in Table 8, in section 4.3.20.2.
The principal work flow steps are the same already given in section 4.3.20.2

5.3.21.3 Data acquisition - Validation and processing/modelling

Partner in charge for sampling	Ephorate/FORTH/UoC
Partner in charge for data acquisition	UoC/FORTH/UNINOVA/CNR-ISMN/CVR-INSTM
Partner in charge for data validation	UoC/FORTH/UNINOVA/CNR-ISMN/CVR-INSTM
Partner in charge for processing/ modelling	UoC/FORTH/UNINOVA/CNR-ISMN/CVR-INSTM

6. Modelling systems implemented on the test beds

6.1 Climate change and extreme weather conditions modelling

In order to understand the potential evolution of the pressure on cultural heritage linked to climate change, a collection of numerical results of IPCC climatic simulations will be gathered. This will allow to analyse the differences between current climatology (<2020) and the future climate (> 2050) as well as to evaluate the impact of pollutant deposition on buildings for a typical year after 2050 for the test cities.
The analysis of climate change pressure on cultural heritage will be based on the EURO-CORDEX modelling initiative.

6.1.1 EURO-CORDEX regional climate downscaling

EURO-CORDEX is the European branch of the CORDEX initiative (Coordinated Regional climate Downscaling Experiment) and will produce ensemble climate simulations based on multiple dynamical and empirical-statistical downscaling models forced by multiple global climate models from the Coupled Model Intercomparison Project Phase 5 (CMIP5). EURO-CORDEX is a voluntary effort of many of the leading and most active institutions in the field of regional climate research in Europe. EURO-CORDEX domain and available data are shown in figure 70.

Region
Lat.: ~27N-72N, Long.:~22W- 45E

Spatial resolution (EUR-11)
0.11 degree

Time periods
- Hindcast (ERA Interim): 1989-2008
- Control: 1951-2005 (1981-2010,1951-80)
- Scenario: 2006-2100 (2041-71, 2011-40, 2071-2100)

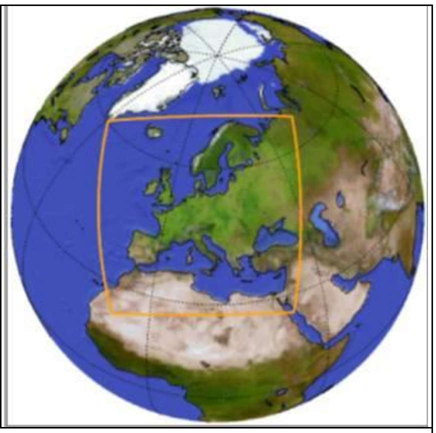

Figure 70: EURO-CORDEX domain and data available.

Unlike most other regions of the earth, coordinated ensembles of regional climate simulations at rather high spatial resolution already exist for Europe (Ensembles, Prudence). These climate scenarios were earlier provided on grid-sizes down to 25 km and were based on the previous generation of emission scenarios (SRES). In order to proceed from this point, the EURO-CORDEX simulations not only considers the new RCP scenarios (Representative Concentration Pathways, IPCC Fifth Assessment Report (AR5)), published in Nov. 2014, but also increase spatial resolution. EURO-CORDEX simulations focus on grid-sizes of about 12 km (0.11 degrees).
The pathways are used for climate modelling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively) (Figure 71).

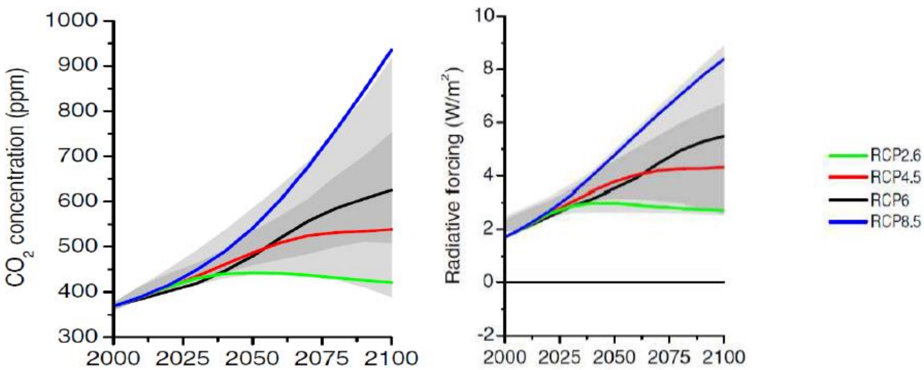

Figure 71: CO_2 concentrations (left) and radiative forcing (right) due to all climate forcers in the RCP scenarios. From van Vuuren et al. (2011) [21].

Mid- and late-21st century projections of global warming from the IPCC Fifth Assessment Report (IPCC AR5 WG1) are illustrated below in Table 12 and in Figure 72. The projections are relative to annual average temperature and precipitation in the late-20th to early-21st centuries (1986-2005 average).

Table 12 – AR5 global warming increase (°C) projections

AR5 global warming increase (°C) projections		
	2046-2065	**2081-2100**
Scenario	Mean and *likely* range	Mean and *likely* range
RCP2.6	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)
RCP4.5	1.4 (0.9 to 2.0)	1.8 (1.1 to 2.6)
RCP6.0	1.3 (0.8 to 1.8)	2.2 (1.4 to 3.1)
RCP8.5	2.0 (1.4 to 2.6)	3.7 (2.6 to 4.8)

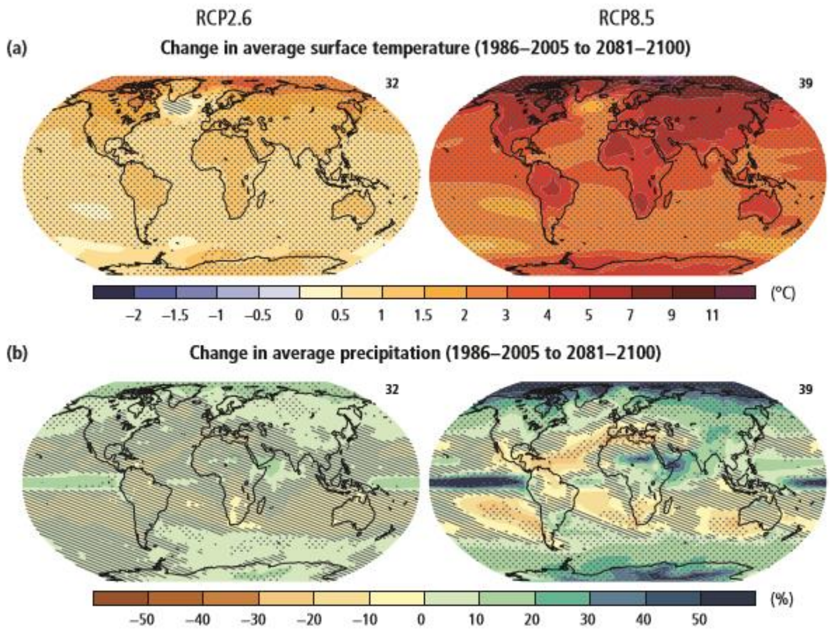

Figure 72: Change in average surface temperature (a) and change in average precipitation (b) based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios.

According to the IPCC, global warming of more than 2°C would have serious consequences, such as an increase in the number of extreme climate events. The Paris Agreement, which entered into force on 4th November 2016, aims at strengthening the global response to the threat of climate change by keeping a global temperature rise this century well below 2 Celsius degrees above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 Celsius degrees.

6.1.2 Methodology for HERACLES test beds

The output from the EURO-CORDEX Regional climate simulations (12.5km resolution over Europe) will be used to analyse the evolution that can be expected in a future climate. No further dynamical downscaling of the climate simulations will be made. The future climate (> 2050) relative to the current climate (<2020) will be analysed for the regions of interest by using the average EUR-11 model ensemble members. The climate scenarios will be based on one of the IPCC RCP scenarios (TBD).

Definition of work:

- Analysis of historical and future climate periods for the EURO CORDEX modelling grids corresponding to the two test-beds
- Preparation of indicators and criteria for the meteorological parameters of interest for the evaluation of Climate Change on Cultural Heritage (impact indices such as severity of rain, intensity of rain, dry spells, heat waves) in coordination with WP1 (user needs requirements) and WP 2 (Cross correlation including the needs expressed by other HERACLES partners on data on future climate change). The indicators will be prepared based on the historical climate period.
- Analyses of the evolution of these indicators for the future climate.

6.1.2.1 Data required for carrying out the modelling task

The input data required for this task correspond to output data from the different models included in the EURO-CORDEX project. ARIA is responsible for the collection of these data. Requirements from other HERACLES partners concerning the need of data from the analyses on climate change will be provided by ARIA within the cross correlation carried out in WP2.

6.2 Anthropogenic pressure modelling

The implementation of a meteorology and air pollution analysis system will be made by setting up a combination of regional scale and micro scale modelling tools.

6.2.1 Modelling tools

The regional scale modelling tools are built around nested versions of the WRF (Weather Research and Forecast) mesoscale meteorological model and of the CHIMERE (or FARM) reactive transport and dispersion models, which take atmospheric emissions and their interactions into account. The solutions can then be nested down to metric resolution with the PMSS model (Parallel Micro SWIFT SPRAY), readily applicable to the detailed description of air pollution at the local scale, and its effects on buildings façades, monuments and statues. The combination of regional and local scale tools allows including the contribution to air pollution from both distant and local emission sources (industrial, traffic, residential sectors, etc). An example of model output is shown in Figure 73.

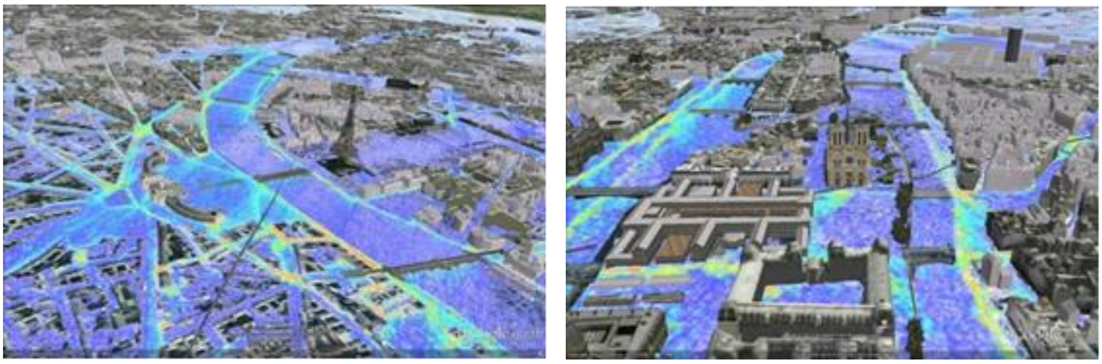

Figure 73: Example of model output: NOx ground level distribution computed in the surrounding of Paris monuments in the framework of the AIRCITY Project with the PMSS model (left: Eiffel Tower area; right: Notre-dame cathedral area).

A more detailed description of the different models and the typical model outputs can be found in the technical document "Model description" prepared within WP2 activity.

6.2.2 Methodology for Heraklion test beds

For the Heraklion site, the detailed actions are listed below and summarised in Figure 74:

- Detailed emission inventory for the city of Heraklion, including significant industrial, traffic and airport/harbour emissions, and its surrounding region (Crete).
- Development of a continuous 24/7 regional scale simulation system (WRF/CHIMERE) with a 3km resolution refined grid over Heraklion.
- Demonstration testing and validation by running the PMSS high-resolution (3m) air quality models on the selected areas of Heraklion (one domain for Knossos and one for Koules) for one year of meteorological data from a recent period (year 2015 or 2016 most likely).
- Analyses of the potential evolution of air quality impact on Cultural Heritage based on future climate scenarios

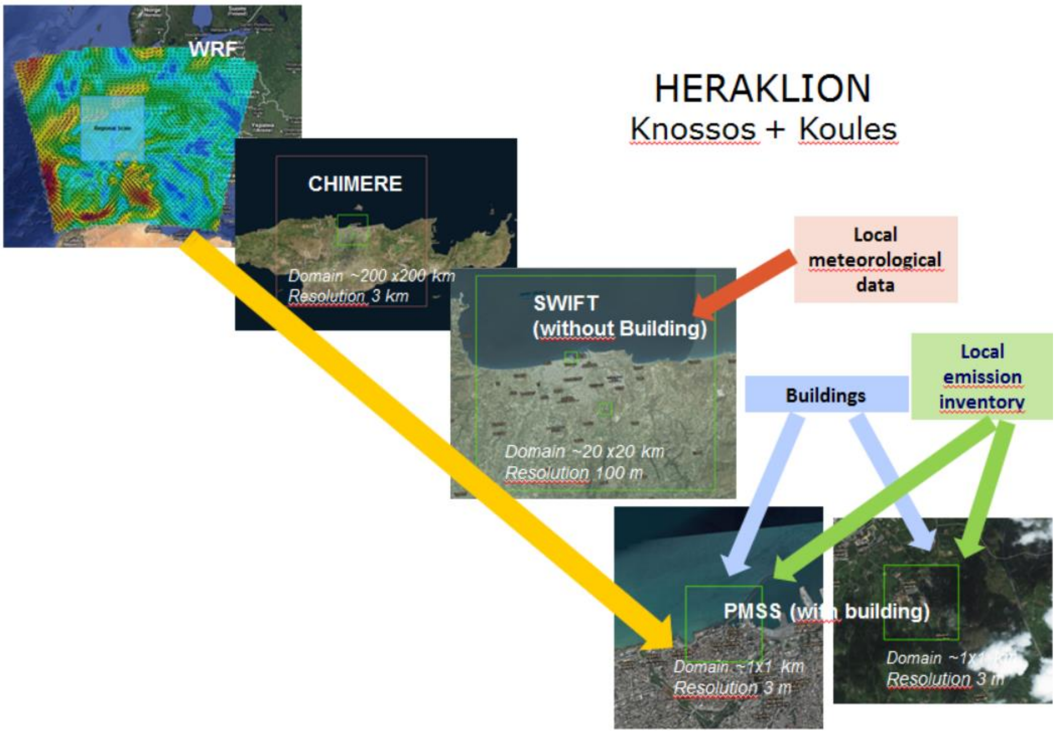

Figure 74: Methodology for Heraklion testbed

6.2.2.1 Input Data required for the modelling

Below is a flowchart (Figure 75) showing the different modules (text in red) of the air quality system as well as the input data (text in black) required to run the models. More details about the input data and formats required to collect in order to run the models can be found in the technical document "Model description" prepared within WP2 activity.

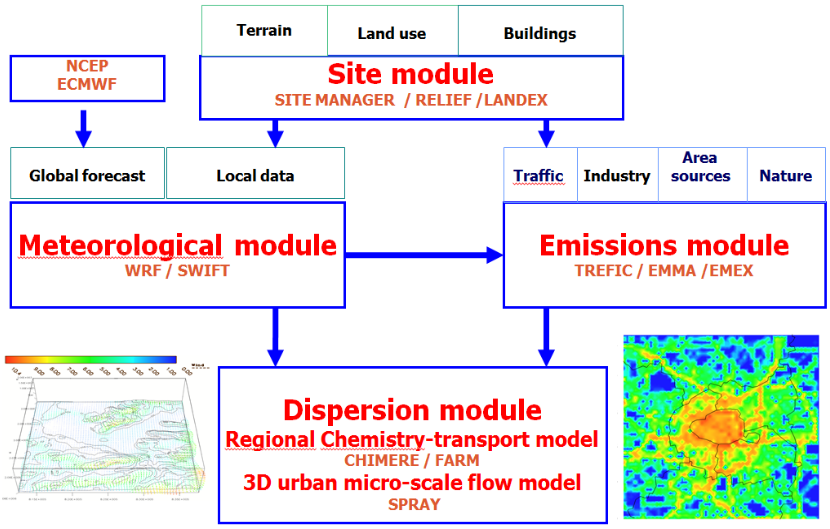

Figure 75: Air Quality system flowchart

The different data to collect, the partner responsible for each task and the time schedule have been defined in WP2 and summarised in Table 13.

Table 13: Planning of data collection and modelling deadlines (according to WP2)

		up to May, 30th	up to June 30th	up to July 15th	up to August 10th	up to September, 15	Up to December, 31th	up to March, 2018
MAIN INPUT PREDISPOSITION (from WP3)								
Responsability								
e-GEOS	DSM (3D topography)	X						
FORTH	Base Cartography (Land Cover 1:10.000/CTR 1:5.000)	X						
e-GEOS	3D landmark (detailed 3D model of the buildings)				X			
FORTH	Pollution sources			X				
SISTEMA	Meteo data		X					
FORTH?	Air Quality data			X				
e-GEOS	LOD1 3D models (raw 3D model on wide area)				X			
MODELING								
Responsability								
SISTEMA	Meteoclimatic data collection			X				
ARIA	Antrophogenic (due in WP8 demo phase)							X
ARIA	Climate Change					X (Oct, 31st)		

6.2.2.2 Model output

The SWIFT meteorological model produces a mass-consistent wind field using data from a dispersed meteorological network and/or by extracting data from a regional scale meteorological model. Temperature, pressure and humidity fields can also be interpolated.

The PMSS dispersion model calculates the average and instantaneous pollutant concentration on a three-dimensional mesh as well as the dry and wet deposition of chemically inert species released in meteorological complex conditions. It can provide high-resolution modelling of pollutant concentrations and deposition on buildings, with metric resolution.

6.2.2.3 Model validation

For the validation of the air quality model, available data on air quality measurements will be used. All existing sources of data for air pollution measurements in the area of the test sites should be collected. An indication on the type of station should further be given: industrial, traffic, urban, suburban or background (rural) or similar.

Unfortunately, for Heraklion only old data on air quality measurements exist (data from before year 2004).

7. Conclusions and further plans

7.1 Conclusions

At the time of writing this deliverable, several activities are running and have already run, in terms of installation, measurements campaigns with in-situ instrumentation, time–continuous monitoring with fixed sensors, as well sampling campaign and ex-situ analysis.

At the Palace of Knossos several activities have already begun and the following systems/sensors have been installed and are providing data:

- 2.1a Weather monitoring: local station NETWORK
- 2.1b Weather monitoring: public local NETWORK
- 2.3b Temperature - Relative Humidity (RH) sensor data logging system (fixed).

Several measurement campaigns have been carried out and the relative data processing is on-going for:

- 2.2 UAV/Drone and field measurement of climatic parameters (portable environmental payload device for the monitoring of local microclimate variables).
- 2.3a Temperature - Relative Humidity (RH) sensor data logging system for specific days of 2.2 activity (portable).
- 2.4 Infrared Thermography

For global long term monitoring of the site, the observations and related data processing have been started for:

- 1.1 Spaceborne radar COSMO-SKYMED
- 2.5 Multispectral remote sensors

In the next months, are expected the activities regarding

- 1.2 UAV/Drone geometrical surveys,

The activities regarding the material characterization by means of the portable instruments have started for:

- 3.1 Portable Raman Spectroscopy system
- 3.2 Portable LIBS, in the next months, are expected.
- 3.3 Portable Multispectral Imaging

In the next months, are expected the activities regarding

- 3.5 Drilling resistance measurement system

Sampling campaigns and material characterization ex-situ started and are on-going.

At Venetian Fortress 'KOULES' there have been installed and providing data the following sensors:

- 2.1a Weather monitoring: local station NETWORK.
- 2.1b Weather monitoring: public local station NETWORK
- 2.4b Temperature - Relative Humidity (RH) sensor data logging system (fixed).

Several measurement campaigns have been carried out and the relative data processing is on-going for:

2.3 UAV/Drone measurement of climatic parameters (portable environmental payload device for the monitoring of local microclimate variables).

2.4a Temperature - Relative Humidity (RH) sensor data logging system (portable).

2.5 Infrared Thermography

For global long term monitoring of the site, the observations and related data processing have been started for:

1.1 Spaceborne radar COSMO-SKYMED

2.6 Multispectral remote sensors

Are expected in the next months the activity regarding:

1.2 UAV/Drone geometrical surveys

2.2 Oceanographic sensors

The activities regarding the material characterization by means of the portable instruments have started for:

3.1 Portable Raman Spectroscopy system

3.2 Portable LIBS, in the next months, are expected.

3.3 Portable Multispectral Imaging

In the next months, are expected the activities regarding

3.5 Drilling resistance measurement system

Sampling campaigns and material characterization ex-situ started and are on-going.

It is estimated that by mid-autumn the installation of the remaining part of the recording systems will have been completed.

It has to be underlined the successful effort which allowed the starting, coordination and integration of the majority of the different activities and systems involved, toward the common goal. Therefore, by the end of 2017 all the sensors/systems and the technical activities, will be active and the demonstration phase will enter in the phase of full operability.

7.2 Heracles Platform Test perspectives

The other main aim of the WP8 activities will be the HERACLES platform validation. According to this, evaluation criteria and indicators should be defined and will be the object of the next WP8 deliverable (D8.3 First evaluation of HERACLES effectiveness and possible recovery actions).

The first tests are planned from December 2017 (according to WP8 kick-off meeting discussion). Important activities for this objective, will be developed in the framework of WP6 activities. Of course, the activities of WP8 are strictly related with those of WP5 and WP6.

In fact, while WP5 defines the system requirements and architecture, WP6 is devoted to develop blocks of integrated functionalities and to release the integrated platform. This platform will made available for testing, according to the evaluation criteria and indicators defined in WP8.

HORIZON 2020

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