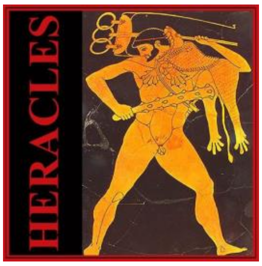

HERACLES

HEritage **R**esilience **A**gainst **CL**imate **E**vents on **S**ite

Deliverable D8.2
Description of the site and detailed end-users requirements and definition of the logistics for the monitoring system at GUBBIO

Version: V1.0

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1.0	13/Sept/ 2017	Final version CNR-ISMN	G.Padeletti, A. Curulli, F. Soldovieri

Table of contents

1 Executive Summary

Deliverable 8.2 “Description of the site and detailed end-users requirements and definition of the logistics for the monitoring system at GUBBIO” 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 on of the activities according to: the definition of a demonstration planning, the setting up of the experimentation phases, the conduction of the experimentation of the different activities, at component/system level. The document recalls the end user needs, and provide a description of the areas of interest with a special focus on the logistics for the demonstration activities, focussing on the modalities of installation of the single sensors. The demonstration activities will be carried on according to the protocols outlined in document D3.1. They have been developed for the Gubbio monument/asset of interest for HERACLES project , i.e. Town Walls and Consoli Palace.

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

The Sections 4 (#1: the Town Walls) and 5 (#2: the Consoli Palace) describe the test-bed sites, providing construction details, the position and finally the necessities and the solutions for 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, 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, processed and evaluated, with the aim to provide an output from the different evaluation batches (data model, material analysis, etc) to the platform and/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 (at different level of details) 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 full effectiveness of the protocols defined in 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 describes the modelling tool implemented on the test-beds.
Section 7 presents the 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 expertise 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**: one of them is the historical town of Gubbio, in Italy (on the Tentative List of immaterial UNESCO Heritage for its traditions and history), which will be the object of the present deliverable. In addition, to the historical value, the two test-beds, (Gubbio and Heraklion) 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 the frequency of extreme events and particularly their 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 interactions).
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 - Survey of the state of art of the technologies of interest for HERACLES	Deliverable D1.4
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
HERACLES-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*

FULL NAME	ACRONYM
2D	Bi-dimensional
3D	Three-dimensional
3DR	Three-Dimensional Reconstruction (shape)
4D	Fourth-dimensional
AAT	Automatic Aero Triangulation
AFM	Atomic Force Microscopy
AIRS	Atmospheric Infrared Sounder on TERRA & AQUA
AMSU	Advanced Microwave Sounding Unit on TERRA & AQUA
AOT	Aerosol Optical Thickness
APM	Anthropogenic Pressure Modelling
AR5	Fifth Assessment Report
ARPA	Agenzia Regionale per la Protezione Ambientale
ASCII	American Standard Code for Information Interchange
ASTM	American Society for Testing and Materials
ATR	Attenuated Total Reflectance
BF	Bright field
CAESAR	Component Analysis and Selection Synthetic Aperture Radar
CC	Climate Change
CCEWM	Climate Change and Extreme Weather Modelling
CCD	Charge-Coupled device
CH	Cultural Heritage
CIR	Colour-InfraRed
CMIP5	Coupled Model Intercomparison Project Phase 5
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
CORDEX	COordinated Regional climate Downscaling Experiment
COSMO-SkyMed	COnstellation of small Satellites for Mediterranean basin Observation
CSV	Comma-separated values
CTE	Coefficient of Thermal Expansion
DAQ	Data acquisition
DEM	Digital Elevation Model
DF	Dark-field
DInSAR	Differential SAR Interferometry technology
DMA	Dynamic Mechanical Analyser
DRMS	Drilling Resistance Measuring System
DSC	Differential Scanning Calorimetry
DSC-TGA	Differential Scanning Calorimetry-Thermogravimetric Analysis
DSM	Digital Surface Model
DTM	Digital Terrain Model
EBSD	Electron Backscatter Diffraction
ED	Energy-Dispersive
EDS	Energy-Dispersive X-ray Spectroscopy
EDXS	Energy Dispersive X-ray Spectroscopy
e-geos	electronics-Global Earth Observation Services
ENVISAT	Environmental Satellite
EO	Earth Observations
ERT	Electric Resistivity Tomography
ERS-2	European Remote Sensing satellite
ESRI	Environmental systems research institute
FARM	Flexible Air quality Regional Model
FIB-SEM	Focused Ion Beam- Scanning Electron Microscopy
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
FTIR	Fourier Transform Infrared Spectroscopy
ftp	File Transfer Protocol
Geotiff	public domain metadata standard which allows geo-referencing information to be embedded within a TIFF (Tagged Image File Format) file
GIS	gas injection system
GIS	Geographic Information System
GM	Geomorphological Modelling
GNSS	Global Navigation Satellite Systems
GOME	Global Ozone Monitoring Experiment
GPR	Ground Penetrating Radar

GS	Ground Stability
GSD	Ground Sample Distance
HA	Hazard Assessment
HDF	Hierarchical Data Format
HR	High Resolution
HSB	Humidity Sounder for Brazil on TERRA & AQUA
IC/DIC	Interference Contrast/ Differential Interference Contrast
IFSAR	Interferometric synthetic aperture radar, abbreviated in SAR (or deprecated IFSAR)
InSAR	SAR Interferometry technology
INSTM	consorzio Interuniversitario Nazionale per la Scienza e Tecnologia dei Materiali (the consortium Inter-universities for Science and Technology of Materials)
IPCC	Intergovernmental panel for Climate Change
ISS	Integrated Sensor Suite
LED	Light Emitting Diode
LIBS	Laser Induced Breakdown Spectroscopy
LIFS	Laser Induced Fluorescence Spectroscopy
LOD1	Level Of Detail 1
LOD2	Level Of Detail 2
LOS	Line Of Sight
LST	Land Surface Temperature
LSM	Laser Scanning Microscopy /microscope
LVDT	Linear Variable Differential Transformer
MCM	Micro Climate Monitoring
MDC	Material Diagnostic and Characterization
MIBACT	Ministero dei Beni e delle Attività Culturali e del Turismo
MISR	Multi-angle Imaging Spectro-Radiometer
MODIS	Moderate Resolution Imaging Spectro-Radiometer
MPEF	Multi Photon Excitation Fluorescence
MS	Multi Spectral sensor
MSG	Meteosat Second Generation satellites
MSI	Multispectral Imaging
MTOW	Max Take-Off Weight
MWT	MicroWave Tomography
Netc.DF	Network Common Data Form
NI	National Instrument
OMI	Ozone Monitoring Instrument
OPT	Optical sensor
PDMS	PolyDiMethylSiloxane
PL	Polarized Light
PM	Particulate Matter (related to particle pollution)
PMSS	Parallel Micro SWIFT SPRAY
PS	Persistent Scatterer

PSI	Persistent Scatterer Interferometry
PSP	Persistent Scatterers Pairs
PXIe	Rugged PC-based platform for measurement and automation system
RAM	Random Access Memory
RASCAN/4000	Holographic radar system
RCP	Representative Concentration Pathways
Res2DInv	Commercial software
RGB	Red, Green and Blue (colour code)
RH	Relative Humidity
RPAS	Remotely Piloted Aerial System
RTK	Real time positioning
SAM	Structural Analysis and Modelling
SAPR	Sistemi Aeromobili a Pilotaggio Remoto (Aeromobil System Remote Piloting)
SAR	Synthetic Aperture Radar
SCIAMACHY	SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY
SD	Secure Digital
SEM	Scanning Electron Microscope
SERS	Surface Enhanced Raman Spectroscopy
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SHD	Salt hydration distress
SFI	Solid Fat Index
SGM	Semi-Global Matching
SHG	Second Harmonic Generation
SHM	Structural Health Monitoring
SONREB	SONic REBound
SRES	Special Report on Emissions Scenarios
SS-EN-ISO	Site Security - International Organization for Standardization
SVD (TSVD)	Singular Value Decomposition (Truncated Singular Value Decomposition)
TBD	To Be Defined
TG- DTA	Thermogravimetry and Differential Thermal Analysis
THG	Third Harmonic Generation
TLS	Terrestrial Laser Scanning
TMC	CAESAR-based SAR Tomography
TMS	Tomographic SAR
TSVD	Truncated Singular Value Decomposition
UAV	Unmanned Aerial Vehicle
UNINOVA	Universidade NOVA de Lisboa
UniPg/UNIPG/	University of Perugia
UNIPG/DICA	University of Perugia/Dipartimento Ingegneria Civile e Ambientale
UNIPG/CIRIAF	University of Perugia/Centro Interuniversitario di Ricerca sull'Inquinamento da Agenti Fisici.

UoC/ UOC	University of Crete
UV-Vis-NIR	UltraViolet–Visible-Near-Infrared
UVB	Ultra-Violet-B
VHR	Very High Resolution
VNIR	Visible - Near Infrared
VOC	Volatile Organic Compound
VU	Vulnerability
WD	Wavelength-dispersive
WDXRF	Wavelength-dispersive XRF
WG	Working Group
WGS84	World Geodetic System 1984
WP	Work Package
WRF	Weather Research and Forecast
XPS	X-Ray Photoelectron Spectroscopy
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

2.3 *Scope & objectives*

This deliverable is an outcome of Task 8.2 of WP 8, which deals with Demonstrators and results analysis.

The focus of Task 8.2 is on demonstration testing and validation at Case study 2-Gubbio.

Deliverable 8.2, starting from the end-user requirements and site detailed description (already provided in the deliverables D1.2), including 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 and the measurements performed. In particular, D8.2 benefits of the work made for delivering:

- 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 deliverable D8.2 is structured according to three main blocks that correspond to:

1. The description of the test-bed scenarios and the scheduling and logistics definition for the HERACLES project experimentation;
2. The detailed description of the site and of the end-users requirements for the Gubbio Town Walls test-bed;
3. The detailed description of the site and of the end-users requirements for the Consoli Palace test-bed.

The Scheduling part (Section 3) is giving an overview of the experimentation schedule, according to the end-to-end scenarios from the WP1 needs definition and refinements and the D3.1 protocols. It presents the different activities set up for a) installation of sensors and use of techniques, b) the different duration and constraints for data and samples collection, c) the validation process scheduling and duration for the different HERACLES analysis, monitoring, simulation, maintenance and remediation phases.

The Test-bed site #1- The Town Walls, Section 4, is detailing the first Gubbio test-bed site, from the risks affecting it on the basis of the end-user requirements to the logistical constraints for the Town Walls demonstration test-bed.

The parallel Section 5, Test- bed site #2 – Consoli Palace is on the second Gubbio test-bed site, and is detailed from the risks affecting it to its logistical requirements.

In both sections, 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 with ex-situ techniques. The ex-situ techniques are not typically considered as sensing techniques, and cannot produce immediate or time-continuous data: for this reason they are not described in the demonstration scheduling, but in Table 12.

The conclusive part is about the experimentation planning for Gubbio test-beds and sets up the perspectives and the further experimentation steps, which will be detailed in the deliverable 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 just in a unique 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 activity needs.

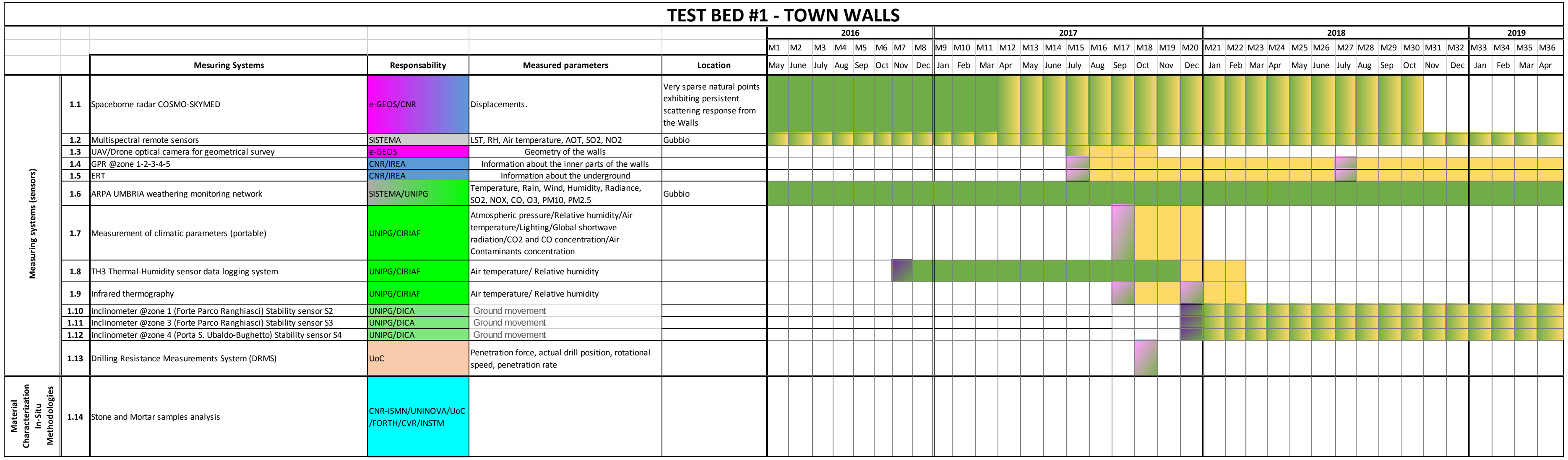
The common activities that are and will be performed are:

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

Details per sensor/model needs are reported in the following sections. In Tables 1 and 2 the planned activities and related agreed time frame for the two Gubbio test-beds, are shown.

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

Table 1 – Measuring Systems Scheduling at testbed#1 – Town Walls



TEST BED #1 - TOWN WALLS

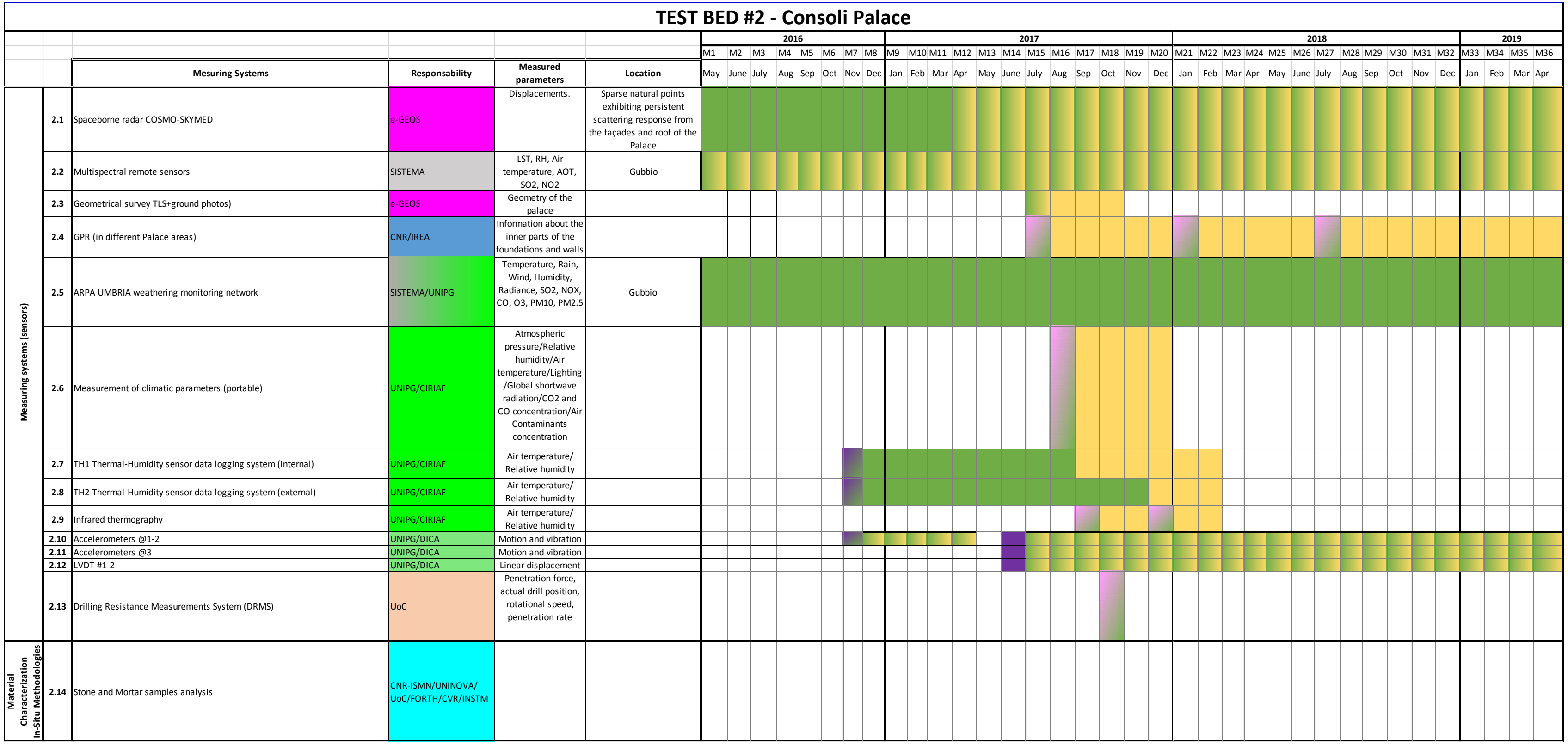
		Mesuring Systems	Responsability	Measured parameters	Location
Measuring systems (sensors)	1.1	Spaceborne radar COSMO-SKYMED	e-GEOS/CNR	Displacements.	Very sparse natural points exhibiting persistent scattering response from the Walls
	1.2	Multispectral remote sensors	SISTEMA	LST, RH, Air temperature, AOT, SO2, NO2	Gubbio
	1.3	UAV/Drone optical camera for geometrical survey	e-GEOS	Geometry of the walls	
	1.4	GPR @zone 1-2-3-4-5	CNR/IREA	Information about the inner parts of the walls	
	1.5	ERT	CNR/IREA	Information about the underground	
	1.6	ARPA UMBRIA weathering monitoring network	SISTEMA/UNIPG	Temperature, Rain, Wind, Humidity, Radiance, SO2, NOX, CO, O3, PM10, PM2.5	Gubbio
	1.7	Measurement of climatic parameters (portable)	UNIPG/CIRIAF	Atmospheric pressure/Relative humidity/Air temperature/Lighting/Global shortwave radiation/CO2 and CO concentration/Air Contaminants concentration	
	1.8	TH3 Thermal-Humidity sensor data logging system	UNIPG/CIRIAF	Air temperature/ Relative humidity	
	1.9	Infrared thermography	UNIPG/CIRIAF	Air temperature/ Relative humidity	
	1.10	Inclinometer @zone 1 (Forte Parco Ranghiasci) Stability sensor S2	UNIPG/DICA	Ground movement	
	1.11	Inclinometer @zone 3 (Forte Parco Ranghiasci) Stability sensor S3	UNIPG/DICA	Ground movement	
	1.12	Inclinometer @zone 4 (Porta S. Ubaldo-Bughetto) Stability sensor S4	UNIPG/DICA	Ground movement	
	1.13	Drilling Resistance Measurements System (DRMS)	UoC	Penetration force, actual drill position, rotational speed, penetration rate	
Material Characterization In-Situ Methodologies	1.14	Stone and Mortar samples analysis	CNR-ISMN/UNINOVA/UoC /FORTH/CVR/INSTM		

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

🟪	Installation
🟩	Data collection
▨	One day measurement - No long-term installation required
🟨	Data analysis

HISTORICAL INFORMATION		up to May 30th 2017	up to June 30th 2017	up to July 15th 2017	up to August 31st 2017
Municipality of Gubbio	Base Cartography (Land Use Map 1:10.000) (from City Plan Map state-of-the-art 2007)	x			
Municipality of Gubbio	Historical Landslide events info since XVIII cent.				x
Municipality of Gubbio	Geological map (1:10.000) (from City Plan Map state-of-the-art 2007)				x
Municipality of Gubbio	Geomorphological map (from City Plan Map state-of-the-art 2007)				x
Municipality of Gubbio	Drainage network (waste water) @ July 2017 from *Umbra Acque* private company				x
SISTEMA	Meteo-climatic parameters historical series (from 2007 - ARPA)	Continuative activity			

Table 2 – Measuring Systems Scheduling at testbed#2 – Consoli Palace



TEST BED #2 - Consoli 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
		Mesuring Systems	Responsability	Measured parameters	Location	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
Measuring systems (sensors)	2.1	Spaceborne radar COSMO-SKYMED	e-GEOS	Displacements.	Sparse natural points exhibiting persistent scattering response from the façades and roof of the Palace	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨
	2.2	Multispectral remote sensors	SISTEMA	LST, RH, Air temperature, AOT, SO2, NO2	Gubbio	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨
	2.3	Geometrical survey TLS+ground photos)	e-GEOS	Geometry of the palace																🟩🟨	🟨	🟨	🟨																		
	2.4	GPR (in different Palace areas)	CNR/IREA	Information about the inner parts of the foundations and walls																🩷🟩	🟨	🟨	🟨	🟨	🟨	🩷🟩	🟨	🟨	🟨	🟨	🟨	🩷🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
	2.5	ARPA UMBRIA weathering monitoring network	SISTEMA/UNIPG	Temperature, Rain, Wind, Humidity, Radiance, SO2, NOX, CO, O3, PM10, PM2.5	Gubbio	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	2.6	Measurement of climatic parameters (portable)	UNIPG/CIRIAF	Atmospheric pressure/Relative humidity/Air temperature/Lighting /Global shortwave radiation/CO2 and CO concentration/Air Contaminants concentration																	🩷🟩	🟨	🟨	🟨	🟨																
	2.7	TH1 Thermal-Humidity sensor data logging system (internal)	UNIPG/CIRIAF	Air temperature/ Relative humidity								🟪🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨														
	2.8	TH2 Thermal-Humidity sensor data logging system (external)	UNIPG/CIRIAF	Air temperature/ Relative humidity								🟪🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨														
	2.9	Infrared thermography	UNIPG/CIRIAF	Air temperature/ Relative humidity																		🩷🟩	🟨	🟨	🩷🟩	🟨	🟨														
	2.10	Accelerometers @1-2	UNIPG/DICA	Motion and vibration								🟪🟩	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨		🟪	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨
	2.11	Accelerometers @3	UNIPG/DICA	Motion and vibration															🟪	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨
	2.12	LVDT #1-2	UNIPG/DICA	Linear displacement															🟪	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨	🟩🟨
	2.13	Drilling Resistance Measurements System (DRMS)	UoC	Penetration force, actual drill position, rotational speed, penetration rate																			🩷🟩																		
Material Characterization In-Situ Methodologies	2.14	Stone and Mortar samples analysis	CNR-ISMN/UNINOVA/ UoC/FORTH/CVR/INSTM																																						

🟪	Installation
🟩	Data collection
🩷	One day measurement - No long-term installation required
🟨	Data analysis

HISTORICAL INFORMATION		up to May 30th 2017	up to June 30th 2017	up to July 15th 2017	up to August 31st 2017
Municipality of Gubbio	Base Cartography (Land Use Map 1:10.000) (from City Plan Map state-of-the-art 2007)	x			
Municipality of Gubbio	Historical Landslide events info since XVIII cent.				x
Municipality of Gubbio	Geological map (1:10.000) (from City Plan Map state-of-the-art 2007)				x
Municipality of Gubbio	Geomorphological map (from City Plan Map state-of-the-art 2007)				x
Municipality of Gubbio	Drainage network (waste water) @ July 2017 from *Umbra Acque* private company				x
SISTEMA	Meteo-climatic parameters historical series (from 2007 - ARPA)	Continuative activity			

4 Test-bed site #1 – Town Walls

4.1 Description of the site

4.1.1 Introduction

The Town Walls were built to protect the city against invasions, sieges and enemies raids over two thousand years, continuously modified through elevations, renovations, expansions, reinforcements, modifications and demolitions, too. The part of the urban Walls exposed to the maximum risk is located on the slopes of Ingino Mountain in N/NE direction and were built before 1302.

Nowadays, the area is mostly interested by olive plantations, while in the past was also used by wood-cutters and farmers. The area inside the Walls was used as military bastions (such as the "*Cassero*") until the XVI Century, after which it has been mostly used for farming uses.

From historic information, i.e. pictures and paintings, it was possible to point out how the forestation, currently visible outside the Walls, is very recent and has arisen only just after the World War II. In fact, in the past, only few trees and bushes were present and unable to stop sediments and surface flows.

4.1.2 Construction details

The Town Walls have a length of 2.85 kilometres, a maximum height of 12 metres, a thickness variable from 0.5 to 3 meters and variable sections. In fact, while in most parts the Walls present a monolithic structure, in other parts (i.e. in some test-bed zones), they have a multi-level hollow core section. These tunnels allowed the soldiers to move through them and to reach all the defensive towers and/or bastions. They are made in masonry with stone (mainly limestone) and mortar.

4.1.3 Exposition and cartographic information

Below, in Table 3, are listed the test-beds areas (also shown in Figure 1) and their geographical coordinates:

Table 3: Test-beds areas

Areas	Coordinates
Zone 1 ("Forte di Parco Ranghiasci");	N 43.354898, E 12.579112
Zone 2 ("Cassero");	N 43.354227, E 12.581295
Between zone 3 ("Torre") and zone 4 ("Porta S. Ubaldo")	N 43.353775, E 12.581751 →N 43.353268, E 12.582156
Between zone 4 and zone 5 ("Bughetto")	N 43.353268, E 12.582156 → N 43.353268, E 12.582156

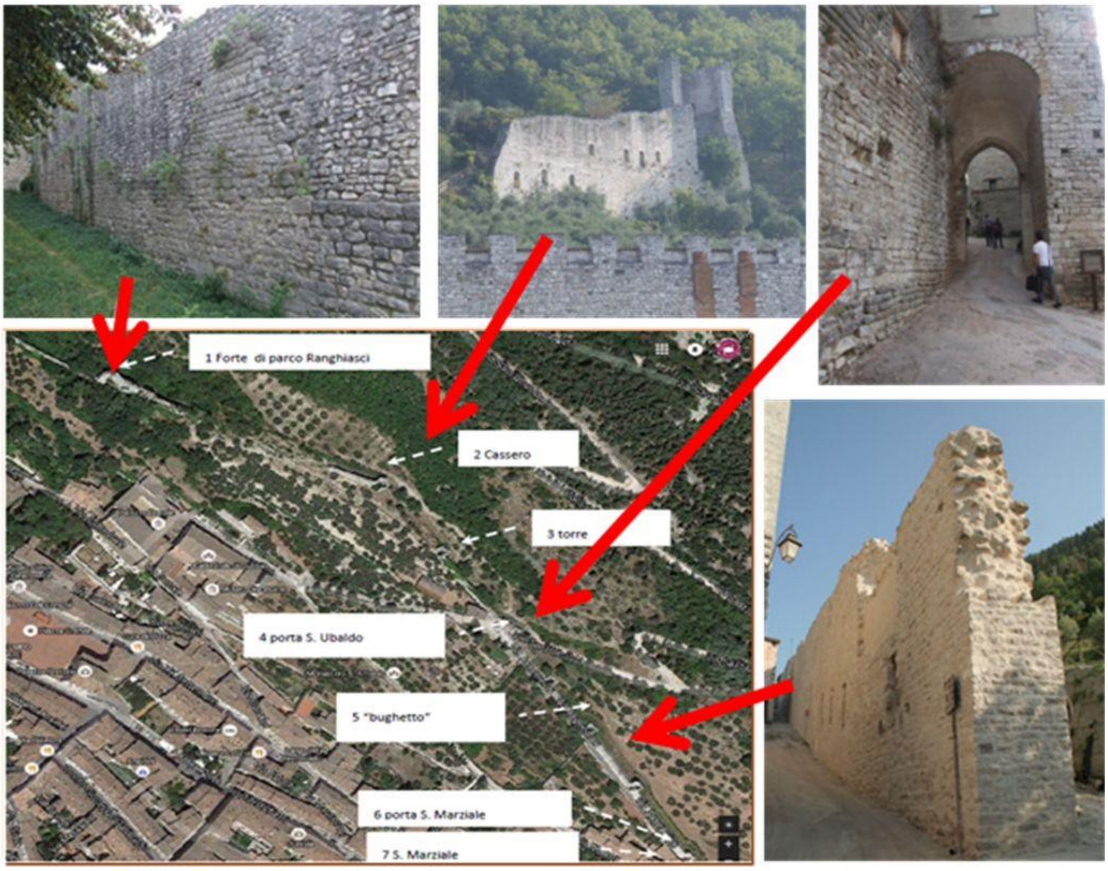


Figure 1: Old Town Walls – test-bed sites location

4.1.4 Logistics

The following images (Figs. 2-4) describe the logistics of the test-beds areas.

There is only one possible access to reach the Town Walls by car: the one through *"Porta Romana"*.

The access with car or small pick-up to the old town is strictly allowed to resident people and a system of automatised check-in is going to be installed, so in case of access, permission should be asked to the Gubbio municipality.

However, there is a free car park nearby.

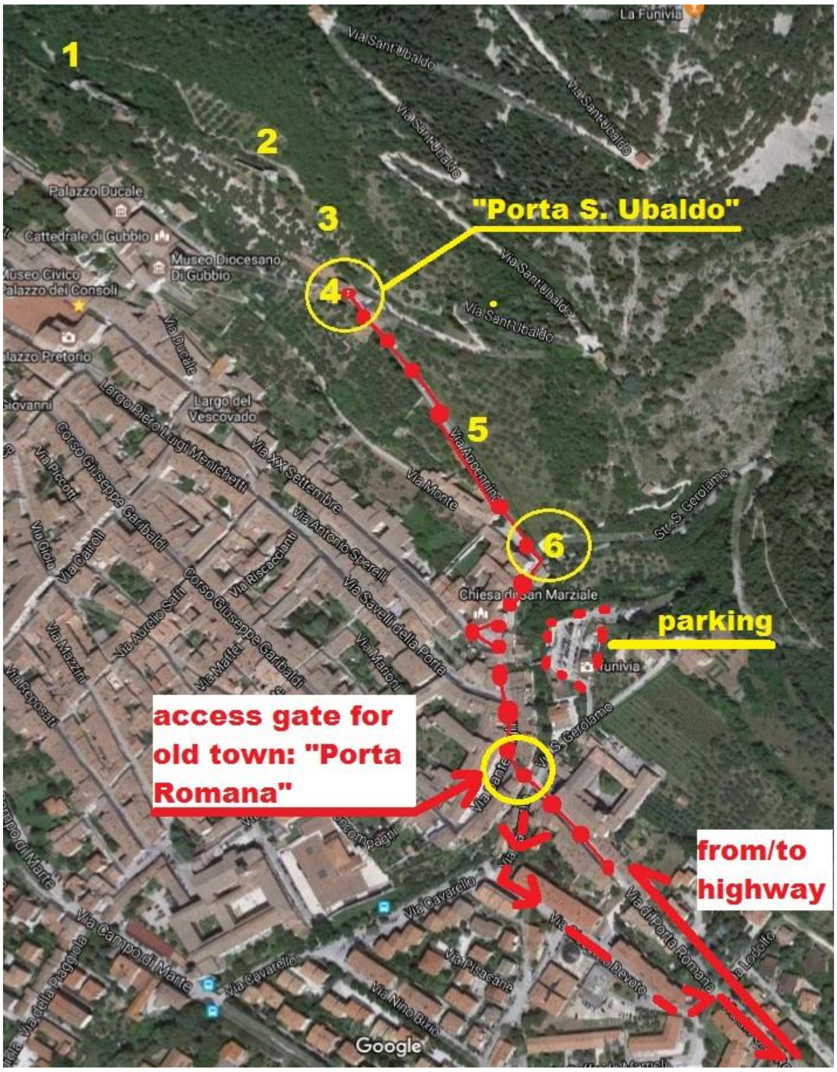


Figure 2: Cartography

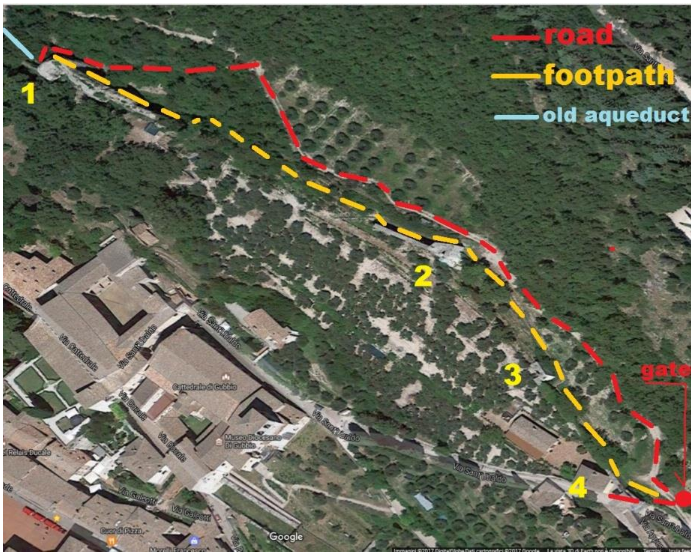


Figure 3 - Road and paths zones 1-2-3-4

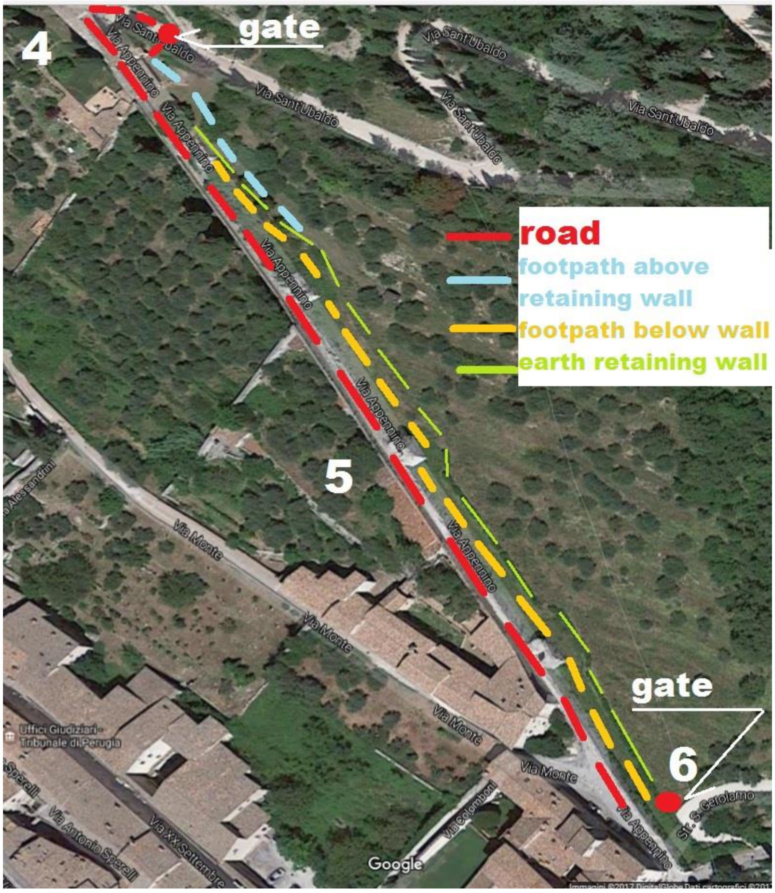


Figure 4 - Road and paths zones 4 -5-6

4.1.4.1 Zone 1 – *Forte di Parco Ranghiasci*

- Access: the access paths are indicated with yellow numbers in Figure 3. Free Access is possible only upstream, since downstream there is a private property and steep footpaths.

  There is only one road leading to this place and 2 public footpaths.
  - The road for vehicles (~470 meters) is unpaved (made with gravel) and starts from zone 4 (*Porta S. Ubaldo*). The entrance has to be allowed by the field owner, in fact there is a closed iron gate in the cross with *via del Monte*. The first part of the road (~150 meters) is going uphill until zone 2 ("Cassero"). After that, for ~120 meters is going downhill. The last 100 meters of the road, are very steep, dusty (in dry seasons) and very muddy (during wet seasons), accessible only for a cross-country vehicle or a small caterpillar.
  - The first footpath (~330m from zone 4) is running between the Town Walls and the road, it is fully accessible. The last 100/150 m are quite difficult to walk since the access is possible only through the road or through a couple of stairs in the bushes.

  - The second footpath starts from “Bottaccione” and it is the “old Aqueduct trail” recently restored. It is longer (~1,8 km) than the previous one, but in plain.

  For all the above reasons, the access on quote is possible only with safety ladder carried by hand but not with safety lifting platforms.
- Power supply: NO
- Internet: NO
- Safe deposition of instruments: NO (public space). Safety warranted only in quote and/or installing a box.

4.1.4.2 Zone 2 – *Cassero*

- Access: access paths are indicated with yellow numbers in Figure 3. Free access is possible only upstream, since downstream there is a private property with steep cliff and narrow footpaths. There is only one road leading to this place and on public footpath.
  - The road for vehicles (~150 m) is uphill, unpaved (made with gravel) and starts from zone 4 (*Porta S. Ubaldo*). The entrance has to be allowed by the field owner, in fact there is a closed iron gate in the cross with *via del Monte*.
  - The footpath (~150m from zone 4) is running between the Town Walls and the road and it is fully accessible.
  - The area close to the Town Walls is accessible on foot because of the concrete retaining wall built upstream around 30 years ago.

For all the above reasons, the access in quote is possible with safety ladder (carried by hand), and only for the first 5-7 meters with safety lifting platforms.

- Power supply: NO
- Internet: NO
- Safe deposition of instruments: NO (public space). Safety warranted only in quote and/or installing a box.

4.1.4.3 Zone 3 - *Torre*

- Access: Access paths are indicated with yellow numbers in Figure 3. Free access is possible only upstream, since downstream there is a private property with steep cliff and narrow footpaths. There is only one road leading to this place and on public footpath.
  - The road uphill is unpaved (made with gravel) and starts from zone 4 (*Porta S. Ubaldo*). The entrance has to be allowed by the field owner, in fact there is a closed iron gate in the cross with *via del Monte*. It is far up to a dozen meters from the Walls.
  - The footpath is running between the Town Walls and the road, it is fully accessible.

For all the above reasons, the access in quote is possible for sure with safety ladder (carried by hand); instead the position of a safety lifting platforms should be checked before.

- Power supply: NO
- Internet: NO

- Safe deposition of instruments: NO (public space). Safety warranted only in quote and/or installing a box.

4.1.4.4 Zone 4 – *Porta Sant'Ubaldo*

- Access: access paths are indicated in Figure 3 and Figure 4, and are free by foot and by car only downstream through the public road, starting from zone 6 (*Porta S. Marziale*) through zone 5 ("*Bughetto*" or "*Via del Monte*"). Upstream the Walls are accessible only for 30 m starting from *Porta S. Ubaldo* through a private garden mainly in plain. Downstream the access in quote is possible only with safety lifting platforms (Walls height 8-10 m).
- Power supply: YES (access to private electric power grid in zone 4 – permission needed). NO for the other parts
- Internet: NO.
- Safe deposition of instruments: YES (in private property areas with the permission of the owner).

4.1.4.5 Zone 5 – "*Bughetto*"

- Access: access paths are indicated in Figure 3 and Figure 4. It is free by foot and by car only downstream through the public road, starting from zone 6 (*Porta S. Marziale*) through zone 5 ("*Bughetto*" or "*Via del Monte*"). Upstream there is a private property (a footpath close to the Walls starting from zone 6) not accessible due to thick bushes.

In these zones, the height of the Walls is 8-10 m. So, the access in quote is possible only downstream with safety lifting platforms.

- Power supply: NO
- Internet: NO
- Safe deposition of instruments: NO

4.2 *End-user detailed requirements*

This section presents the risks/hazard linked to the Gubbio Town Walls.

These aspects were deeply described **deliverable D1.2**; here are only reported the main aspects/conclusions, specifically useful to support the demonstration activities.

The first scenario is due to the following risks/hazards:

- Atmospheric moisture change and intense rainfall and related floods
- Damages derived by faulty or inadequate water disposal systems after an extreme event
- Subsoil instability, such as: ground heave, subsidence, landslide.

During the last eight/ten centuries, several meters of ground material accumulated against the Walls. The situation was only partially mitigated (in zone 1) by the historic aqueduct, which had also the function of retaining the Walls. At present, the estimated soil accumulation, insisting on the Walls, is more than 5/6 metres and increases with a rate of around 50 cm / century.

As risk mitigation action, the water flow out through the Walls and the drainage of the gravel soil were ensured by means of on-purpose designed holes/channels in the structure. However, the ground material, during the time, continues obstructing the channels. This causes the increase of the groundwater level and consequently the risk of the structural instability of the Walls.

Currently, there are no major landslides in place, but collapses of the Walls occurred over the last centuries, and even in more recent times.

According to this scenario, the activities of the HERACLES project will be directed to the mitigation of the hydrogeological risk on that area. The Walls suffer mainly from the torrential rains and humidity characterizing the soil surrounding the area, and closely connected with the mountain natural area. The heavy rains increase the pushing on the Walls in two ways:

- through the washout producing and transporting rubbles,
- through the increase of the aquifer level.

All these conditions can adversely affect the statics of the Walls themselves.

The second scenario is the material degradation mainly deriving from the following risks/hazard:

- Erosion of inorganic materials due to flood waters;
- Temperature changes coupled with wind (rain driven by wind can penetrate moisture into porous materials weakening them; combined with ice can create cracks in stones and mortars);
- Climate and pollution acting together.

The Walls of Gubbio exhibit several issues related to the materials degradation (limestone, travertine, sandstone-*serena* stone, plasters, binders) used for building and restoration. These materials suffer of increased deterioration due to climate change effects coupled with pollution. The structural material principally used is the limestone. The degradation effects of the outer surface are: loss of material (formation of hollows, differential degradation, erosion, gap, lacking, pitting); decay of the material cohesion (disintegration, pulverization); loss of continuity perpendicular or parallel to the outer surface (fracturing/cracking, peeling, warping, swelling, scaling); addition of foreign material (concretion, “black crusts”, surface deposit, efflorescence, scaling, stain, film formation); colour variations (discoloration and patina).

Another predominant issue is the gradual degradation of the mortar binding the Walls and making spatially uniform the stresses through the joints between the stones. The degradation/reduction of the mortar entails the loss of homogeneous distribution of the stresses on the stone surfaces and leads to a heterogeneous stone-binder system behaviour. The HERACLES activities for this scenario, will address the quality of the mortars used and their properties.

4.3 Demonstration activity on Town Walls

In the previous sections all the criticalities affecting the Town Walls have been briefly reported.

In the following picture (Figure 5), a summary of the systematic protocol proposed for the Town Walls is presented. It was the outcome of the work done in deliverable D3.1, where the methodologies suitable to study this CH asset have been considered. This protocol is the basis for the definition of the demonstration activities.

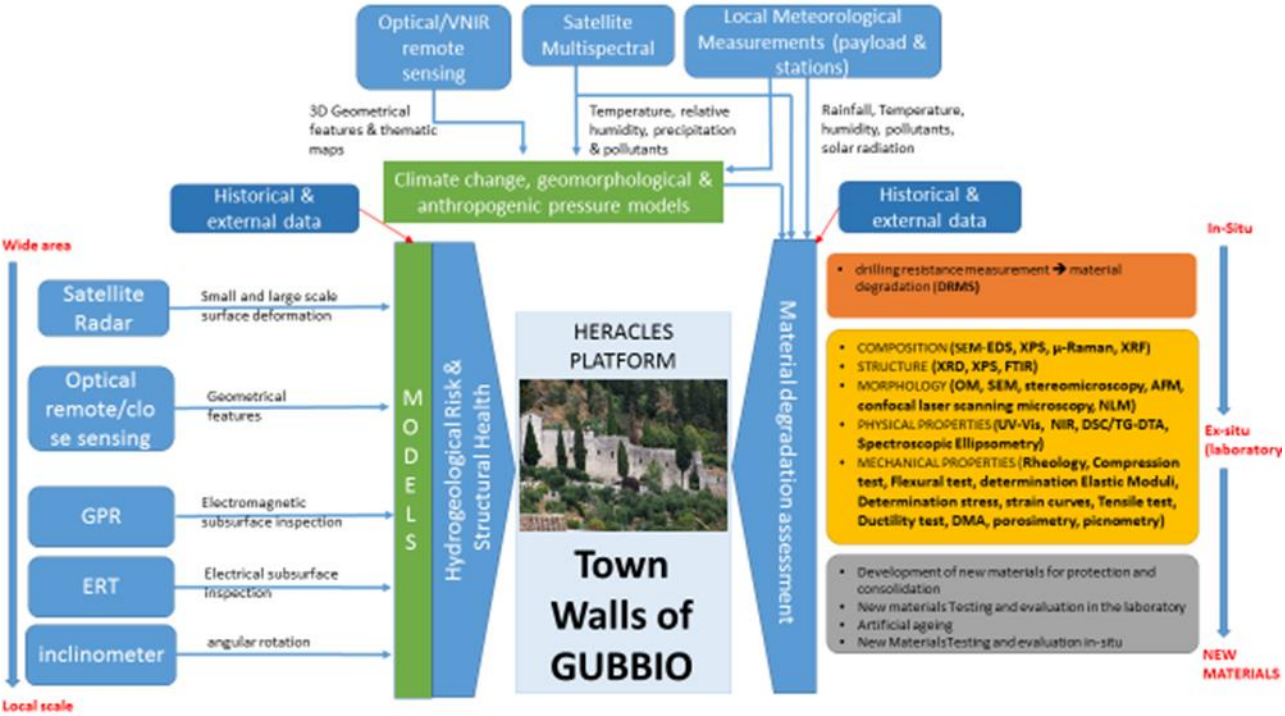


Figure 5 - Systematic and complete protocol flow-view for Gubbio Town Walls test-bed.

The aim is to provide a clear and easy visualization of all the phases/actions necessary to assess the current situation of the Town Walls.

4.3.1 Measuring systems installed and to be installed

According to the protocol developed in WP3 (D3.1 and D3.2), the test/measuring system that will be installed or used on Town Walls will be the following:

1.1 Spaceborne radar COSMO-SKYMED [e-GEOS]
1.2 Multispectral Remote Sensors [SISTEMA]
1.3 UAV/Drone optical camera for geometrical survey [E-GEOS]
1.4 GPR (georadar) #zone 1 -2 -3 – 4- 5 [CNR/IREA]
1.5 ERT (Electrical Resistivity Tomography) [CNR/IREA]
1.6 ARPA UMBRIA weather monitoring station network [SISTEMA+UNIPG/CIRIAF]
1.7 Measurement of climatic parameters (drone and/or portable environmental payload device for the monitoring of local microclimate variables) [UNIPG/CIRIAF]
1.8 TH3-Thermal-Humidity sensor data logging system [UNIPG/CIRIAF]
1.9 Infrared Thermography [UNIPG/CIRIAF]
1.10 Inclinometer @ zone 1 – Town Walls (*Forte Parco Ranghiasci*) Stabiliy sensor S2 [UNIPG/DICA]
1.11 Inclinometer @ zone 3 – Town Walls (*Forte Parco Ranghiasci*) – Stabiliy sensor S3 [UNIPG/DICA]
1.12 Inclinometer @ zone 4 – Town Walls (*Porta S.Ubaldo-Bughetto*) – Stabiliy sensor S4 [UNIPG/DICA]

1.13 Drilling Resistance Measurements System (DRMS) – [UoC]
1.14 Stone and Mortar samples analysis [CNR-ISMN, UNINOVA, UoC, FORTH-IESL, CVR/INSTM]

4.3.2 Town Walls: Test-bed sensor #1.1: Spaceborne radar (COSMO-SKYMED)

4.3.2.1 Description

The activity of this task concerns the processing of data acquired by Spaceborne Synthetic Aperture Radar (SAR) Data with multi-temporal differential interferometric techniques aimed at carrying out high resolution environmental monitoring at regional scale. Specifically, Very High Resolution (VHR) Cosmo-Skymed data and High Resolution (HR) Sentinel1 data will be considered. Processing at high resolution will be performed with the Persistent Scatterers Pairs (PSP) and, for VHR data, with the SAR Tomography (TMS) techniques [1,2]. Both techniques are devoted to the analysis at the full available resolution of concentrated targets on the ground, i.e. the persistent scatterers (PS), whose backscattering response is coherent over the entire acquisition temporal interval. For TMS, the CAESAR option implies a small degradation of the resolution. These techniques are able to perform an accurate 3D reconstruction (point clouds) of single building and infrastructures as well as to measure with millimetre/centimetre accuracy the superficial deformation of the observed objects by allowing the study of the stability of each single built structure and of the surrounding elements.

A detailed description of these techniques are reported in the Deliverables D2.1 and D3.3.

4.3.2.2 Measured parameters

The standard output product of the interferometric processing is a sparse map of the detected PS characterized by ancillary information as localization parameters (geographic coordinates and heights with respect to the WGS84 ellipsoid), superficial deformation parameters (time series of the measured deformation at the SAR acquisition instants, deformation mean velocity in the observation period), quality index representing the temporal coherence of the PS and the directional cosines of the radar line-of sight (LOS).

Products will be delivered in both ASCII and Shapefile format.

4.3.2.2.1 ASCII file description

The ASCII file product is organized as a sequence of rows, whose number, but for the header row, is equal to the number of output PS, each row corresponding to a specific PS measurement point.

The first row of the file is the header containing the labels of the reported parameters.

For each row, several fields are reported corresponding to a specific PS parameter. The number of fields depends on the number of processed SAR acquisitions, specifically the first 10 fields are always reported as they refer to general information

of the PS, whereas number of the remaining fields coincides with the number of the processed images. Each field is separated by a space.
In the following Table 4, an example of the header row and of a generic PS measurement row is reported:

Table 4: PS measurements headers

CODE	LAT	LON	HEIGHT	VEL	COHERENCE	V_STDEV	LOS_E	LOS_N	LOS_H	D20110422	D20121029
TMS24DC	41,850891	12,475312	130,5	-15	0,66	0	-0,0994	-0,5509	0,8285	0	-22,8

For a generic row, each field is filled with the following information/measured parameters:

- CODE – Alphanumerical PS identifier expressed in the form *PROCid* where *PROC* denotes the interferometric processing technique, i.e. Persistent Scatterers Pairs (PSP), Single-Look SAR Tomography (TMS), CAESAR-based SAR Tomography (TMC) whereas *id* is a sequential numerical id in hexadecimal notation;
- LAT – Latitude of the PS in decimal degrees with respect to the WGS84 ellipsoid;
- LON – Longitude of the PS in decimal degrees with respect to the WGS84 ellipsoid;
- HEIGHT – Height of the PS in meter with respect to the WGS84 ellipsoid;
- VEL – deformation mean velocity of the PS in the total period of observation expressed in mm/year;
- COHERENCE – temporal coherence of the PS, belonging to the [0, 1] interval;
- V_STDEV – standard deviation of the estimated deformation velocity;
- LOS_E – East component of the directional cosines of the radar line-of sight
- LOS_N – North component of the directional cosines of the radar line-of sight
- LOS_H – Vertical component of the directional cosines of the radar line-of sight.
- YYYYMMDDstart to YYYYMMDDend – *N* fields reporting the time series of deformation from the starting to the end acquisition dates. Time series are measured in mm. time series at the first acquisition is set to 0 mm for reference.
-

4.3.2.2.2 Shapefile description

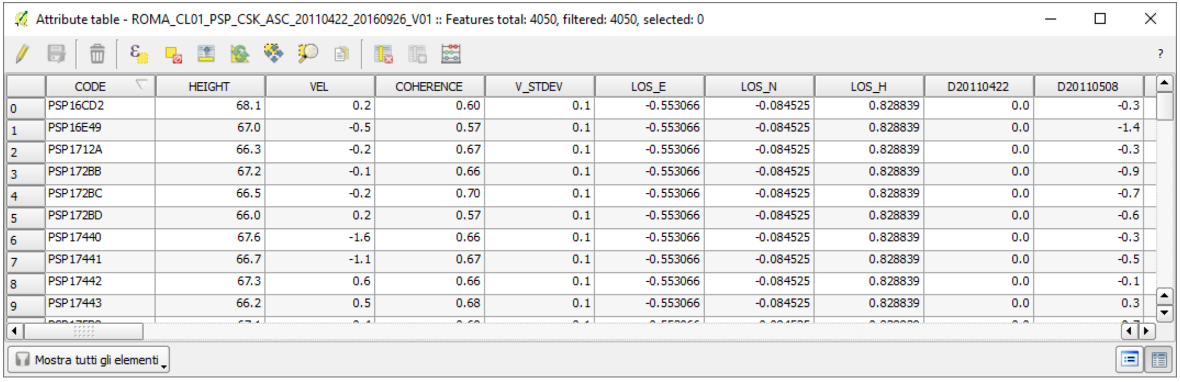
The product provided in ESRI shapefile vector format is compatible with all proprietary and free GIS software.
The ESRI shapefile, or simply a shapefile, is a geospatial vector data format for geographic information system software (proprietary or free). Shapefiles spatially describe features: points, lines, and polygons, representing, for example, water wells, rivers, and lakes. Each item usually has attributes that describe it. The shapefile format is useful for analyse the data, thanks to the possibilities offered by the GIS software.

The features of the PSP-IFSAR products shapefile are points, representing the selected PSs. To each PS (or feature) of the shapefile the following attributes are provided:

- CODE – Alphanumerical PS identifier expressed in the form *PROCid* where *PROC* denotes the interferometric processing technique, i.e. Persistent Scatterers Pairs (PSP), Single-Look SAR Tomography (TMS), CAESAR-based SAR Tomography (TMC) whereas *id* is a sequential numerical id in hexadecimal notation;
- HEIGHT – Height of the PS in meter with respect to the WGS84 ellipsoid;
- VEL – deformation mean velocity of the PS in the total period of observation expressed in mm/year;
- COHERENCE – temporal coherence of the PS, belonging to the [0, 1] interval;
- V_STDEV – standard deviation of the estimated deformation velocity;
- LOS_E – East component of the directional cosines of the radar line-of sight
- LOS_N – North component of the directional cosines of the radar line-of sight
- LOS_H – Vertical component of the directional cosines of the radar line-of sight
- YYYYMMDDstart to YYYYMMDDend – *N* fields reporting the time series of deformation from the starting to the end acquisitions. Time series are measured in mm. time series at the first acquisition is set to 0 mm for reference.

The following table 5 shows all the attributes present in the shapefile format.

Table 5- Attributes present in the shapefile format



Attribute table - ROMA_CL01_PSP_CSK_ASC_20110422_20160926_V01 :: Features total: 4050, filtered: 4050, selected: 0

	CODE	HEIGHT	VEL	COHERENCE	V_STDEV	LOS_E	LOS_N	LOS_H	D20110422	D20110508
0	PSP16CD2	68.1	0.2	0.60	0.1	-0.553066	-0.084525	0.828839	0.0	-0.3
1	PSP16E49	67.0	-0.5	0.57	0.1	-0.553066	-0.084525	0.828839	0.0	-1.4
2	PSP1712A	66.3	-0.2	0.67	0.1	-0.553066	-0.084525	0.828839	0.0	-0.3
3	PSP172BB	67.2	-0.1	0.66	0.1	-0.553066	-0.084525	0.828839	0.0	-0.9
4	PSP172BC	66.5	-0.2	0.70	0.1	-0.553066	-0.084525	0.828839	0.0	-0.7
5	PSP172BD	66.0	0.2	0.57	0.1	-0.553066	-0.084525	0.828839	0.0	-0.6
6	PSP17440	67.6	-1.6	0.66	0.1	-0.553066	-0.084525	0.828839	0.0	-0.3
7	PSP17441	66.7	-1.1	0.67	0.1	-0.553066	-0.084525	0.828839	0.0	-0.5
8	PSP17442	67.3	0.6	0.66	0.1	-0.553066	-0.084525	0.828839	0.0	-0.1
9	PSP17443	66.2	0.5	0.68	0.1	-0.553066	-0.084525	0.828839	0.0	0.3

It has to be noted that for the shapefile format the geographic coordinates are not present as attributes but are intrinsic in the format and written in the shape files.

The data volume depends on the area to be monitored, in principle, for structural monitoring, there will be a high density of points resulting in up to 20000 points per km^2. Shapefiles can reach also a disk occupation of few GBs so it is important to foresee efficient storage methods to allow further visualisation and analysis.

4.3.2.3 Installation

Sensing Technique	PSP-IFSAR, TMC and TMS
Sensor location	Not applicable (No in-situ sensors)
Where to fix the sensor (post, tripod, etc)	Not applicable
The sensor installation require to drill, glue, paint or other actions 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

4.3.2.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	Two/three months after the reception of all the SAR image stacks
How many measurements are planned to be done	Typically the measurements are available over non-cultivated and scarcely vegetated areas, and in particular corresponding to man-made or natural structures like buildings, rocks, etc. In any case, the following values can be considered: - Sentinel1- Thousands of measurements points per km^2 in urban areas. Hundreds of measurements points per km^2 elsewhere. - COSMO-Skymed HIMAGE mode – Tens of thousands of measurements points per km^2 in urban areas. Thousands of measurements points per km^2 elsewhere.
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	Not applicable

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.	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.

4.3.2.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	Not applicable
Partner in charge for data acquisition	E-GEOS, CNR/IREA
Partner in charge for data validation	E-GEOS, CNR/IREA
Partner in charge for processing/modelling	E-GEOS, CNR/IREA + UNIPG/DICA

4.3.3 Town Walls: Test-bed sensor # 1.2: Multispectral remote sensors

4.3.3.1 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 remote 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 Gubbio.

4.3.3.2 Measured parameters

The multispectral remote 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.

4.3.3.3 Installation

This section does not apply to satellite multispectral remote sensors.

4.3.3.4 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 on 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 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.)	Not applicable

4.3.3.5 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

4.3.4 Town Walls: Test-bed sensor # 1.3: UAV/Drone optical camera for geometrical survey

4.3.4.1 Description

Within geospatial data collection in Gubbio, the use of UAV for a high oblique and nadiral flight with SAPR rotor is expected. The UAV-survey consists in a photogrammetric acquisition of photograms, in correspondence of four sections of urban Walls, for a total length of about 500 m at the area indicated in the Figure 6.

Final output of this survey is the 3D reconstruction of those parts of Walls, in a very detailed and accurate representation.

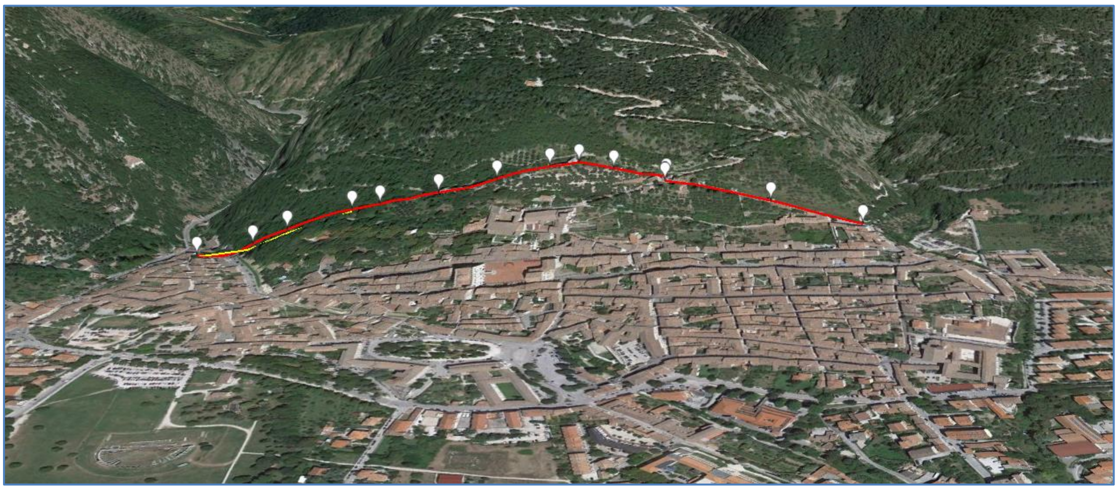


Figure 6 - Perspective view of the urban Walls area in Gubbio

4.3.4.2 Measured parameters

Hue, saturation and intensity (or brightness) are the principal component parameters analysed and measured during the survey. RGB colorimetric system is further used for depth map fusion and for absolute elevation computation via photogrammetry, thanks to the stereoscopy properties of this type of technique. These parameters are used for the final geometric three dimensional reconstruction of the target.

4.3.4.3 Installation

Sensing Technique	UAV survey, close range photogrammetry
Sensor location	Along four sections of the Town Walls
Where to fix the sensor (post, tripod, etc)	Not applicable
The sensor installation requires 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.)	Permission of access to a private property. Presence of rocks and natural obstacles upstream or downstream of the Walls.

4.3.4.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable, etc.)	3-4 hours
How many measurements are planned to be done	4 flights, one for each part of Town Walls
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery
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	Sun azimuth, wind, illumination, obstacles.

conditions, etc)	

4.3.4.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	E-GEOS
Partner in charge for data acquisition	E-GEOS
Partner in charge for data validation	E-GEOS + UNIPG/DICA
Partner in charge for processing/modelling	UNIPG/DICA

4.3.5 Town Walls: Test-bed sensor # 1.4: GPR (georadar) @ zone 1 -2 -3 - 4-5

4.3.5.1 Description

A GPR system is a portable radar instrumentation designed to perform subsurface investigations, i.e. to detect and localize buried or hidden targets. In the frame of HERACLES project, and in particular at the Gubbio test sites, the time domain K2-Ris system, manufactured by Ingegneria Dei Sistemi Spa and available at CNR-IREA, will be used. The working principle of this system is quite simple and can be summarized as it follows. An antenna system, made by a transmitting and a receiving antennas, with the same linear polarization, is moved along a line and at each measurement point a probing pulse is transmitted. The probing signal propagates into the investigated medium and when a strike on an electromagnetic discontinuity occurs, a back-scattered signal arises. This signal is measured and stored as a time dependent waveforms. Since the back-scattered field is in some way “modulated” by the encountered electromagnetic discontinuities, it provides information on them. Accordingly, by properly processing all the waveforms gathered by moving the GPR system along the measurement line, i.e. for each GPR B-scan, an image of the scenario under test is obtained from which one can infer information about the presence, location and size of unknown targets. At the Town Walls test-bed the K2-RIS GPR system will be equipped by means of an antenna suitable to perform ground investigation. In particular, a shielded dual frequency antenna system working at the nominal central frequencies of 200 MHz and 600 MHz will be used. By doing so, for each GPR B-scan, two data sets are available, which are characterized by a different range coverage and spatial resolution. In details, the data sets corresponding to the 200 MHz central frequency provide images of deeper targets than those detected at 600 MHz but with a lower spatial resolution.

4.3.5.2 Measured parameters

The GPR system used in the frame of the HERACLES project measures the time dependent waveforms, which are backscattered by the scenario under test, i.e. the variations of the electromagnetic parameters (dielectric permittivity, electric conductivity) occurring into the investigated spatial domain. By properly processing the gathered waveforms, images providing information about unknown targets, i.e. their presence, location, size and shape, are obtained.

4.3.5.3 Installation

Sensing Technique	Subsurface imaging
Sensor location	GPR data are acquired by moving manually the instrumentation
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.	No installation has to be performed
Time required to install the sensor	The time to acquire a GPR data set depends on the extent and accessibility of the area under test
Possible constraints for the installation (authorizations – announcement in advance etc.)	The accessibility of the area is the only issue

4.3.5.4 Monitoring

Which is the time required to perform the measurement (measurement duration - a possible timetable, etc.)	The time to acquire a GPR data set depend on the extent and accessibility of the area under test and generally is in the range from few minutes up to some hours
How many measurements are planned to be done	At least a survey will be performed at each zone
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The system is battery operated
Dimension of the sensor system (sensor + any electronic control or computer)	The system equipped with the dual frequency antenna looks like a lawnmower, whose base is about 0.6 m x 0.6 m and height is 1.30 m
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	A calibration procedure is needed and it requires about 1 minute
Compatibility or not with the other sensing techniques (what are the other	GPR measurement are compatible with other sensing techniques

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

4.3.5.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	CNR/IREA
Partner in charge for data acquisition	CNR/IREA
Partner in charge for data validation	CNR/IREA + UNIPG/DICA
Partner in charge for processing/modelling	CNR/IREA+UNIPG/DICA

4.3.6 Town Walls: Test-bed sensor # 1.5: ERT (Electrical Resistivity Tomography)

4.3.6.1 Description

ERT is an electromagnetic sensing technique useful to characterize areas of complex geology. Indeed, ERT provides 2D and 3D images of subsurface targets/structures in terms of electrical measurements made at the surface. This is performed by injecting an electrical current (I [mA]) in the subsoil by means of a pair of electrodes (A and B) and by measuring the subsequent electrical potential (ΔV [mV]) by using another pair of electrodes (M and N). The ERT allows changing easily the depth of investigation and spatial resolution by varying the electrode spacing. Small electrode spacing provides a great spatial resolution and a small investigation depth, while great electrode spacing allows achieving a great investigation depth but a low spatial resolution.

In the frame of HERACLES project, ERT measurements will be performed by using an IRIS Syscal R2 system equipped with multicore cables at 32 or 48 electrodes fixed into the ground on a horizontal surface. The spatial offset among the electrodes will range from some tens of centimetres to few meters according to the desired penetration depth. It is worth noting that the multicore cable ensures the electrical link with a switch and then with the acquisition unit.

4.3.6.2 Measured parameters

ERT allows us to obtain high resolution images of the resistivity subsurface patterns. Accordingly, it can be considered as a powerful tool for detecting and imaging shallow subsurface targets characterized by conductive properties that are very different from the ones of the host medium.

4.3.6.3 Installation

Sensing Technique	Subsurface imaging
Sensor location	ERT data are acquired by positioning the electrodes into the ground
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	ERT measurements involve the creation of small holes, which are due to the positioning of the electrodes into the ground. Steel electrodes, having size 30-40 cm × 1.5 cm, will be used
Give a description of the installation procedure.	A temporary installation of the electrodes is performed, whose duration is commonly of few hours
Time required to install the sensor	The time to install the electrodes depends on the extent and accessibility of the area under test and the nature of the soil under test. Usually, it is less than one hour.
Possible constraints for the installation (authorizations – announcement in advance etc.)	The accessibility of the area is the main issue

4.3.6.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	The time required to gather ERT data depends on the extent, accessibility of the area under test and time required to install the electrodes. Generally, this time is one hour / one hour and half
How many measurements are planned to be done	At least a survey will be performed at each accessible zone
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The system is battery operated
Dimension of the sensor system (sensor + any electronic control or computer)	The whole volume of the ERT system is about a pair of cubic meters and the system is easily transportable
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 system will be dismantled after the measurement
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	About 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 specific technique?)	ERT measurements are compatible with other sensing techniques
Factors affecting the measurement (sun	Driving rain

insulation, temperature, meteorological conditions, etc)	

4.3.6.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	CNR/IREA
Partner in charge for data acquisition	CNR/IREA
Partner in charge for data validation	CNR/IREA + UNIPG/DICA
Partner in charge for processing/modelling	CNR/IREA + UNIPG/DICA

4.3.7 Town Walls: Test-bed sensor # 1.6: ARPA UMBRIA weather monitoring station network

4.3.7.1 Description

The network of microclimate monitoring sensors currently installed in the area of the city of Gubbio is managed and operated by a local public environmental authority, i.e. A.R.P.A. Umbria, and is composed by five monitoring stations located at ground level, i.e. pedestrian level, both (i) nearby and (ii) inside the city centre.

Figure 7: - Location of ground microclimate monitoring stations in the Gubbio area

In details, all the ground monitoring stations are provided with air quality monitoring devices. Additionally, three of them are equipped also with meteorological sensors, i.e. air temperature, relative humidity, rainfall, wind speed and direction. The ground station located in the city centre has been operating since 2008, while the four ground stations located outside the Gubbio historical urban area have been collecting meteorological data since 2009. In particular, stations 3 and 4 (Figure 7 - left side), positioned in the northern part, are located in the close proximity of the cement factory Aldo Barbetti SpA, while stations 2 and 5, located the south area, are positioned around the cement plant Colacem SpA (Figure 7 - left side). Furthermore, a sixth meteorological station is currently positioned in the historical city centre, i.e. station 6 (Figure 7 - left and right sides), and it is operated by a local volunteer meteorological association.

It is important to note that this weather monitoring station network is suitable to evaluate the microclimate for both the test-beds in Gubbio, (i.e. Town Walls and Consoli Palace)

4.3.7.2 Measured parameters

The monitoring parameters for each monitoring station measured by the six different ground microclimate stations are summarized in the following table 6:

Table 6 - Monitoring parameters for each monitoring station

N	Name	Position	Parameters
1	Gubbio *Piazza 40 Martiri*	Lat. 43.352849580 Long. 12.576515592 Alt. 505 m	SO_2, NO_2, CO, O_3, PM10, PM2.5 Wind, Atmospheric Pressure, Temperature, Relative Humidity, Solar Radiation
2	Gubbio Ghigiano	Lat. 43.352849580 Lon. 12.611487603 Alt. 524m	SO_2, NO_2, CO, O_3, PM10, PM2.5 Wind, Atmospheric Pressure, Temperature, Relative Humidity, Solar Radiation, Precipitation
3	Gubbio Semonte alta	Lat. 43.368326000 Long. 12.547132000 Alt.623 m	SO_2, NO_2, CO, O_3, PM10, PM2.5
4	Gubbio via Leonardo da Vinci	Lat. 43.359056823 Long. 12.557227918 Alt.472 m	SO_2, NO_2, CO, O_3, PM10, PM2.5
5	Gubbio Padule	Lat. 43.318617775 Long. 12.618547478 Alt.442 m	SO_2, NO_2, CO, O_3, PM10, PM2.5 Wind, Atmospheric Pressure, Temperature, Relative Humidity, Solar Radiation, Precipitation
6	Gubbio Corso Garibaldi	Lat.43.349618 Long.12.582886 Alt. 510 m	Wind, Atmospheric Pressure, Temperature, Relative Humidity, Precipitation

For what concerns the non-institutional data sources, such as the weather station managed by voluntary association, those data must be continuously verified before the use in order to identify any bias. In that case, a formal free agreement could be established with the association or the owner of the meteorological stations.

4.3.7.3 Installation

Sensing Technique	microclimate monitoring sensors
Sensor location	Installed since 2008, two stations are located within the city centre and four outside the historical urban area. All the

	stations are at ground level, i.e. pedestrian perspective.
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.	Already installed: #1 since 2008, #2-3-4-5 since 2009.
Time required to install the sensor	Not applicable
Possible constraints for the installation (authorizations – announcement in advance etc.)	The regional environmental authority (A.R.P.A. Umbria) managing most of the above-mentioned meteorological monitoring stations **has subscribed a letter of support to the HERACLES project allowing the access to the collected environmental data**. Contacts with the technical department of A.R.P.A. Umbria and HERACLES consortium are on-going to define the terms of the data exchange: - Data access policy (who and when it is possible to access the data); - Data access protocols (which data and how the data can be collected e.g. ftp, web app, etc.); - Reliability of data (acceptable temporal data unavailability due to regular/irregular maintenance operations); - Early Warning of the local authority in case of failure;

4.3.7.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	Continuous monitoring. In order to set up an automatic data collection system, according to the agreement with A.R.P.A. UMBRIA, the data collection could start with a phase-in step to set up the automatic download of real time data and, in case, archive data.
How many measurements are planned to be done	Continuous monitoring
The system is battery operated or	Managed by ARPA. Power grid source.

requires electric energy necessities (Voltage, Power, etc)	
Dimension of the sensor system (sensor + any electronic control or computer)	The meteorological station is reported in Figure 8
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 – already installed
Time required to perform a preliminary signal processing to ensure the measurement reliability	Already on line
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 measurements after agreement between HERACLES and ARPA UMBRIA about data access in terms of responsibility, estimated effort, duration, constraints, and data policy
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	Not applicable

Figure 8 - ARPA Umbria weather station #1

4.3.7.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	GUBBIO (through ARPA)
Partner in charge for data acquisition	SISTEMA Gmbh
Partner in charge for data validation	SISTEMA Gmbh for old data
Partner in charge for processing/modelling	LEONARDO + THALES for new data modelling ARIA for weather modelling

4.3.8 Town Walls: Test-bed sensor # 1.7: Drone measurement of climatic parameters (portable environmental payload device for the monitoring of local microclimate variables)

4.3.8.1 Description

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 dedicated newly developed geo-referenced payload made up by miniaturized environmental sensors (Figure 9). The system is also equipped by visible and infrared cameras to detect superficial temperature [°C] of the surrounding environment.

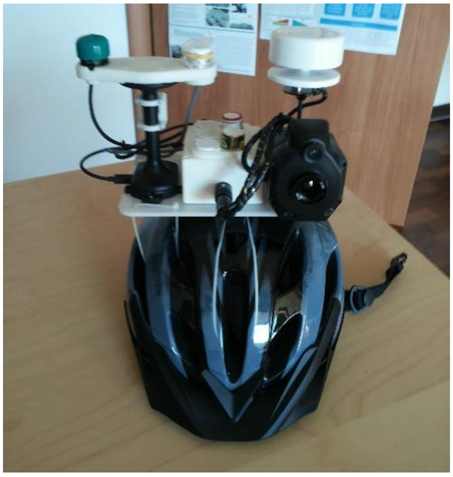


Figure 9 - Miniaturized microclimatic station

These monitoring campaigns will be carried on both at sky by means of drone, and at the ground (i.e. pedestrian perspective). Compatibly with equipment availability and regulation constraints, with respect to drone flight, these monitoring activities are foreseen in the second part of 2017.

4.3.8.2 Measured parameters

Sensors composing the payload and monitored parameters are summarized in the following Table 7.

Table 7 – Payload and monitored sensor parameters

Sensors	Parameters
BME280	Atmospheric pressure [Pa], relative humidity [%] and air temperature [°C]
Eko ML-020S-O	Lighting [lux]
SP-110	Global shortwave radiation [W/m^2]
TDS0037	Carbon Dioxide concentration [ppm]

GS+4CO	Carbon Monoxide concentration [ppm]
TGS 8100	Air Contaminants concentration [ppm]

4.3.8.3 Installation

Sensing Technique	Microclimate monitoring sensors
Sensor location	Payload device will be used to perform measurement in space and time so it will not be positioned in a specific location. The one-day monitoring path, both at sky and at pedestrian level, will take place along Town Walls area accessible by drone and by foot respectively.
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 needed
Give a description of the installation procedure.	Payload device will be installed on drone and wearing helmets
Which is the time required to install the sensor	-
Possible constraints for the installation (authorizations – announcement in advance, etc.)	Drone flight has to be planned in advance and the path arranged with municipality

4.3.8.4 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 least, one at sky by means of drone and one at pedestrian level
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)	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	Sensors composing the monitoring system are preliminary calibrated so the measurement reliability is guaranteed. Data analysis and post-processing will require 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)	Not applicable

4.3.8.5 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

4.3.9 Town Walls: Test-bed sensor # 1.8: TH3-Thermal-Humidity sensor data logging system

4.3.9.1 Description

Punctual ambient parameters monitoring is carried on by means of TGP-4500 devices. In specific, these are rugged, waterproof temperature and relative humidity loggers with built-in sensors, able to monitor temperatures within -25 and +85°C and all the spectra of relative humidity (i.e. 0-100%). The device could not be wired to an acquisition network, but has an internal memory which guarantees data collection of 113 days of continuous monitoring. Data collected by these systems are used to validate numerical microclimate models so, concerning Town Walls model, the thermal-humidity data logging systems described are located in proximity of "*Porta Sant'Ubaldo*" as it is shown in Figure 10. The installation was performed on 26th November 2016.

Figure 10 - Thermal-humidity sensor data logging system location with respect to Town Walls zones

4.3.9.2 Measured parameters

Parameters monitored by TGP-4500 sensor are (i) air temperature and (ii) relative humidity, as summarized in the following table 8.

Table 8 - TGP-4500 sensor monitoring parameters

Name	Position	Parameters
TGP-4500	Lat. 43.353328 Long. 12.582193 Alt. -	Air Temperature (°C), Relative Humidity (%)

The operative ranges of the devices are -25 ÷ +85°C and 0 ÷ 100% for temperature and relative humidity respectively.

4.3.9.3 Installation

Sensing Technique	Microclimate monitoring sensors
Sensor location	Sensor is yet located in proximity of the Town Walls, in particular close to *Porta S. Ubaldo*
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 needed
Give a description of the installation	The sensor is clamped on available

procedure.	supports yet present in the area and specifically individuated for the purpose, as shown in Figure 11
Time required to install the sensor	The sensor was installed on 26th November 2016 and only few minutes were requested.
Possible constraints for the installation (authorizations – announcement in advance etc.)	No authorizations were needed

Figure 11 - Thermo-hygrometer located in proximity of the Town Walls

4.3.9.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	Continuous monitoring. Due to internal memory space, every 113 days of monitoring data has to be downloaded.
How many measurements are planned to be done	Continuous monitoring.
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.	One year of monitoring (installed on 26th November 2016)
The instrument requires an Ethernet connection during the experiment.	No
Time required to perform a preliminary signal processing to ensure the measurement reliability	Preliminary signal process was already done and data were matched with the ones provided by ARPA stations

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

4.3.9.5 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

4.3.10 Town Walls: Test-bed sensor #1.9: Infrared Thermography

4.3.10.1 Description

Infrared thermography will be performed by means of a thermographic camera available at UNIPG/CIRIAF laboratories. The aim of this monitoring is to detect specific inner structural diseases and non homogeneity. For this purpose, several one-day surveys will be planned during all the project duration in order to assess the Town Walls response to various meteorological events (i.e. extreme rainfall) in terms of superficial temperature [3].

4.3.10.2 Measured parameters

Infrared thermographic camera detects infrared energy emitted by bodies and so their superficial temperature [°C] which is converted in electronic signal then elaborated to produce images as the one reported below (Figure 12). By thermography, superficial temperature of the body object is therefore collected [4].

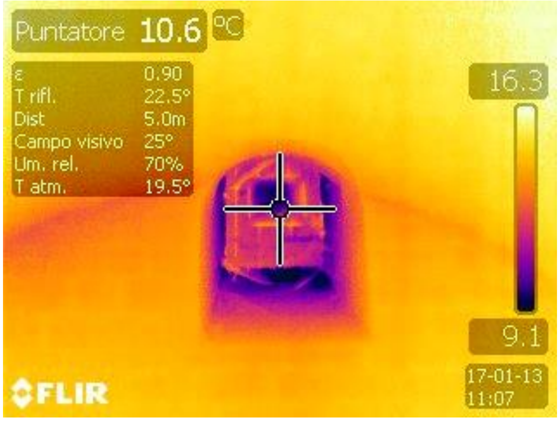


Figure 12 – Example of infrared thermography result

4.3.10.3 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, 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	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

4.3.10.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	One-day measurement
How many measurements are planned to be done	Exception made for a preliminary monitoring campaign, the number of infrared thermography surveys will depend on the occurrence of extreme meteorological events within the project duration
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	Compatible with all the other sensing techniques

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 Town Walls: Test-bed sensor # 1.10: inclinometer @ zone 1 – Town Walls (*Forte Parco Ranghiasci*) Stability sensor S2

4.3.11.1 Description

The inclinometer will be used for the static monitoring of the out-of-plane rocking of specific portions of the Town Walls. The identified position for the installation of the sensor in the Zone #1, called “*Forte Parco Ranghiasci*”, is approximately indicated in Figure 13.

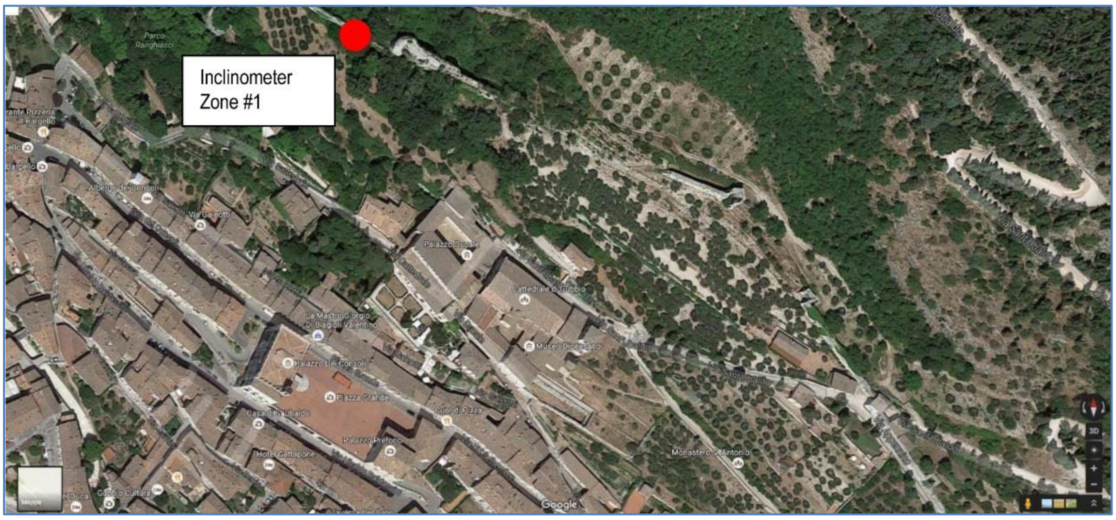


Figure 13 - Possible identified location in the Zone #1 for the installation of the inclinometer S2

4.3.11.2 Measured parameters

The details related to the inclinometer of zone #1 for the static monitoring is described in the following Table 9:

Table 9 - Inclinometer of zone #1: static monitoring parameters

Name	Position	Parameters
Not yet specified	Lat.: 43.354890 Long.: 12.579134 Alt.: -	Angle (degree/rad)

4.3.11.3 Installation

Sensing Technique	Inclinometer
Sensor location	The sensor will be anchored on an adequate portion of the Walls, in the mount side.
Where to fix the sensor (post, tripod, etc)	The sensor will be installed directly on the wall through anchors and covered with a specific box fixed on the wall.
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	The installation requires drillings of small diameters (ø 6mm).
Give a description of the installation procedure.	After drillings, the sensor will be fixed on the desired position.
Time required to install the sensor	About 30 minutes.
Possible constraints for the installation (authorizations – announcement in advance etc.)	The drillings require the authorizations of the authority.

4.3.11.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	The acquisition will be continuous from the installation until the end of the project.
How many measurements are planned to be done	The measurements will be manually acquired on site about one times per two weeks.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The system requires a local power (12V) which can be provided by the laptop during the acquisition.
Dimension of the sensor system (sensor + any electronic control or computer)	The sensor has a parallelepiped on shape with few centimetres per side. The box covering the sensor could have dimensions of about 40x20x20cm.
If 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	The connection to the acquisition

connection during the experiment.	system installed inside Consoli Palace through a wireless system could be useful to share the data directly online with the project platform.
Time required to perform a preliminary signal processing to ensure the measurement reliability	One day
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?)	Some correlations will be carried out with temperature measurements and with the remote sensing data derived by SAR techniques.
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	-

4.3.11.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	UNIPG/DICA
Partner in charge for data acquisition	UNIPG/DICA
Partner in charge for data validation	UNIPG/DICA
Partner in charge for processing/modelling	UNIPG/DICA+LEONARDO (through "inverse velocity technique")

4.3.12 Town Walls: Test-bed sensor # 1.11: inclinometer @ zone 3 – Town Walls (Tower) Stability sensor S3

4.3.12.1 Description

The inclinometer will be used for the static monitoring of the out-of-plane rocking of specific portions of the Town Walls. The position identified for the installation of the sensor in the Zone #3, called “Torre”, is approximately indicated in Figure 14.

Figure 14 - Possible location identified in the Zone #3 for the installation of the inclinometer S3.

4.3.12.2 Measured parameters

The details related to the inclinometer of zone #3 for the static monitoring is described in the following table 10.

Table 10 - Inclinometer of zone #3: static monitoring parameters

Name	Position	Parameters
Not yet specified	Lat.: 43.353398 Long.: 12.572081 Alt.: -	Angle (degree/rad)

4.3.12.3 Installation

Sensing Technique	Inclinometer
Sensor location	The sensor will be anchored on an adequate portion of the wall, in the mount side.
Where to fix the sensor (post, tripod, etc)	The sensor will be installed directly on the wall through anchors and covered with a specific box fixed on the wall.
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	The installation requires drillings of small diameters (ø 6mm).
Give a description of the installation procedure.	After drillings, the sensor will be fixed on the desired position.
Time required to install the sensor	About 30 minutes.
Possible constraints for the installation (authorizations – announcement in advance etc.)	The drillings require the authorizations of the authority.

4.3.12.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	The acquisition will be continuous from the installation until the end of the project.
How many measurements are planned to be done	The measurements will be manually acquired on site about one times per two weeks.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The system requires a local power (12V) which can be provided by the laptop during the acquisition.
Dimension of the sensor system (sensor + any electronic control or computer)	The sensor has a parallelepiped on shape with few centimetres per side. The box covering the sensor could have dimensions of about 40x20x20cm.
It is planned to leave the sensor instrumentation on the test-bed	Yes

location during all the experiment period to perform a several days monitoring.	
The instrument requires an Ethernet connection during the experiment.	The connection to the acquisition system installed inside Consoli Palace through a wireless system could be useful to share the data directly online with the project platform.
Time required to perform a preliminary signal processing to ensure the measurement reliability	One day
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?)	Some correlations will be carried out with temperature measurements and with the remote sensing data derived by SAR techniques.
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	-

4.3.12.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	UNIPG/DICA
Partner in charge for data acquisition	UNIPG/DICA
Partner in charge for data validation	UNIPG/DICA
Partner in charge for processing/modelling	UNIPG/DICA+LEONARDO (through "inverse velocity technique")

4.3.13 Town Walls: Test-bed sensor # 1.12: inclinometer @ zone 4 – Town Walls (*porta S.Ubaldo-Bughetto*) Stability sensor S4

4.3.13.1 Description

The inclinometer will be used for the static monitoring of the out-of-plane rocking of specific portions of the Town Walls. The position identified for the installation of the sensor in the Zone #4, called "*Porta S.Ubaldo-Bughetto*", is approximately indicated in Figure 15.

Figure 15 - Possible location identified in the Zone #4 for the installation of the inclinometer S4.

4.3.13.2 Measured parameters

The details related to the inclinometer of zone #4 for the static monitoring is described in the following table 11.

Table 11 - Inclinometer of zone #4: static monitoring parameters

Name	Position	Parameters
Not yet specified	Lat.: 43.352979 Long.: 12.572466 Alt.: -	Angle (degree/rad)

4.3.13.3 Installation

Sensing Technique	Inclinometer
Sensor location the	The sensor will be anchored on an adequate portion of the wall, in the mount side.
If a mechanical support where to fix the sensor (post, tripod, etc) needs	The sensor will be installed directly on the wall through anchors and covered with a specific box fixed on the wall.
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	The installation requires drillings of small diameters (ø6mm).
Give a description of the installation procedure.	After drillings, the sensor will be fixed on the desired position.
Time required to install the sensor	About 30 minutes.
Possible constraints for the installation (authorizations – announcement in advance etc.)	The drillings could require the authorizations of the authority.

4.3.13.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	The acquisition will be continuous from the installation until the end of the project.
How many measurements are planned to be done	The measurements will be manually acquired on site about one times per two weeks.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The system requires a local power (12V) which can be provided by the laptop during the acquisition.
Dimension of the sensor system (sensor + any electronic control or computer)	The sensor has a parallelepiped on shape with few centimetres per side. The box that will cover the sensor could have dimensions of about 40x20x20cm.
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.	The connection to the acquisition system installed inside Consoli Palace through a wireless system could be useful to share the data directly online with the project platform.
Time required to perform a preliminary signal processing to ensure the measurement reliability	One day
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?)	Some correlations will be carried out with temperature measurements and with the remote sensing data derived by SAR 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/DICA
Partner in charge for data acquisition	UNIPG/DICA
Partner in charge for data validation	UNIPG/DICA
Partner in charge for processing/ modelling	UNIPG/DICA+LEONARDO (through "inverse velocity technique")

4.3.14 Town Walls: Test-bed sensor # 1.13: Drilling Resistance Measurements System (DRMS)

4.3.14.1 Description

The application of the drilling resistance measuring will be focused on two distinct targets: i) the evaluation of stone current state preservation of the building and architectural elements of the Town Walls in Gubbio and ii) the sampling of the drilling residue (dust) from distinct interval depths for further physicochemical analyses. The materials will be tested and evaluated in-situ [5-9]

4.3.14.2 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

4.3.14.3 Installation

Sensing Technique	DRMS
Sensor location	Town Walls surfaces at different states of preservation.
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.

4.3.14.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	30 minutes per spot
How many measurements are planned	For each site minimum (if possible):

to be done	- 2 measurements for stones - 2 measurements for mortars (original or "middle age" mortar): - 2 measurements for mortars (cement mortar): - 2 measurements for mortars ("new" mortar last approved by superintendence). The measurements could increase due to local conditions
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	DRMS is a battery operated system
Dimension of the sensor system (sensor + any electronic control or computer)	Approximately 50cm^3
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. 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)	High humidity content inside the examined stone might affect drilling resistance results.

4.3.14.5 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, UNIPG/DICA

4.3.15 Town Walls: Test-bed analytical techniques # 1.14: Stone and Mortar samples analysis

4.3.15.1 Description

The atmospheric moisture change is the main hazard affecting the Town Walls since its major consequence is intense rainfalls which lead to flooding.

Furthermore, risks are mainly associated with stone deterioration caused by climate change effects coupled with pollution and degradation of the mortars as binding agents of the Walls, as evidenced in detail in deliverable D1.2, with particular emphasis to the hydrogeological risk. In addition, the combined action of the acid rainfall, the air pollution, the cold and the biological agents, produces a visible material degradation of the outer surfaces.

The HERACLES activities for this scenario, will address the weathering state of the building materials and mortars used and their properties.

In particular, the study of the degradation mechanisms will be carried on through the characterization and study of the degraded materials.

4.3.15.2 Measured parameters

This activity refers to ex-situ characterization and analytical methods applied to Gubbio test-bed materials. This approach is valid for both Gubbio test-beds (Town Walls and Consoli Palace). 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 concrete, mortars, binders and stones. The mechanical and thermo-physical characterizations allow to verify the state of the conservation and the resistance to the 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, as well the compounds present on their surfaces. 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 12. Any sampling campaign requires the authorization from MIBACT.

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 MIBACT Superintendence.
- **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.

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

4.3.15.3 Data acquisition - Validation and processing/modelling

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

Table 12 - Characterisation 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
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
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	nm	Å to μm	μm	Up to cm	Few minutes to some hours	UNINOVA

			materials						
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)-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-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 resolution	≈1 mm	Depends on magnification	any	Few minutes to some hours	FORTH-IESL
4D surface volume	White light	Backscatter	Artworks and	extremely	To be	To be	any	Few minutes to some	FORTH-IESL

topography	illumination	ed light	monuments for structural analysis	high (versatile imaging system)	determined	determined		hours	
Non-linear Microscopy	fs laser	Non-linear phenomena emitted from the sample	laser scanning microscopy to detect interfaces, non-centrosymmetric molecules and fluorescence	~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 - 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
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 – Consoli Palace

5.1 Description of the site

Figure 16 - A view of the Consoli Palace complex, in the higher part of the town

5.1.1 Introduction

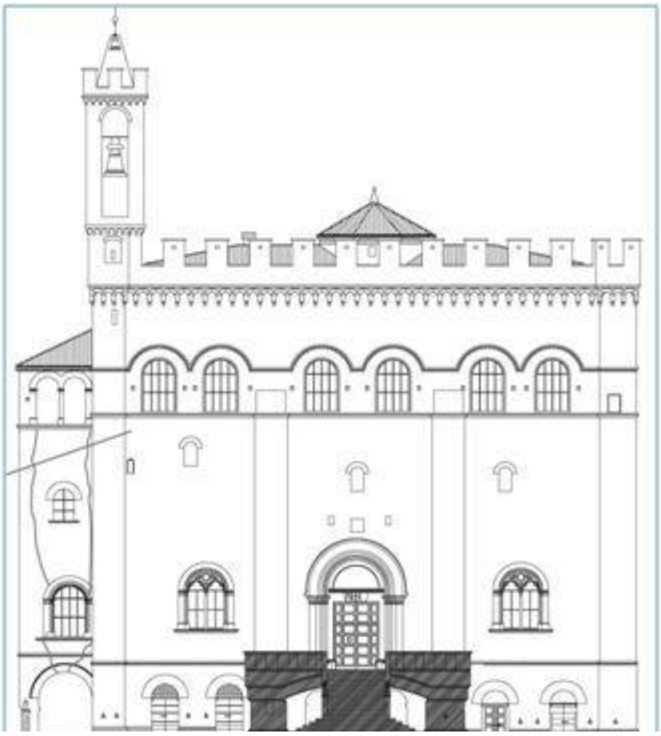


Figure 17 - Consoli Palace façade

The Consoli Palace (Figure 16) was built between 1332 and 1349. The Palace has a rectangular shape, and a very articulated distribution of volumes divided into 9 levels:

- Level +6 (roof and bell tower)
- Level +5 (ex-kitchen, now “*Campanari*’s hall in SW façade and Consoli’s chamber in NW façade)
- Level +4 (“*piano nobile*” or main floor, the art gallery and upper open Lodge)
- Level +3 (upper closed Lodge – now Hall of “lustred ceramics”)
- Level +2 (Lower closed Lodge and chapel – now hall of *Tavole Eugubine*)
- Level +1 (the “*Arengo*”, a barrel vault hall which, during late Middle Ages, was used for meetings and assembly of citizens for city administration)
- Level 0 (“*Capitano del Popolo*” halls – now *Risorgimento section)*
- Level -1 (Lower entrance from Gattapone street – now museum)
- Level -2 (Halls in Baldassini street)

Construction details:
The main façade (Figure 17) overlooking the square is made of ashlar stone and it stands for over 44 meters up to the top of the bell tower. The entryway is through a fan-shaped staircase leading to the "*Arengo*" (level +1). This hall has two mullioned windows positioned on the two sides of the Gothic style portal, decorated with a XVI-century fresco in the lunette. In the main floor (level +4), six windows with round centre in pairs, divided by pillars, are present, while the battlement is supported by small pointed arches.

Since 1901, the building hosts the town museum, presenting art gallery, ceramics section, archaeological and oriental collection, and a collection section on Italian *Risorgimento* (*Risorgimento* is the period leading to the unification of Italy in 1861). In the tower the big bell ("*campanone"*) is placed that since 1380 marks with its sound (*sonate)* very few and special events during the years.

Several restorations were made after the 1982 and 1984 earthquakes and completed in the first half of the '90s. During these restorations, the façades were completely cleaned by the accumulations of dirt. After only thirty years, however, smog, concretions and localized phenomena of black patina are again clearly visible.

5.1.2 Exposition and cartographic information

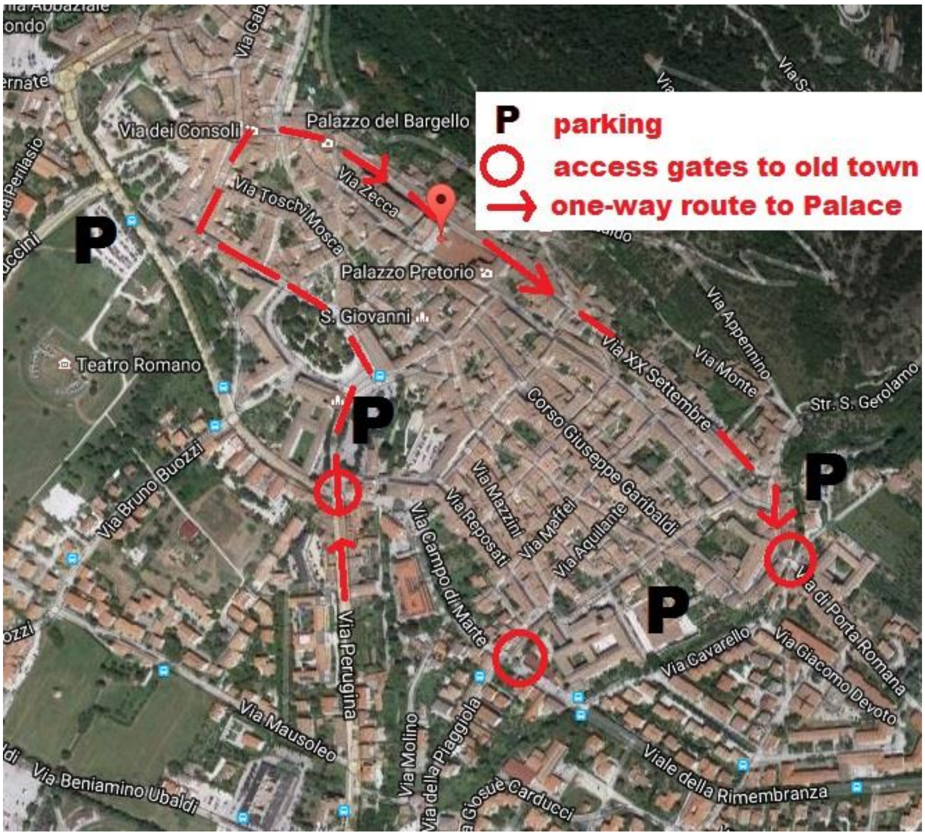


Figure 18 - Position of Consoli Palace

Figure 19 - Consoli Palace complex aerial view

In Figures 18 and 19 are shown aerial views of the Consoli Palace area and complex. The position of Consoli Palace main entrance is located at N 43.353372, E 12.578478.

5.1.3 Logistics

The Consoli Palace is located right in the centre of the Old Town. The only way to reach it by car is through one of the 3 old gates of the city, where a van or a small truck could pass. The access to the old town by car or similar is strictly allowed to resident people and a system of automatized check-in is going to be installed, so in case of access, a permission should be asked to the Municipality of Gubbio. Nearby the Old Town there are free/pay car parks from which the Consoli Palace could be reached (from 300 to 700 m walking). Some of the car parks are connected with lifts to the upper streets. The access to the museum is allowed only during opening time: h 10-13 and 15-18 and has to be asked at least 2 days before to the company in charge for the management of the museum ("Gubbio Cultura Multiservizi"). Indeed, due to the local celebrations (the "*Corsa dei Ceri*"), from the first Sunday of May until June 3rd, all the timetable of the tests should be agreed with the Municipality of Gubbio and the sensors removed, since thousands of people gets into the Consoli Palace for this event, especially in the *Arengo* Hall, *Campanari*'s hall and the Roof.

All the rooms inside Consoli Palace are accessible on foot only: there are no lifts inside and all the sensors have to be light enough to be carried on foot. Some sensors over level +4 must have a dimensional limit (a diameter less than 1 m) since they have to be carried over a steep and narrow spiral staircase.

In all the rooms a three phase current is provided.

5.1.3.1 *Arengo* Hall (level +1)

- Internet: YES – using the web line of the museum and during opening time.
- Safe deposition of instruments: YES (in the box ticket)

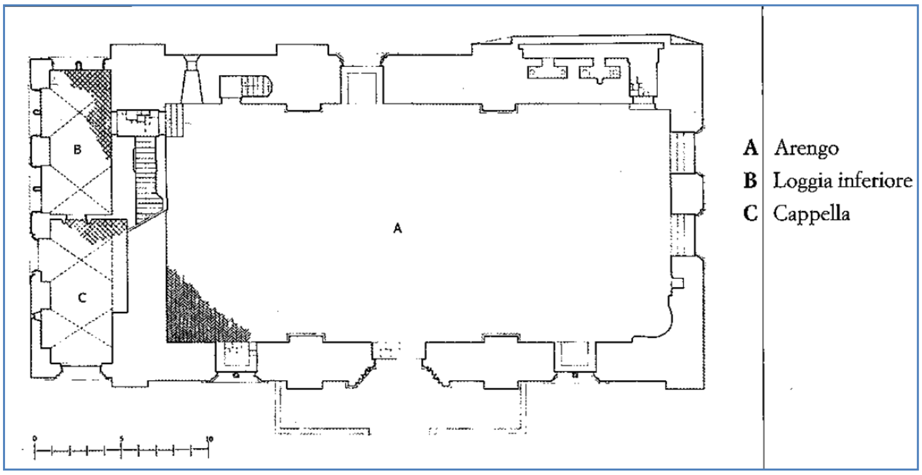


Figure 20 - Levels +1 (Arengo hall) and +2 (Lower closed Lodge and Chapel)

5.1.3.2 "*Piano Nobile*" (level +4)

- Internet: NO
- Safe deposition of instruments: NO

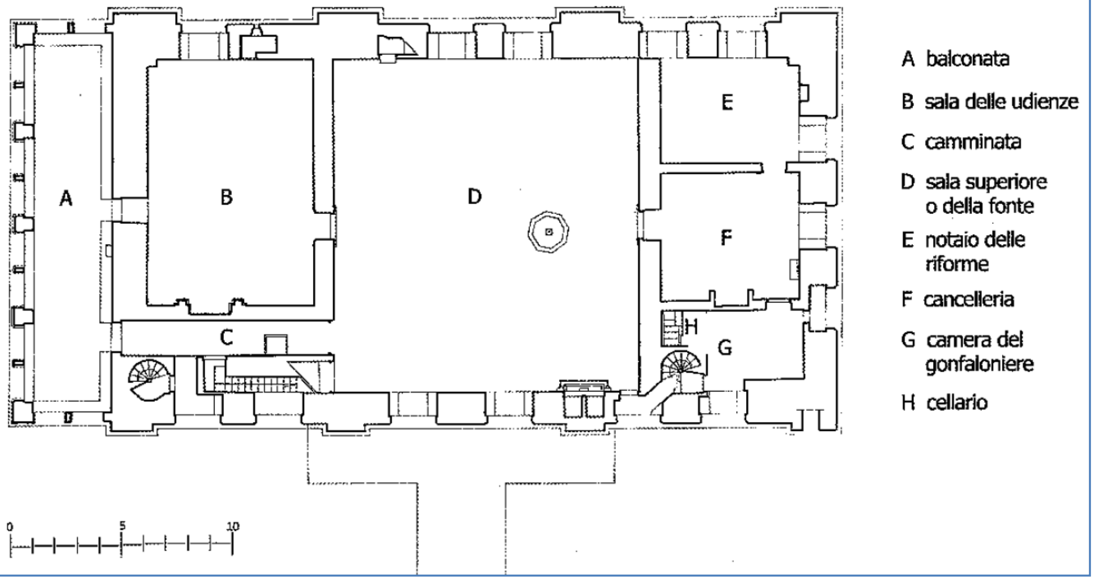


Figure 21 - Level +4 ("*Piano Nobile*" level)

5.1.3.3 "Campanari" Hall (or ex-Kitchen) (level+5)

- Internet: YES: a dedicated web line will be installed
- Safe deposition of instruments: YES

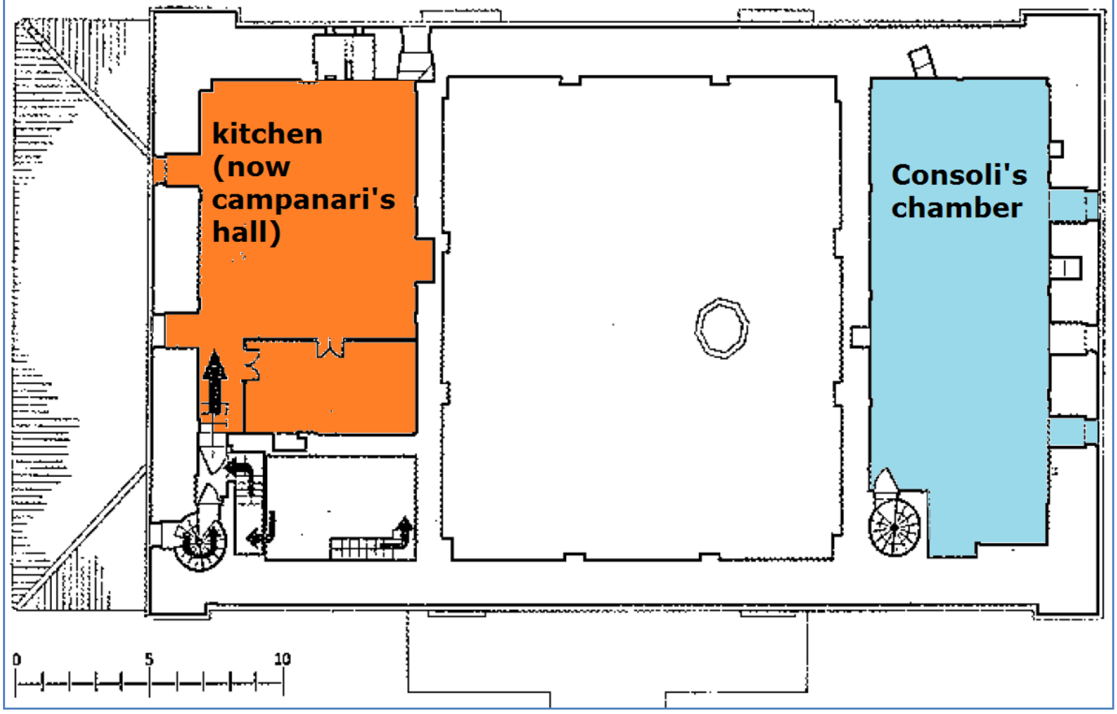


Figure 22 - Level +5: kitchens (on left) and Consoli's chamber (on right)

5.1.3.4 Consoli’s chamber (level +5)

- Power supply: YES
- Internet: NO
- Safe deposition of instruments: YES

5.1.3.5 Roof (level +6)

- Power supply: NO
- Internet: YES, through cable to the router in the underlying “Campanari’s hall”
- Safe deposition of instruments: NO

5.1.3.6 Town Hall Terrace (external)

- Access: YES only on feet. Permission required from Municipality of Gubbio.
- Power supply: NO
- Internet: NO
- Safe deposition of instruments: YES, but there is no protection against atmospheric agents

5.2 End-user detailed requirements

This section presents the risks/hazard related to the Consoli Palace.
This part was the object of the **deliverable D1.2**; here are only reported the main aspects/conclusions, useful to support the demonstration activities.

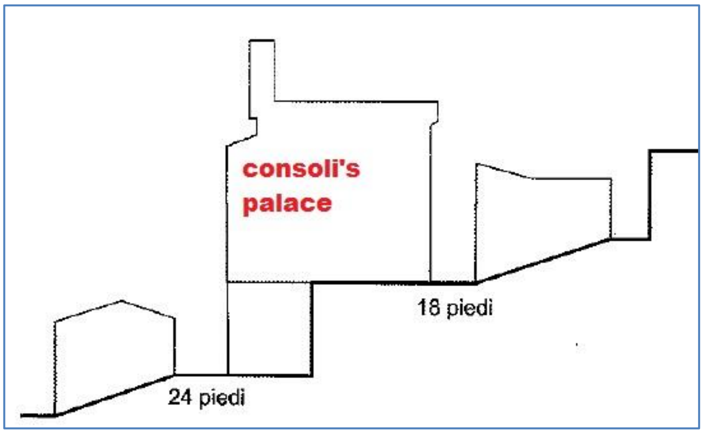


Figure 23 – external shape of Consoli Palace and the surroundings

The first scenario is linked to atmospheric moisture change, intense rainfall and flooding. Main risks are related to the consequent variation of the aquifer level that could induce foundation settlement. The Consoli Palace has the foundations placed at two different levels, due to the local topography (Figure 23). This aspect confers to the SW façade of the structure a remarkable height of about 60 metres, where, at the top of the structure, is located a slender bell tower. The difference in height of the two foundation levels is more than 10 meters. This could lead to a first structural problem regarding differential displacements. The main critical aspect is highlighted in the south-west part, where an out-of-plane rocking mechanism is becoming evident by a widespread crack pattern, in the cross vaults of the loggia, in the form of activated local mechanisms. This aspect could be due to differential settlements of foundations caused by several reasons, also related to environmental actions and other natural hazards as the earthquake (a multi risk, domino effect could be considered).

The second scenario is due to climate, wind and pollution acting together.

The most frequent events that are consequences of temperature change are diurnal, seasonal, extreme events (i.e. heat waves, snow loading), changes in freeze-thaw cycles and ice storms, and the frost increase. All these factors induce damages inside stone and/or mortars undergoing wet-frozen cycles inside material before drying. Wind-driven rain can penetrate moisture into porous materials weakening them and combined with ice can create cracks in stones and mortars, inducing structural instability (Figure 24).

Figure 24 - Consoli Palace- main stairs - thermoclasts due to freeze-thaw/frost damage with loss of material (see red circle)

Figure 25 - Consoli Palace- column of the lodge showing differential blackening (limestone).

Figure 26 - Consoli Palace- differential blackening in the arch of the lodge

Acid rains and changes in deposition of pollutants can lead to stone erosion by dissolution of carbonates and/or stone blackening.

Dark patinas are widely visible and well highlighted by the presence of other adjacent stones that are not minimally blackened, even if experiencing the same environmental conditions (Figures 25 and 26).

5.3 Demonstration activity on Consoli Palace

In the following picture (Figure 27) a summary of the systematic protocol proposed for the Consoli Palace 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 Consoli Palace.

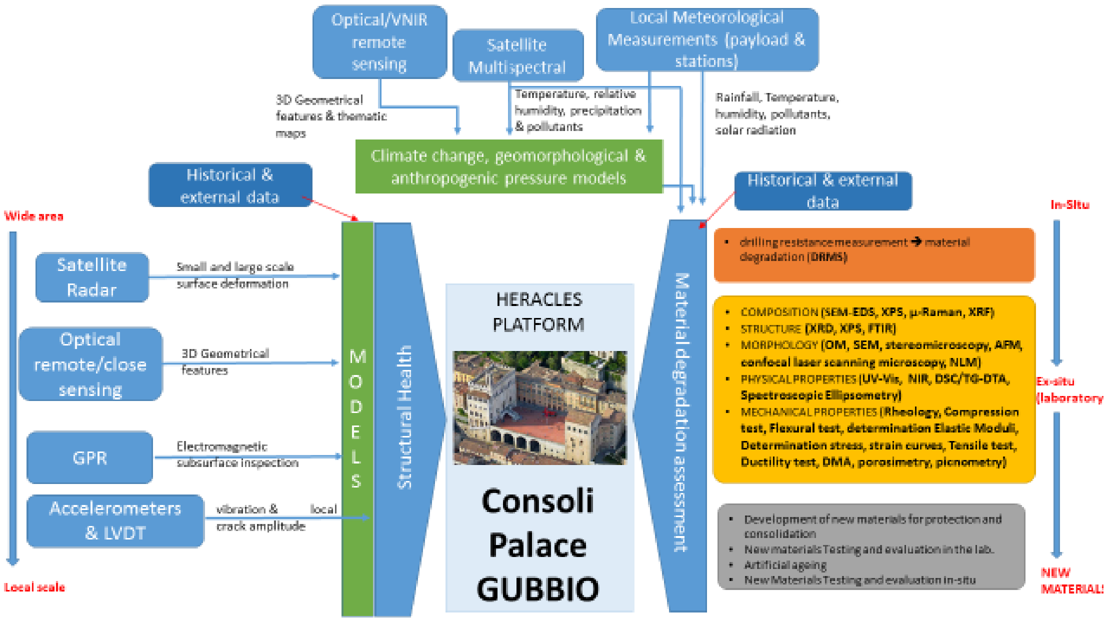


Figure 27 – Systematic and complete protocol flow view for Consoli Palace

5.3.1 Measuring systems installed and to be installed

The test/measuring system that will be installed or used on Consoli Palace will be the following:

2.1. Spaceborne radar COSMO-SKYMED [e-GEOS]
2.2. Multispectral Remote Sensors [SISTEMA]
2.3. Geometrical survey (TLS + ground photos) [E-GEOS]
2.4. GPR (georadar) in different Palace areas [CNR-IREA]
2.5. ARPA UMBRIA weather monitoring station network [SISTEMA+UNIPG/CIRIAF]
2.6. Measurement of climatic parameters (Drone and/or portable environmental payload device for the monitoring of local microclimate variables) [UNIPG/CIRIAF]
2.7. TH1-Thermal-Humidity sensor data logging system [UNIPG/CIRIAF] - Consoli Palace (internal)
2.8. TH2-Thermal-Humidity sensor data logging system [UNIPG/CIRIAF] - Consoli Palace (External)
2.9. Infrared Thermography [UNIPG/CIRIAF]
2.10. Accelerometers #1-2-3 [UNIPG/DICA]
2.11. LVDT #1 (linear variable differential transformer) - *"piano nobile"* [UNIPG/DICA]
2.12. LVDT #2 (linear variable differential transformer) – Consoli's chamber [UNIPG/DICA]
2.13. Drilling Resistance Measurements System (DRMS) - [UoC]
2.14. Stone and Mortar samples analysis [CNR-ISMN; UNINOVA; FORTH; CVR/INSTM;]

5.3.2 Consoli Palace: Test-bed sensor #2.1: Spaceborne radar COSMO-SKYMED

5.3.2.1 Description

The description for this sensor was already provided in section 4.3.2.1, since it is referred to the same system that is used in both the Gubbio test-beds.

5.3.2.2 Measured parameters

The measured parameters were already described in section 4.3.2.2

5.3.2.3 Installation

The installation details were already provided in section 4.3.2.3.

5.3.2.4 Monitoring

The monitoring details were already given in section 4.3.2.4

5.3.2.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	Not applicable
Partner in charge for data acquisition	E-GEOS, CNR-IREA
Partner in charge for data validation	E-GEOS, CNR-IREA
Partner in charge for processing/modelling	CNR-IREA, UNIPG/DICA

5.3.3 Consoli Palace: Test-bed sensor # 2.2: Multispectral remote sensors

5.3.3.1 Description

The description of this sensing methodology was already provided in section 4.3.3.1, since it is referred to the same system that is used in both the Gubbio test-beds.

5.3.3.2 Measured parameters

The measured parameters were already described in section 4.3.3.2.

5.3.3.3 Installation

This section does not apply to satellite multispectral remote sensors

5.3.3.4 Monitoring

The monitoring details were already given in section 4.3.3.4

5.3.3.5 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

5.3.4 Consoli Palace: Test-bed sensor #2.3: Geometrical survey (TLS + ground photos)

5.3.4.1 Description

A complete three dimensional reconstruction will be carried out for Consoli Palace trough laser and photo scanning survey. The combination of these optical sensors will be processed and fused at 3D point cloud level with centimetre detail.

5.3.4.2 Measured parameters

A scanning laser system provides a direct measurement result of a three-dimensional coordinate set, generally in a reference system related to the instrument, referring to a very high number of points that are affected by the laser beam. The point cloud thus generated describes the outer surface of the scanned object. In the same way, a non-metric optical camera performs photographic scan on the top part of the building, that is not achieved by laser scanning from the ground.

5.3.4.3 Installation

Sensing Technique	Close range sensing
Sensor location	on the four sides of Consoli Palace
Where to fix the sensor (post, tripod, etc)	Yes (for TLS survey)
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.	Positioning of a ground stand with a distance of about 10m-15m from the target
Time required to install the sensor	Less than 10 minutes for each scanning (4 station)
Possible constraints for the installation (authorizations – announcement in advance etc.)	Permission access in a private property, on the Nord-East side of the Consoli Palace

5.3.4.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	3-4 hours
How many measurements are planned to be done	four, one for each side of building
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	Battery
Dimension of the sensor system (sensor	Main station, approx. dimension: Size:

+ any electronic control or computer)	240 x 200 x 100mm. Weight 5.2 kg
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)	Obstacles, minimum scanning distance (10-15 m from target)

5.3.4.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	e-GEOS
Partner in charge for data acquisition	e-GEOS
Partner in charge for data validation	e-GEOS/FRAU-IOSB
Partner in charge for processing/modelling	E-GEOS,UNIPG-DICA/FRAU-IOSB/LEONARDO/THALES

5.3.5 Consoli Palace: Test-bed sensor # 2.4: GPR (georadar)

5.3.5.1 Description

The GPR system has been described in detail in Section 4.3.5.1. Therefore, in this section, it is only underlined that at Consoli Palace the K2-RIS GPR system equipped with the dual frequency antenna will be used to perform floor surveys, while vertical structures, such as the walls of the Palace, are investigated by equipping the system with a high frequency antenna, whose nominal central frequency is 2 GHz.

5.3.5.2 Measured parameters

As previously explained in section 4.3.5.2, the GPR instrumentation measures time dependent waveforms accounting for the variations of the electromagnetic parameters occurring into the spatial region under test and provides images from which it is possible to detect unknown targets and infer information about their geometrical features, i.e. location, size and shape.

5.3.5.3 Installation

The installation details were already given in section 4.3.5.3

5.3.5.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	The time to acquire a GPR data set depends on the extent and accessibility of the area under test and generally is in the range from few minutes up to some hours
How many measurements are planned to be done	At least a survey will be performed at each accessible area
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The system is battery operated
Dimension of the sensor system (sensor + any electronic control or computer)	The system equipped with the dual frequency antenna looks like a lawnmower, whose base is about 0.6 m x 0.6 m and height is 1.30 m. The system equipped with the 2 GHz antenna has small size. In particular, the antenna is about 10 cm x 7 cm x 7 cm, while the electronic control and the computer can be located in a properly designed backpack, which is worn by the operator
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	A calibration procedure is needed and it requires about 1 minute
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?)	GPR measurement are compatible with other sensing techniques
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	The indoor survey are not affected by weather factors, while outdoor measurements are affected by rain

5.3.5.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	CNR-IREA
Partner in charge for data acquisition	CNR-IREA

Partner in charge for data validation	CNR-IREA + UNIPG/DICA
Partner in charge for processing/modelling	CNR-IREA + UNIPG/DICA

5.3.6 Consoli Palace: Test-bed sensor #2.5: ARPA UMBRIA weather monitoring station network

5.3.6.1 Description

As already discussed in section 4.3.7.1, the network of microclimate monitoring sensors currently installed in the area of the city of Gubbio is managed and operated by a local public environmental authority, i.e. A.R.P.A. Umbria, and is composed by five monitoring stations located at ground level, i.e. pedestrian level, both (i) nearby and (ii) inside the city centre. It is important to note that this weather monitoring station network is suitable to evaluate the microclimate for both the test-beds in Gubbio, (i.e. Town Walls and Consoli Palace). The location of the weather monitoring stations are indicated in Figure 7. For their detailed description refer to section 4.3.7.1.

5.3.6.2 Measured parameters

The parameters measured by the six different ground microclimate stations are summarized in Table 6 and are discussed in section 4.3.7.2.

5.3.6.3 Installation

The Installation details were already given in section 4.3.7.3

5.3.6.4 Monitoring

The Monitoring details were already given in section 4.3.7.4

5.3.6.5 Data acquisition - Validation and processing/modelling

Partner in charge for installation	GUBBIO (trough ARPA)
Partner in charge for data acquisition	SISTEMA Gmbh
Partner in charge for data validation	SISTEMA Gmbh for old data
Partner in charge for processing/modelling	LEONARDO + THALES for new data modelling ARIA for weather modelling

5.3.7 Consoli Palace: Test-bed sensor #2.6: Portable environmental payload for the monitoring of local microclimate variables

5.3.7.1 Description

The description of the system used was already given in section 4.3.8.1 and in Fig.9.

5.3.7.2 Measured parameters

The description of the microclimate parameters was already provided in Section 4.3.8.2 and Table 7.

5.3.7.3 Installation

Sensing Technique	Microclimate monitoring sensors
Sensor location	Payload device will be used to perform measurement in space and time so it will not be positioned in a specific location. The one-day monitoring path, both at sky and at pedestrian level, will take place along the main streets of the historic city centre of Gubbio (i.e. Consoli street and Baldassini street).
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 needed
Give a description of the installation procedure.	Payload device will be installed on drone and wearing helmets
Time required to install the sensor	-
Possible constraints for the installation (authorizations – announcement in advance etc.)	Drone flight has to be planned in advance and the path arranged with municipality

5.3.7.4 Monitoring

For Monitoring details, please refer to section 4.3.8.4

5.3.7.5 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

5.3.8 Consoli Palace: Test-bed sensor #2.7: TH1-Thermal-Humidity sensor data logging system Consoli Palace-internal

5.3.8.1 Description

Punctual ambient parameters monitoring is carried on by means of TGP-4500 devices. In specific, these are rugged, waterproof temperature and relative humidity loggers with built-in sensors, able to monitors temperatures within -25 and +85°C and all the spectra of relative humidity (i.e. 0-100%). The device could not be wired to an acquisition network, but has an internal memory which guarantees data collection of 113 days of continuous monitoring. Data collected by the system are used to validate the dynamic energy building model of Consoli Palace. Therefore, the device is located within the *Sala Nobile* of the Consoli Palace (Figure 28). The installation was performed on 24th November 2016.

Figure 28 - Thermo-hygrometer location within the Consoli Palace

5.3.8.2 Measured parameters

Parameters monitored by TGP-4500 sensor are (i) air temperature and (ii) relative humidity, as summarized in the following table 13.

Table 13– TGP-4500 sensor monitored parameters in #2.7

Name	Position	Parameters
TGP-4500	Inside Consoli Palace	Air Temperature (°C), Relative Humidity (%)

The operative ranges of the devices are -25 ÷ +85°C and 0 ÷ 100% for temperature and relative humidity respectively.

5.3.8.3 Installation

Sensing Technique	Microclimate monitoring sensors
Sensor location	Sensor is located in the *Sala Nobile* of the Consoli Palace
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 needed
Give a description/visualisation of the installation procedure.	The device is simply positioned on the door frame in the *Sala Nobile* of Consoli Palace, as shown in figure 29.
Time required to install the sensor	Only few minutes were requested. The sensor was installed on 24th November 2016 and
Possible constraints for the installation (authorizations – announcement in advance etc.)	Authorization needs

Figure 29 - Thermo-hygrometer located within Consoli Palace (*Sala Nobile*)

5.3.8.4 Monitoring

The monitoring details are the same already given in section 4.3.9.4.

5.3.8.5 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

5.3.9 Consoli Palace: Test-bed sensor #2.8: TH2-Thermal-Humidity sensor data logging system Consoli Palace- external

5.3.9.1 Description

Punctual ambient parameters monitoring is carried on by means of TGP-4500 devices. In specific, these are rugged, waterproof temperature and relative humidity loggers with built-in sensors, able to monitors temperatures within -25 and +85°C and all the spectra of relative humidity (i.e. 0-100%). The device could not be wired to an acquisition network, but has an internal memory which guarantees data collection of 113 days of continuous monitoring. Data collected by the system are used to validate numerical microclimate model of Gubbio historic district. For this purpose, the thermal-humidity data logging system described is located on the top of Gubbio municipality building (Figure 30). The installation was performed on 24th November 2016.

Figure 30 - Gubbio municipality building terrace where the sensor is located

5.3.9.2 Measured parameters

Parameters monitored by TGP-4500 sensor are (i) air temperature and (ii) relative humidity, as summarized in the following Table 14.

Table 14 – TGP-4500 sensor monitored parameters in #2.8

Name	Position	Parameters
TGP-4500	Lat. 43.353064 Long. 12.579095 Alt. -	Air Temperature (°C), Relative Humidity (%)

The operative ranges of the devices are -25 ÷ +85°C and 0 ÷ 100% for temperature and relative humidity respectively.

5.3.9.3 Installation

Sensing Technique	Microclimate monitoring sensors
Sensor location	The sensor is located on the top of Gubbio municipality building
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 needed
Give a description of the installation procedure.	The outside sensor is clamped on available supports already present in the Gubbio municipality building terrace (Figure 31)
Time required to install the sensor	Only few minutes were requested. The sensor was installed on 24th November 2016.
Possible constraints for the installation (authorizations – announcement in advance etc.)	Authorization needed

Figure 31 - Thermo-hygrometer located on the top of Gubbio municipality building terrace

5.3.9.4 Monitoring

The monitoring details are the same already given in section 4.3.9.4.

5.3.9.5 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

5.3.10 Consoli Palace: Test-bed sensor #2.9: Infrared Thermography

5.3.10.1 Description

Infrared thermography is performed by means of a thermographic camera available at UNIPG/CIRIAF laboratories. The aim of this monitoring is to detect specific inner structural diseases and non homogeneities [3]. For this purpose, several one-day surveys will be planned during all the project duration in order to assess the Consoli Palace response to various meteorological events (i.e. extreme rainfall) in terms of superficial temperature and therefore moisture content.

5.3.10.2 Measured parameters

Infrared thermographic camera detects infrared energy emitted by bodies and so their superficial temperature [°C] which is converted in electronic signal than elaborated to produce images as the one already reported in Figure 12, section 4.3.10.2. By thermography, superficial temperature of the body object is therefore collected [4].

5.3.10.3 Installation

The installation details were already provided in section 4.3.10.3.

5.3.10.4 Monitoring

The monitoring details were already provided in section 4.3.10.4.

5.3.10.5 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

5.3.11 Consoli Palace: Test-bed sensor #2.10: Accelerometers #1-2-3

5.3.11.1 Description

The dynamic monitoring system consists of three high-sensitivity, uni-axial accelerometers installed on the structure. The sensors are placed on the roof of Consoli Palace, fixed on two corners of the perimetral walls for the detection of the three rigid motion degrees of the roof in its plane (see Figure 32). The three sensors are connected through cables to an acquisition system placed in the so called "*Campanari*'s room", located in an intermediate level between the roof and the art gallery.

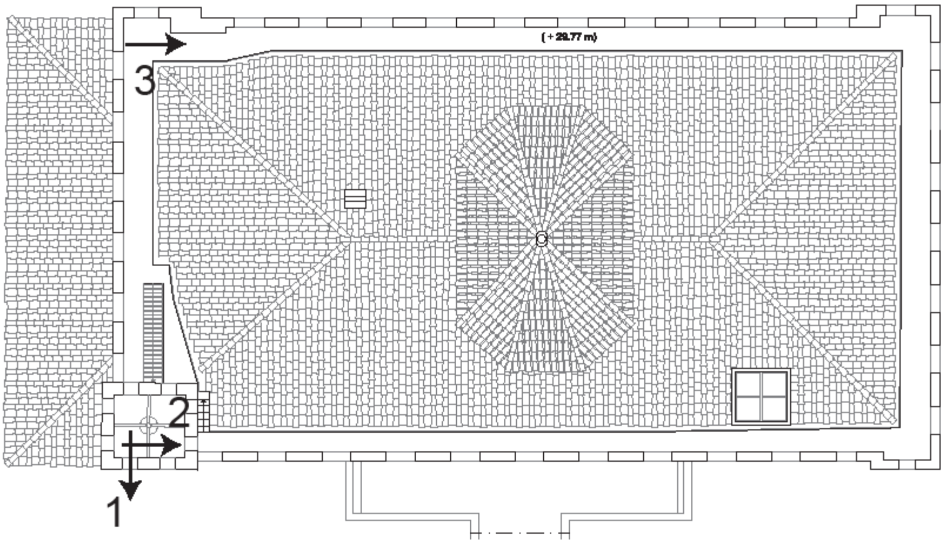


Figure 32 - Installation layout of the three accelerometers at the roof level of Consoli Palace

The system will allow to continuously extract the dynamic parameters of the structure [10, 11].

5.3.11.2 Measured parameters

The specific type of sensors used in the dynamic monitoring is described in the following table 15.

Table 15 – Dynamic monitoring parameters in Test-bed sensor #2.10

Name	Position	Parameters
PCB-393B12	Lat.: 43.353326 Long.: 12.578197 Alt.: -	Acceleration (g)

5.3.11.3 Installation

Sensing Technique	Uni-axial, high-sensitivity piezoelectric Accelerometers
Sensor location	On the roof of Consoli Palace (2 under the bell tower and 1 in another corner at the same level)
Where to fix the sensor (post, tripod, etc)	The sensors are fixed to a little plexiglass support (a cube of 6x6x6cm dimensions) anchored to the walls of the palace. The sensors will be covered with a specific box for the protection against environmental actions.
The sensor installation require to drill,	Little drillings of small diameters (ø6mm)

glue, paint or other action that could change the state or the aspect of the structure	are necessary to anchor the plexiglass supports to the wall.
Give a description of the installation procedure.	The sensors are screwed to the supports previously anchored to the wall
Time required to install the sensor	About 15 minutes
Possible constraints for the installation (authorizations – announcement in advance etc.)	The drillings could require the authorization of the authority.

5.3.11.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	The acquisition will be continuous from the installation (June 2017) until the end of the project.
How many measurements are plannned to be done	High frequency measurements (100 Hz)
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The system requires electric energy.
Dimension of the sensor system (sensor + any electronic control or computer)	The box covering the sensors has dimensions of about 20x20x20cm. The box where the acquisition system will be placed has dimensions of about 60x40x30cm (Figure 33).
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.	The connection is useful to share the data directly online with the project platform.
Time required to perform a preliminary signal processing to ensure the measurement reliability	One day
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?)	Some correlations will be carried on with temperature measurements.
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	-

Figure 33 - Accelerometers used for the dynamic monitoring of Consoli Palace.

5.3.11.5 Data acquisition - Validation and processing/modelling

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

5.3.12 Consoli Palace: Test-bed sensor #2.11: LVDT#1 (linear variable differential transformer) - "*piano nobile*"

In Figure 34 the sensor position, is shown.

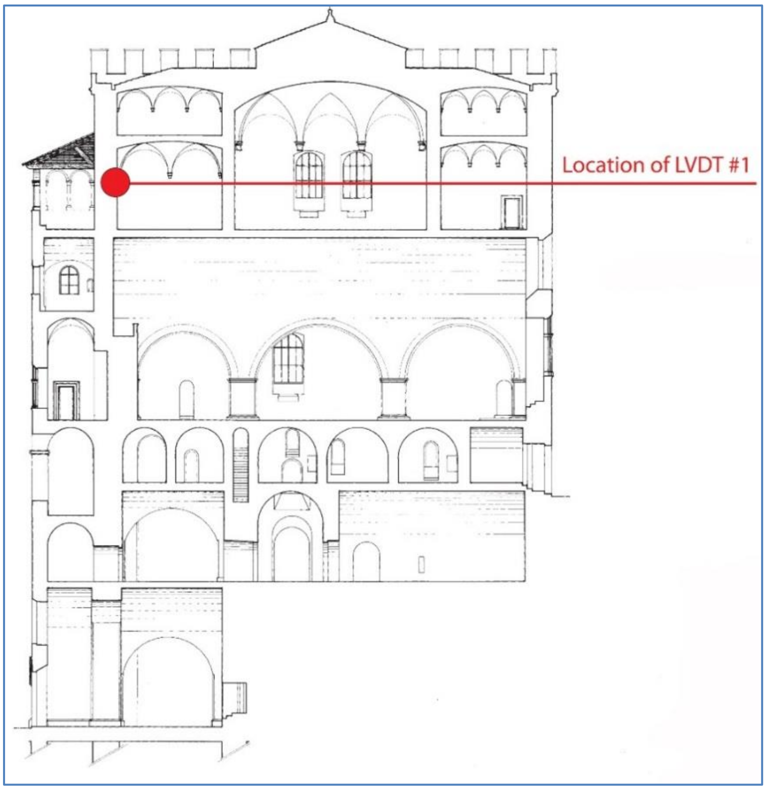


Figure 34 - Position of LVDT#1 for the static monitoring of the south wall

5.3.12.1 Description

The LVDT #1 is installed at the gallery level for the monitoring of the south wall out-of-plane motion (Figure 34). The sensor is protected with a specific box and connected through a cable to the acquisition system, placed in the above floor.

5.3.12.2 Measured parameters

The LVDT sensor used for the static monitoring is described in the following table 16.

Table 16 – LVDT sensor used for the static monitoring in #2.11

Name	Position	Parameters
PCB-393B12	Lat.: 43.353326 Long.: 12.578197 Alt.: -	Displacement (mm)

5.3.12.3 Installation

Sensing Technique	Linear Variable Displacement Transducer (LVDT)
Sensor location	Across a crack
Where to fix the sensor (post, tripod, etc)	The sensor is installed directly on the wall through anchors and covered with a specific box fixed on the wall.
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	The installation requires drillings of small diameters (ø6mm).
Give a description of the installation procedure.	After drillings, the sensor is fixed on the desired position. Special attention will be paid to the position of the cable for the connection to the acquisition system.
Time required to install the sensor	About 15 minutes
Possible constraints for the installation (authorizations – announcement in advance etc.)	The drillings requires authorization from the authority.

5.3.12.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	The acquisition will be continuous from the installation (June 2017) until the end of the project.
How many measurements are planned to be done	One measure per hour
The system is battery operated or	The system requires electric energy.

requires electric energy necessities (Voltage, Power…)	
Dimension of the sensor system (sensor + any electronic control or computer)	The sensor is a cylinder with a length of 20cm and a diameter of about 2cm (Figure 35). The box where the acquisition system will be placed has dimensions of about 60x40x30cm.
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.	The connection is useful to share the data directly online with the project platform.
Time required to perform a preliminary signal processing to ensure the measurement reliability	One day
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?)	Some correlations will be carried on with temperature measurements and with the remote sensing data derived by SAR techniques.
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	-

Figure 35 - LVDT used for the static monitoring of Consoli Palace

5.3.12.5 Data acquisition - Validation and processing/modelling

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

5.3.13 Consoli Palace: Test-bed sensor #2.12: LVDT#2 (linear variable differential transformer) – Consoli's chamber

5.3.13.1 Description

The LVDT #2 is installed across a crack detected on a vault of the roof for the monitoring of the east wall out-of-plane motion (Figure 36). The sensor is protected with a specific box and connected through a cable to the acquisition system.

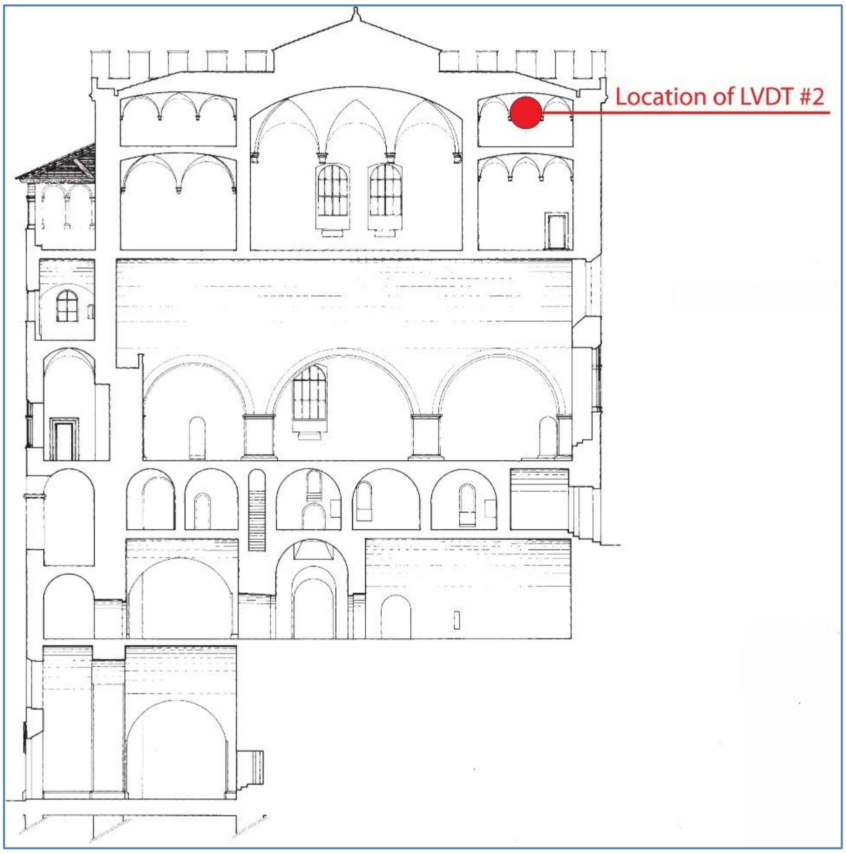


Figure 36 - Position of LVDT#2 for the static monitoring of the east wall

5.3.13.2 Measured parameters

The LVDT sensor used for the static monitoring is described in the following Table 17.

Table 17 – LVDT sensor used for the static monitoring in #2.12

Name	Position	Parameters
PCB-393B12	Lat.: 43.353384 Long.: 12.578249 Alt.: -	Displacement (mm)

5.3.13.3 Installation

Sensing Technique	Linear Variable Displacement Transducer (LVDT)
Sensor location	Across a crack

Where to fix the sensor (post, tripod, etc)	The sensor is fixed directly on the wall through anchors. The sensor is covered with a specific box fixed on the wall.
The sensor installation require to drill, glue, paint or other action that could change the state or the aspect of the structure	The installation requires to make drillings of small diameters (ø6mm).
Give a description of the installation procedure.	After drillings, the sensor is fixed on the desired position. Special attention will be paid to the position of the cable for the connection to the acquisition system.
Time required to install the sensor	About 15 minutes
Possible constraints for the installation (authorizations – announcement in advance etc.)	The drillings require authorization from the authority.

5.3.13.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	The acquisition will be continuous from the installation (June 2017) until the end of the project.
How many measurements are planned to be done	One measure per hour
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	The system requires electric energy.
Dimension of the sensor system (sensor + any electronic control or computer)	The sensor is a cylinder with a length of 20cm and a diameter of about 2cm (Figure 35). The box where the acquisition system will be placed has dimensions of about 60x40x30cm.
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.	The connection is useful to share the data directly online with the project platform.
Time required to perform a preliminary signal processing to ensure the measurement reliability	One day
Compatibility or not with the other sensing techniques (what are the other techniques that can be used without	Some correlations will be carried on with temperature measurements and with the remote sensing data derived

affecting the measurement of the specific technique?)	by SAR techniques.
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	-

5.3.13.5 Data acquisition - Validation and processing/modelling

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

5.3.14 Consoli Palace: Test-bed sensor #2.13: Drilling Resistance Measurements System (DRMS)

5.3.14.1 Description

The application of the drilling resistance measuring will be focused on two distinct targets: i) the evaluation of current state of preservation of the stone building and architectural elements of the Consoli Palace in Gubbio and ii) the sampling of the drilling residue (dust) from distinct interval depths for further physicochemical analyses. The materials will be tested and evaluated in-situ [5-9].

5.3.14.2 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

5.3.14.3 Installation

Sensing Technique	DRMS
Sensor location	Consoli Palace surfaces with differential colouring.
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	Drilling on the surface of the

procedure.	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 by the authority.

5.3.14.4 Monitoring

Time required to perform the measurement (measurement duration - a possible timetable etc.)	30 minutes per spot
How many measurements are planned to be done	For each site minimum (if possible): - 2 measurements for stones - 2 for mortars (original or "middle age" mortar): - 2 for mortars (cement mortar): - 2 for mortars ("new" mortar last approved by superintendence). The measurements could increase due to local conditions.
The system is battery operated or requires electric energy necessities (Voltage, Power, etc)	DRMS is a battery operated system
Dimension of the sensor system (sensor + any electronic control or computer)	Approximately 50cm^3
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. The specimens collected will be examined with several other ex-situ analytic techniques (SEM-EDS, XRD, XPS etc.)
Factors affecting the measurement (sun insulation, temperature, meteorological conditions, etc)	High humidity content inside the examined stone might affect drilling resistance results.

5.3.14.5 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 + UNIPG

5.3.15 Consoli Palace: Test-bed analytical techniques #2.14: Stone and Mortar samples analysis

5.3.15.1 Description

Similarly to the case of the Town Walls, the main risks are associated to acid rains (pH precipitation) and changes in deposition of pollutants. These can lead to stone erosion by dissolution of carbonates and/or stone blackening, especially affecting limestone

As reported in the deliverables D1.2 and D3.1, several restorations were made after the 1982 and 1984 earthquakes and completed in the first half of the ‘90s. Initially, the façades were completely cleaned from the crusts/patinas. After only twenty years, however, they are again clearly visible.

5.3.15.2 Measured parameters

All the considerations already made in section 4.3.15.2 are appropriate for the present discussion, too. The investigation approach is similar to the one chosen for the Town Walls described in the previous section 4.3.15.2. 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 concrete, mortars, binders and stones. 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 12 in section 4.3.15.2.

The principal workflow steps are the same already given in section 4.3.15.2.

5.3.15.3 Data acquisition - Validation and processing/modelling

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

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 data available are shown in Figure 37.

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)

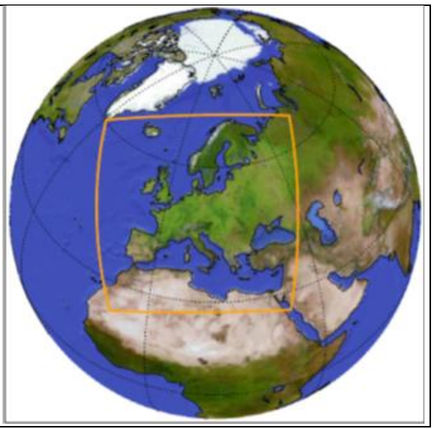


Figure 37 - EURO-CORDEX domain and data available

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 consider 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 38).

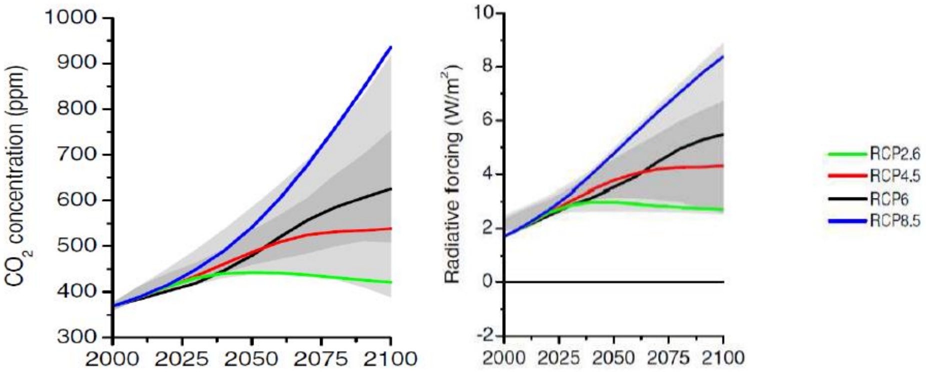
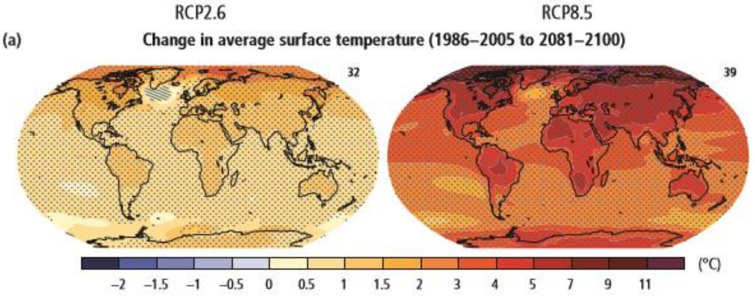


Figure 38 - CO_2 concentrations (left) and radiative forcing (right) due to all climate forcers in the RCP scenarios. From van Vuuren et al. (2011) [12].

Mid- and late-21st century projections of global warming from the IPCC Fifth Assessment Report (IPCC AR5 WG1) are illustrated below in Table 18 and in Figure 39. The projections are relative to annual average temperature and precipitation in the late-20th to early-21st centuries (1986-2005 average).

Table 18 – 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)



(a) Change in average surface temperature (1986–2005 to 2081–2100)

(b) Change in average precipitation (1986–2005 to 2081–2100)

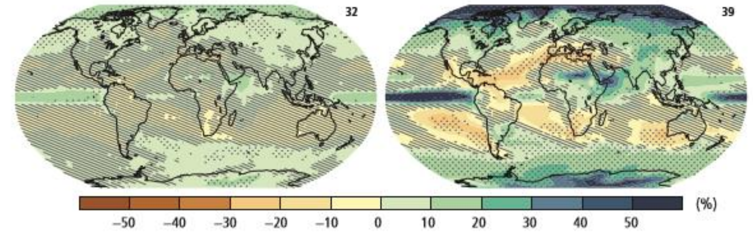


Figure 39 - Change in average surface temperature (a) and change in average precipitation (b) based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios

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 WP2 (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 on 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 activity carried on 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 to include the contribution to air pollution from both distant and local emission sources (industrial, traffic, residential sectors, etc).
An example of model outputs is shown in Figure 40.

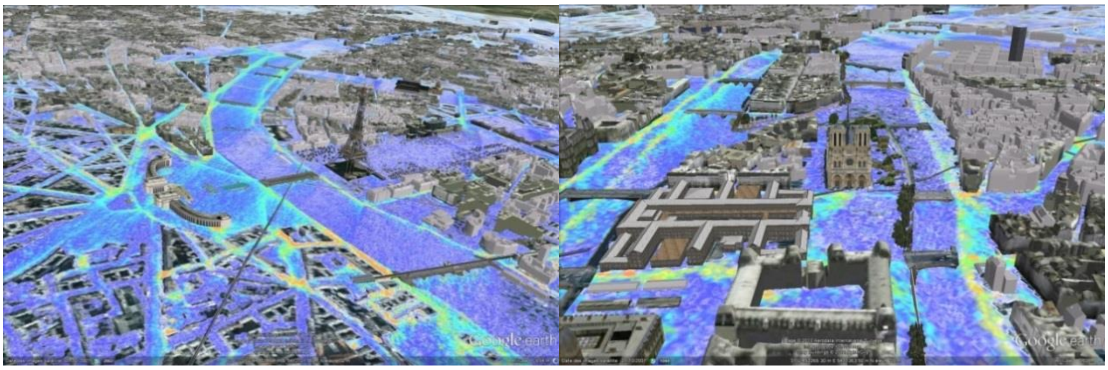


Figure 40 - Example of model output: NOx ground level distribution computed in the surrounding of Paris monuments in the framework of the AIRCITY Project with the PMSS model (left: Eiffel Tower area, right: Notre-Dame Cathedral area)

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 Gubbio test-beds

For the Gubbio site, the detailed actions are listed below, and summarised in Figure 41:

- Detailed emission inventory for Gubbio and the surrounding area, including significant industrial, traffic and residential emissions.
- Development of a regional scale simulation system (WRF/CHIMERE) with a 3km resolution refined grid over Gubbio.
- Demonstration testing and validation by running the PMSS high-resolution (3m) air quality models on the selected areas of Gubbio 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

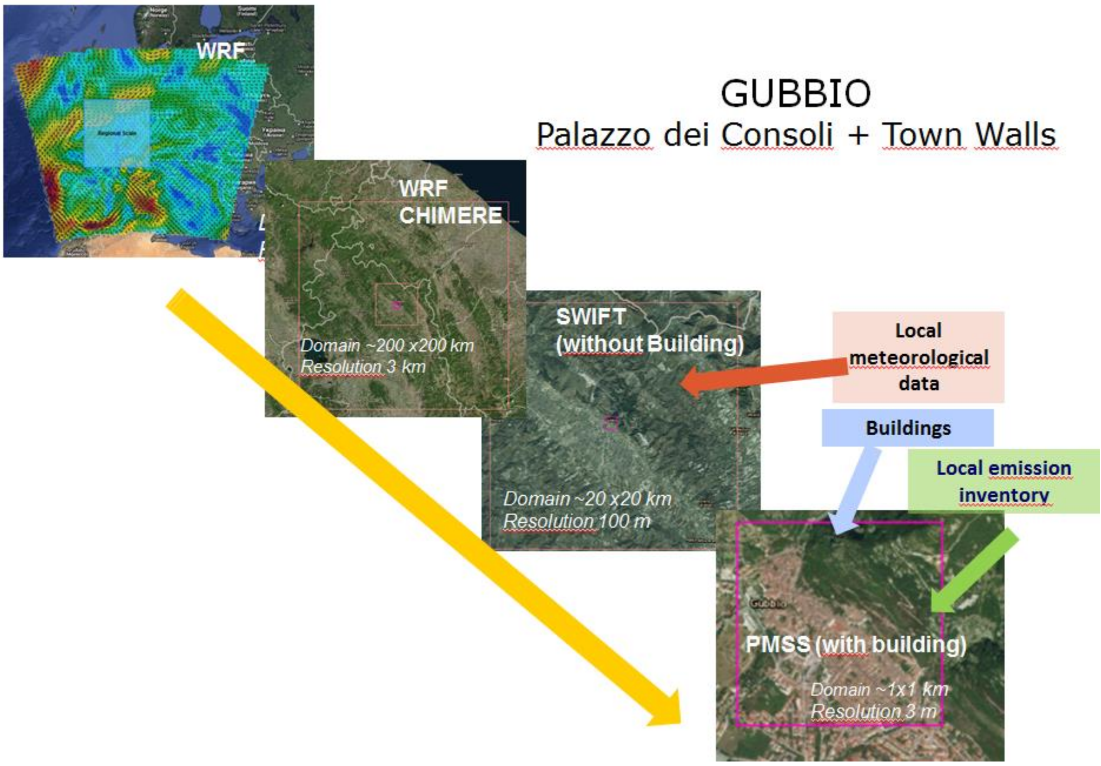


Figure 41 – Methodology for Gubbio test-beds

6.2.2.1 Input Data required for the modelling

Below is a flowchart (Figure 42) 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.

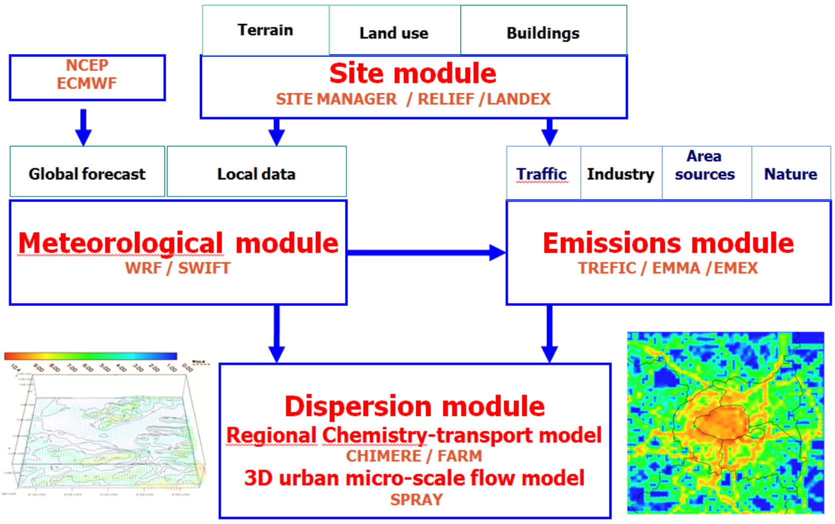
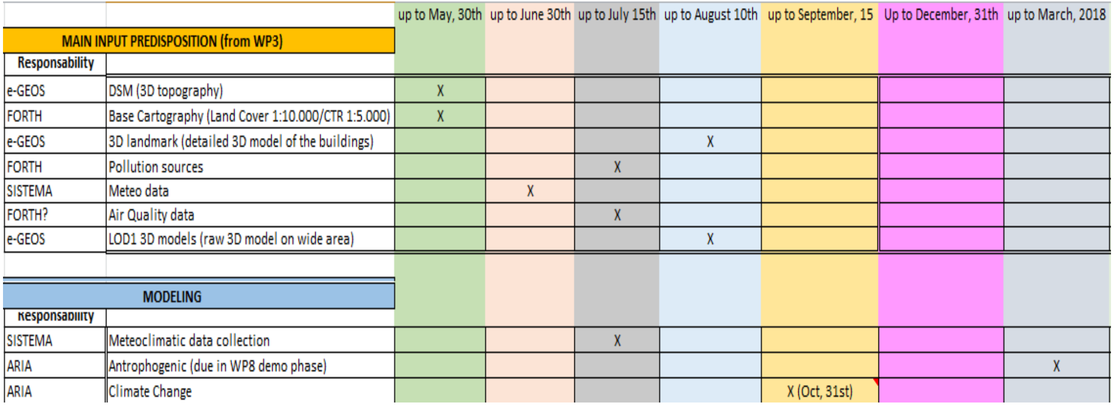


Figure 42 – Air Quality system flowchart

The different data to collect, the partner responsible for each task, and the time schedule have been defined in WP2 and summarised in Table 19.

Table 19: 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 the 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.

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 Town Walls, several activities have already begun and the following systems/sensors have been installed and are providing data:

1.6. ARPA UMBRIA weather monitoring station network
1.8. TH3-Thermal-Humidity sensor data logging system

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

1.3. UAV-Drone optical camera for geometrical survey
1.4. GPR (georadar) @ zone 2-3-4-5
1.5. ERT (Electrical Resistivity Tomography)
1.7 Measure of climatic parameters (portable)

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

1.1. Spaceborne radar COSMO-SKYMED
1.2. Multispectral Remote sensors

Sampling campaigns and material characterization started and are on-going:

1.14. Stone and Mortar samples analysis

On Consoli Palace several activities have already begun and the following systems/sensors have been installed and are providing data:

2.5. ARPA UMBRIA weather monitoring station network
2.7. TH1-Thermal-Humidity sensor data logging system Consoli Palace (internal)
2.8. TH2-Thermal-Humidity sensor data logging system Consoli Palace (external)
2.10. Accelerometers #1-2-3
2.11. LVDT #1 (linear variable differential transformer) - "*piano nobile*"
2.12. LVDT #2 (linear variable differential transformer) – Consoli's chamber

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

2.3. Geometrical survey (TLS + ground photos)
2.4. GPR (georadar) in different Palace zones (internal and external/vertical walls)
2.6. Measurement of climatic parameters (portable payload)

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

2.1. Spaceborne radar COSMO-SKYMED
2.2 Multispectral Remote sensors

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

2.14. Stone and Mortar samples analysis

The activities regarding :

- 2.9 Infrared Thermography
- 2.13 Drilling Resistance Measurements systems

Are expected in the next months

It is expected 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 that, 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 design and 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.

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