HERACLES NEWSLETTER

Nº9 - May 2019

HERACLES

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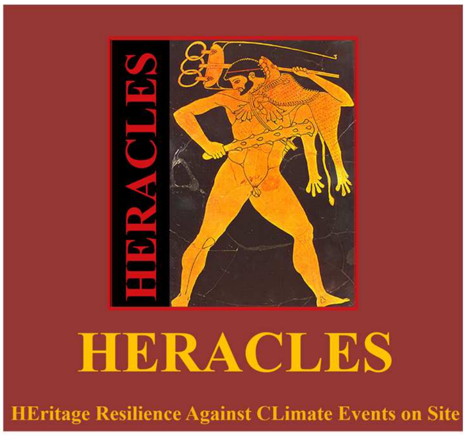
CASE STUDIES

GUBBIO, ITALY:

3. Town Walls
4. Consoli Palace

CRETE, GREECE:

1. Minoan Knossos Palace
2. Venetian coastal fortress of Koules



CONCLUSION OF THE PROJECT

Welcome to the ninth edition of the HERACLES Newsletter. This final issue is focused on the conlcusions of the project and aims at keeping you up to date on the latest actions carried by our consortium.

To refresh a little bit your memory, the HERACLES project was launched in May 2016 and will come to its end on the 30th of April 2019. Our aim, in leading this project as a European consortium is to design, validate and promote responsive systems and solutions for effective resilience of cultural heritage assets against climate change effects (end users, industry/SMEs, scientists, conservators-/restorators, social experts and decision-/policy-makers).

We are very proud of what we have been able to achieve through HERACLES and to showcase it we organised our final newsletter by describing Work Package by Work Package our results.

Without waiting any longer, I wish you a good reading, hoping that you will enjoy this newsletter.

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PRESENTATION OF THE PROJECT

WP1: USERS' NEEDS & REQUIREMENTS, RISK AND VULNERABILITY ANALYSIS AND TECHNOLOGIES SURVEY

1. EXECUTIVE SUMMARY

The first work package of HERACLES was devoted to define the users' needs and requirements with a general approach, but with a specific focus on the HERACLES test beds. The scope was to provide a survey of the strategies for a correct risk and vulnerability analysis and of the methodologies/technologies suitable for CH management and protection. The main issues, guidelines and procedures for the management of Cultural Heritage (CH) were analysed by referring to national, European, international and UNESCO/ICOMOS (International Council on Monuments and Sites) documentation. A thorough survey of the state of art of guideline, procedures and tools, like Risk maps, of CH management has been carried out and detailed. As well, a detailed analysis of the legal regulation interesting the CH management has been carried out, focusing on the international and national framework. Particular attention was paid to the management of CH in the Countries involved in the HERACLES project with their test-beds (Greece and Italy). Finally, the gaps in the national legislations and the possible contribution of the HERACLES added value in overcoming them, have been analysed and described. The detailed definition of end-user requirements were the starting point for the planning of the actions to be undertaken. Furthermore, the HERACLES modelling process is based on the identification of the environmental/anthropic characteristics of each test bed, by taking into account the geomorphological, meteo-climatic and structural site modelling coupled to analysis of the socioeconomic impact of CH related to each site. The planning and implementation of mitigation actions are also considered. The aim is to set a baseline methodology in order to estimate the risks deriving from natural hazards and extreme climate-related events, affecting the cultural heritage sites/assets.

2. INTRODUCTION

Guidelines and procedures for the management of CH have been discussed in European and UNESCO documentation. A thorough survey of "Guidelines on Cultural Heritage Technical Tools for Heritage conservation and management", published by the Council of Europe in 2012, was considered, among others. These Guidelines were the starting point for setting heritage standards and measures in order to stimulate an active involvement of both the managing authorities and of the wider cultural heritage community at local level on issues related to heritage protection and promotion. Furthermore, Operational Guidelines for the Implementation of the World Heritage Convention (UNESCO, 2013) and the Guidance on Heritage Impact Assessments for Cultural World Heritage properties (UNESCO, 2011) were used as guidance for the Heritage Impact Assessments (HIAs). A detailed analysis of the legal regulation was carried out focusing on the international framework (EU, UNESCO, etc.) regarding the management and protection of the Cultural Heritage. Another important source for Cultural Heritage Legislation at international, EU and national level is the International Art and Heritage Law database (EUI, 2012).

Risk assessment methodology to be followed in HERACLES is based on the analysis and identification of the environmental characteristics of each test bed by coupling geomorphological and structural site modelling and Satellite based remote sensing technologies. This approach allows to identify potential risks related to climatic characteristics and changes in relative frequency and intensity. Additional data related to the capability of the exposed structures to withstand climate change related events, include geometric characteristics such as height or shape, and are derived from remote sensing technologies, while other data (e.g. type and strength of materials) are obtained from in-situ measurements. This information are integrated with socioeconomic data regarding the exposure of each site and the mitigation actions management. Moreover, a survey of the features and performance of the monitoring/diagnostics/ICT technologies in the application field of the Cultural Heritage managements and protection was made. This was carried out by a survey of the international (FP7, on-going H2020, JPI Cultural heritage) and national projects, the recommendations of European (European Construction Technological Platform, CH Focus area) national technological platforms and scientific production. This survey supported a gap analysis in view of a full acceptance of the technological approaches from the different stakeholders involved in CH, by focusing to an economically sustainable use of the technologies respecting the historical and cultural integrity of CH. The results of these surveys offered a panorama of the different technological approaches available for different end-users, stakeholder and decision makers involved in the protection and management of Cultural Heritage. The survey, enabled a gap analysis and allowed an evaluation useful to identify and highlight what is still missing for their needs and what can be optimised, always recommending economically sustainable approaches and respecting the CH integrity.

3. TECHNICAL EQUIPMENT AND PROCEDURES USED

The State-of-the-art on Guidelines and procedures of Cultural Heritage (CH) management was surveyed and analysed in terms of principle, processes and practices related to conservation. In this survey, the Risks mapping, which is a very useful tools for an advanced and sustainable management of Cultural Heritage, was considered. This analysis evidenced that, at present, a holistic approach to CH management and protection has not been yet designed and adopted, even though this has been identified as a stringent necessity by stakeholders. The survey on National laws and especially of those of Italy and Greece, indicated that national legislations, even though of significant level, regarding the preservation and restoration of CH should be improved. In fact, Greek and Italian laws recognize and adopt technological achievements that can be useful for the protection and restoration of Cultural Heritage, but it is still lacking a clear and specific link with climate change. The survey allowed to define several issues/opportunities for the development of the ICT platform, in order to contribute to the use of multisource information, in a holistic and multidisciplinary approach. Finally, an effort to review and identify common terms definitions to classify concepts and actions related to CH was done.

Activities were devoted to the analysis and study of the sites selected as HERACLES test beds, in view also of the demonstration activities. The aim is to evaluate the effectiveness of the HERACLES approach/system in enabling an assessment and situational awareness, in providing information and decision support system for the full implementation of diagnosis, monitoring, remediation and crisis management services, through the integration of multi-source data. The methodologies and analysis have taken into account the climatic change effects (at European, national and proper regional downscaling) for weather forecasting (with emphasis on extreme events occurrence, frequency and intensity) and the identification of the relationship between meteo-climatic parameters and environmental risks for CH (in a holistic approach of a coupled air-sea-land interaction). General description of the test beds was provided, and after a focus on the assets, which are specifically the object of the demonstration activities, was done. Variations in climate parameters connected with Climate Change trigger risks and consequent impacts on CH assets. The major risks affecting the HERACLES test beds and their relative consequences were considered, with the aim to hypothesize and plan effective mitigation actions.

In order to identify users' needs and requirements according to the social, economic and cultural dimensions, a questionnaire was defined and sent to the two partners that in HERACLES represent the end-users. The methodology to assess the risk was considered; as well, the current CH risk management in Italy and Greece was analysed and the related limits were evidenced. From this scenario, the need of new tools was identified.

The survey of the state-of-the-art of the monitoring/diagnostics/ICT technologies in the specific application field of Cultural Heritage management and protection, was carried out through two different approaches. Firstly, through surveys and reviews were performed for the more recent international (FP7, JPI Cultural heritage, on-going H2020) and national projects and platforms, as well as on ICT technological platforms and tool and scientific literature investigation. Secondly, a questionnaire which was disseminated among institutions of different countries, involved in EU and national projects in the CH field. The scientific literature survey of the state of the art on technologies, methodologies and instruments devoted to cultural heritage protection and management, included the use of environmental Sensors and monitoring systems, structural conditions monitoring for Cultural Heritage management and protection. Also, the survey was devoted to the state-of-the-art of in-situ monitoring and diagnosis of the materials and surface condition of CH monuments as long as ex-situ physicochemical investigations for material analysis and Information and Communication Technologies.

The Literature review of European, national technological platforms focused on the similar systems for CH heritage management and protection and ICT platforms was focused on the survey of the state-of-the-art of the monitoring/diagnostics/ICT technologies in the specific application field of Cultural Heritage management and protection, by considering their features and performance. The survey was carried out through two different approaches. Firstly, through surveys and reviews were performed for the more recent international (FP7, JPI Cultural heritage, on-going H2020) and national projects and platforms, as well as on ICT technological platforms and tool and scientific literature investigation. Secondly, a questionnaire which was disseminated among institutions of different countries, involved in EU and national projects in the CH field.

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4. TECHNICAL OBJECTIVES IN THIS PROJECT AND THEIR EXPECTED OUTCOMES. POSSIBLE DIFFICULTIES

Many indications on the important topics related to CH and here reviewed, were already provided in the past and are still today object of debate. There is in general a growing attention and awareness towards these themes and this represents indeed a positive aspect. Nevertheless, is has to be underlined that the majority of these indications has not a jurisprudential value and this represents a limit in the application of these possible best practices. It has been observed that in several European countries, especially those in the South, national legislation regarding the preservation and restoration of CH are outdated and overcome, in few cases, by the application of modern technological solutions provided to handle these problems, but with no a clear regulation behind that.

In Italy, the legislative framework and the general situation on that matter seems to be more organically developed with respect to other Countries, but still no clear connections with climate change exist as well related organic actions. A major achievement of HERACLES project is that among its partnership and in its Advisory Board as well, there are State institutions as stakeholders, which can be able to interact in a straightforward way with the research partners and be familiarised to all novelties, regarding protocols, methods, techniques, materials, data and ICT products such as decision support systems. These stakeholders can not only suggest, but point out as well, for changes/integrations in national legislation to include these aspect of scientific innovation addressed to particular problems. In addition, these stakeholders, involved in HERACLES since the beginning, can be a "information flow channel" towards to their relevant communities, by disseminating the HERACLES results in a more general context. Moreover, from a social point of view, HERACLES provide a multidisciplinary and inclusive approach that involves all the different actors of the territories in a process of knowledge sharing and in building a common awareness on the problem of climate change and their effects on Cultural Heritage management. This approach involves dimensions such as the economic, social, cultural, technological and the scientific one in a holistic view of Cultural Heritage, which has to be contextualized in a territory. The CH is considered as a crucial factor in the economic, territorial, social and cultural planning of a territory and as element to reinforce the cultural identity, too. The method applied in the areas of interest for the project will produce new shared information and new opportunities in economic, cultural and social terms for the territory.

The work was focused firstly on setting/specifying the definitions of the terms used, since there are many definitions used in risk assessment methodologies based on the area of application. In a second phase, the relationship between cultural heritage and natural hazards were identified with a special focus on the attributes of the HERACLES test beds. Those include the effect of environmental hazards which can cause damage/deterioration till to the destruction of cultural heritage site/asset, due to a combination of long-term and catastrophic processes. This leads to the necessity of CH preservation and protection measurements. A detail survey of the different kinds of natural hazards with different impacts on cultural heritage was carried out. In addition, a state of art of the most relevant methodologies for the risk assessment was implemented.

In this task, the methodology used for the vulnerability assessment was identified and a baseline description of the data management and processing, adopted in HERACLES platform, was presented along with the general methodology that will be used to implement risk analysis. Moreover, the specific methods for addressing environmental; climatic; geomorphological; structural issues and the use of modelling techniques and Satellite based technologies was specified. The socioeconomic data regarding the exposure of each site and the mitigation actions was surveyed, as well.

5. WORK ALREADY PERFORMED TOWARDS THE OBJECTIVES

WP1 is now closed and provided info on guidelines and procedures survey of CH management, on the end-users needs, considered very important and a starting point for the HERACLES project. It has to be underlined the socio-economic issues influencing user's needs, impacting on Social Sciences and Humanities and Responsible Research and Innovation. In addition, the definition of the methodology for the risk and vulnerability analysis, as well on the-state-of-the-art of the technologies of interest for the project, were provided. These Guidelines set the standards for the definition of the framework under which the HERACLES activities will be carried on. These guidelines consider the different legislations, and a focus on the different roles and responsibilities of the stakeholder organization involved in the managements of the HERACLES Test beds. A set of detailed use-cases describing the possible interactions between users and HERACLES system was identified as one of the starting points of the demonstration phase (WP8 activities). The methodology to assess the risk and vulnerability of climate change impacts including domino effects, was identified. The methodology is based on the environmental characteristics of each test bed by using geomorphological and structural site modelling coupled with remote sensing satellite based technologies. In particular, at the HERACLES test-beds, the effects of the geomorphologic dynamics resulting from climate change natural hazards (e.g. landslides, floods, and coastal erosion) are explicitly accounted for the methodology. All the data will be processed and then visualized through a Geographic Information System (GIS). This information will be integrated with socioeconomic data regarding the exposure of each site and the mitigation actions management. Moreover an evaluation of the features and performance of the monitoring/diagnostics/ICT technologies in the application field of the Cultural Heritage managements and protection, was made. A questionnaire was designed and sent to a number of end-users and/or stakeholder having in charge of CH protection and management at national, European and international level. Meanwhile, the context of the available technologies and methodologies was investigated/surveyed, within the international (FP7, on-going H2020, JPI Cultural heritage) and national projects, Research Infrastructures (E-RIHs, IPERION, CHARISMA,etc.) and the recommendations of European (European Construction Technological Platform, CH Focus area), national technological platforms and scientific literature were also considered for the purpose of this task. A gap analysis was performed, in view of a full acceptance of the HERACLES technological approaches from the different stakeholders involved in CH, by focusing to an economically sustainable use of the technologies respecting the historical and cultural integrity of CH.

Those results provide essential information to ongoing tasks by setting the regulatory framework and the end-users requirements as they have been identified, acting as guideline for the implementation of all tasks. Moreover, the environmental characteristics and the societal data identified, provided additional inputs. Finally, the gap analysis sets the baseline for the design of the general guidelines and operational procedures for long-term strategies and for quick damage assessment after crisis. Through these procedures, the users' needs were identified for the HERACLES test-beds. In particular, in Gubbio, atmospheric moisture change and intense rainfall and flooding were found to be the main factors affecting the Town Walls and the Consoli Palace. Damages derived by faulty or inadequate water disposal systems, occurring after extreme events are a major threat for the Town Walls. Extreme climate events (mostly heavy rain) are a major threat for Consoli Palace. Subsoil instability which includes ground movements, subsidence, landslide, affects the Town Walls, by arising dangerous situation of structural instabilities. Inorganic materials are eroded due to floodwaters and temperature changes in both Town Walls and Consoli Palace. Materials and surfaces suffer of increased deterioration due to the combined effect of the climate change effects and pollution and there is a worsening of the damage in the last years, due to a higher concentration of CO_2. The risks / hazards & technical aspects for the Heraklion test beds include the extensive damage due to mechanical and biological factors, combined with the local microclimate and the aging of the walls of the buildings. The main factors which contribute to these effects are the direct exposure to sunlight, rainfall, wind and sea waves' impact for Rocca al Mare. In addition, atmospheric pollution, and relative humidity and temperature changes have impacts on material weathering and degradation with related structural

The same climate factors are responsible for the risk in all sites, although, their impact is the result of different processes and specific sites conditions. In cooperation with the other WP activities, the hazards can be estimated by the modelling activities in WP2 (e.g. climatic modelling outputs related to rainfall, wind and waves), Vulnerability and Exposure can be estimated by using the data collected by the monitoring procedures in WP3 (for example, flooding and sea wave impact).

The methodology is based on six methodological steps following the logical flow of “risk identification”, risk estimation” and “risk evaluation”. The methodology permits to evaluate each hazard and classify the assets/monuments under investigation based on their overall vulnerability, following a six step procedure.

The first step requires knowledge of the nature and extent of all heritage values (artefacts/monuments/sites) considered important for the site (e.g. local, regional or global value). At this step, thanks to the involvement of the end users in the process, potential hazards of each case study area are identified and the current state and the problems affecting the areas are described. For this step, also the profile of each hazard is defined. The creation of a spatial “hazard” database is needed in order to drive the use and processing of all the data to “quantify” the hazards affecting each HERACLES test bed. In the second step, the definition of the vulnerability and exposure for each test bed and their changes over time is defined. Vulnerability is a function of several factors; whose specific identification and estimation requires to consider a wide range of primary (raw data from measurements and modelling) and secondary sources data (from bibliographic source and from end-users/stakeholders). These data including environmental and social information should be used to gain an understanding of these factors. For all the test beds, this includes both published and unpublished documentation. The definition of end users requirement, provided the preliminary basic knowledge necessary for the first-hand understanding of the relationship between the CH items/values and the surrounding environment, such as topography, geomorphology, climate, and land use. Exposure is estimated by combining future projections with evidence gathered from end users/stakeholders. In this way, it is possible to describe the exposure of heritage values to the main climatic parameters (wind, moisture change and temperature) and their associated impacts The above first two steps make it possible the “Risk Identification”.

The third step deals with the identification of the likelihood of a hazard to occur under future climate events. The estimation of the vulnerability must be based on the knowledge of heritage values and likely impacts of climate change. The potential hazards, for each heritage value under the projected future climate, are initially identified, while assessing also the exposure. For this step, all the available evidences and a priori knowledge is analysed under a unique frame in order to estimate the possible future (direct and indirect) impacts under projected conditions. This step is related to “Risk Estimation”.

The last three steps below are related to “Risk Evaluation”. In the fourth step, the development of the vulnerability and exposure indicators for each hazard is implemented. In general, indicators should be provided based and related to, at least, one of the key elements of vulnerability of the CH values to Climate Change impacts. In the fifth step, the estimation the assessment of the vulnerability and exposure is implemented. Vulnerability and exposures are ranked by interrogating primary (measured data) and secondary data (stakeholder response). This allows to identify gaps in primary and secondary data, due for example to a lack of site- monitoring, also on the basis of stakeholder information. The application of indicators provides a quantifiable evidence, basis for the future review of this qualitative assessment. In the sixth step, the risk analysis for each hazard will be implemented by combining the vulnerability and exposure of each hazard in each test bed. Also, by using a multi-criteria risk assessment methodology, the overall risk for each site is estimated. Risk assessment will be estimated by following the UNISDR (United Nations International Strategy for Disaster Reduction) (2009) definition of Risk the European Commission (ISO-International Organisation for Standardization/EC-European Commission, 2009), which proposed that risk assessment has to be estimated by using the “interaction between vulnerability and exposure”. The Spatial Multi-Criteria Evaluation (SMCE) will be based on the Analytical Hierarchy Process (AHP). For each site, risk maps will be produced by using spatial multi-criteria evaluation quantifying the risk of cultural heritage objects/asset to each hazard, and a combined hazard map (multi-hazard). To quantify the total expected annual exposure to multiple hazards, the Overall Risk will be estimated and ranked in five categories, corresponding to Very Low, Low, Medium, High and Very High-ranking values.

The results provided and an understanding on what is still missing and to identify what is the added value that HERACLES can provide. From this framework, many important topics were addressed, but still there is the need to integrate all these efforts in a multidisciplinary and a holistic approach, which encompasses different steps. These steps are definition of the problems to solve and the definitions and implementation of the practical solutions (best practices) to apply for an effective management tool in view of a cost effective maintenance and restoration of CH assets, by taking also into account the social and economic implications they have. This is exactly the philosophy and vision that HERACLES project proposes, since an integrated strategy is essential for responsive actions directed to protection, safeguarding and conservation of a CH monument/asset. In addition, a clear indication deriving from the questionnaire is the need to improve the societal and end-users' awareness and the acceptance of the use of the HERACLES technological approach. In particular, it is highlighted the need of training activities for the CH end-users/stakeholders (Ephorate, Superintendence, municipalities, etc.) for a full effective and reliable adoption and use of the sensing system, the portable instruments, the ICT technologies and the ex-situ analytical methodologies. The gaps highlighted by the surveys and the questionnaire will be filled by the HERACLES holistic approach. In this context, in the first part of the project, the main challenge derived from the multidisciplinary approach, was, and still is, the set-up of a common language among the scientists, conservators/restorers, social experts and end-users. This will allow the clear and shared definition and the implementation of really useful and shared solutions, which will be (hopefully) adopted by the end-users/stakeholders not only during the project, but also beyond.

WP2: EXPLORING ADVANCED MODELLING FOR VULNERABILITY AND RISK EVALUATION

1. EXECUTIVE SUMMARY

The HERACLES project aims to determine the level of vulnerability of CH to different environmental risks derived from climatic changes.

This Work Package addresses the usage of the main existing models in order to define, for each test bed, a scenario of the main risks to which every CH is exposed. Furthermore, the activity of this WP involved the analysis of the possible correlations between information coming from different models ad from in situ sensors networks. All at the scope to better define the risk scenarios and to put in place a suitable intervention plan for each CH.

The analysis of the context led to point out two different risk scenarios, one related to the Stability, the second related to Pollution.

The identified scenarios could became a guideline to be applied to a wider number of test cases than those foreseen in HERACLES project, in order to collect a significant number of observations about he correlation events. Those collections would be used to statistically define the main correlation trends and events and, finally, to create eventual "super models" combining in a athematic/statistic procedure all the relevant information and outputs (i.e structural deformations and microclimatic factors, ground displacements and temperature trends, and so on).

2. INTRODUCTION

The UNESCO cultural heritage (CH) sites in Europe are almost 400, located in different Climatic European Regions. Environmental factors, worsened by the increasing climate change impact, represent significant threats to CH assets as monuments, historic structures and settlements, places of worship and archaeological sites.

In many cases the existing information about a CH are not so immediately available to the final users, even in case of public user (public entities involved in CH protection, monitoring and planning) because of their various property sources. Furthermore, data has to be interpreted and correlated with other kind of information, at the scope to detail the level of knowledge on the single CH and to calibrate the quality and quantity of preservation interventions.

The scope of this Work Package was to supply the project's platform with a set of data coming from the modelling and to give some scientific criteria to correlate data between them and with data from other sources, in order to build the best information scenario on the project's testbeds.

3. TECHNICAL EQUIPMENT AND PROCEDURES USED

A. <u>For the investigation of the Stability scenario:</u>

Applied Models and methodologies:

- Geomorphological and Hydrodynamic models by FORTH.
- SAR interferometry methodology by e-GEOS;
- Structural statistical models for the analysis of monitoring data by UNIPG;
- Finite Element Model by UNIPG
- Measurements from in situ sensors by UNIPG;
- Structural monitoring by inverse velocity techniques by LEONARDO;
- Climate change and extreme weather conditions modelling

All presented models are based on dedicated technologies and take care of different aspects of the overall stability and structural analysis.

Geomorphological model (FORTH)

Principles

Methods which may be used to identify hazards include geomorphological mapping, gathering of historic information on slides in similar topography, geology and climate.

Landslide susceptibility can be defined as the propensity of an area to generate landslides.

Methodology

A GIS software was used to prepare data and represent modelling results. A spatial analysis of the affected areas will be performed using a logistic regression approach.

Input Data

The application of logistic regression for the purpose of landslide susceptibility mapping requires a reliable inventory of the type, activity and spatial distribution of all landslides in the study area. The main trigger factor for landslides is heavy precipitation due to the increase in precipitation extremes and intensity observed.

Mainly, the following landslide-conditioning parameters: profile curvature, slope, aspect, land use, relative relief, distance to rivers, topographic wetness index and lithology.

Outputs

Landslide densities will be computed for each class of landslide-conditioning parameters.

After a regression coefficients analysis, the susceptibility values will be spatially classified from very low to very high according to the natural breaks method algorithm.

Hydrodynamic model (FORTH)

Principles
Waves and wave-induced effects can be computed by a third-generation wave model, which explicitly represents all relevant physics for the development of the sea state in two dimensions.
Limits and Potentials
The model can be run on large scales (much larger than coastal scales), however its application on ocean scales is not recommended from an efficiency point of view.
Methodology
As a spectral wave model, employs a phase – averaged representation of the wave field.
The evolution of the two-dimensional (frequency and direction) wave spectrum is considered as a short-crested random wave field and it is transformed by spatial and temporal variations of the wind, currents, water depth and other physical processes.
In essence, the spectral wave model solves the wave action conservation equation with source terms representing the effects of generation, dissipation and non-linear wave-wave interactions. The numerical schemes are based on finite differences.
Input Data
The user must specify one or more computational grids, the bathymetry of the area to be modelled and the boundaries and resolution of the directional and frequency space.
Outputs
The output is generated on one or more computational grids or at user-defined locations.
The outputs can be contour maps or time series.

SAR Interferometry for structural analysis (e-GEOS)
Principles
Repeat-pass satellite synthetic aperture radar interferometry (IFSAR) is a very effective technique for terrain and structure displacement mapping. IFSAR technique measures terrain displacements with millimetre accuracy, processing data acquired from satellites orbiting over 500 kilometres above the Earth, equipped with SAR sensors.
Limits and potentials
Repeat-pass SAR interferometry exploits the phase difference between different acquisitions to retrieve information about the topography of the observed scene and its changes over time. The accuracy in the displacement measurements is a fraction of the radar wavelength. Changes in the characteristics of the transmission medium, i.e. different atmospheric conditions between the acquisitions, introduce phase delay that affects the estimation of the distance between the radar and the target.
Methodology
e-GEOS developed an end-to-end processing chain for SAR interferometry processing, named PSP, which is able to identify either point-like or distributed scatterers. The PSP method is able to reconstruct at full resolution the displacement (and the 3D position) without explicit need of adaptive spatial averages.
Input data
SAR data, typically a temporal series of many single look complex SAR images over the area of interest. The number of images typically used to obtain high quality results is at least 30

A Digital Elevation Model (DEM) at medium resolution (used as a starting point to remove the topographic phase contribution). SRTM DSM will be used.
Outputs
The information are available over a sparse grid of points (PS) corresponding to objects on the ground providing a radar backscatterer stable with respect to angles and times of observation, typically non-cultivated and scarcely vegetated areas, and in particular man-made or natural structures like buildings, rocks, etc.
The product is a point shapefile (ESRI format integrable in GIS environment) representing the PS extracted by the interferometric processing. For every PS the following information is associated:
PS positions: It is a list of terrain points positions (geographic coordinates and heights with respect to the WGS84 ellipsoid), corresponding to the PS selected for the interferometric analysis over the AOI.
PS mean velocity in the analysed period: It provides the measurements of the PS mean velocities, expressed in mm/year, in the temporal range between the first and the last date of SAR acquisition.
PS displacement temporal evolutions: It provides the PS displacement measurements, expressed in mm, occurred at each acquisition date in the analysed period. It is fundamental in order to identify early warning and possible critical events.

PS elevation: this product provides information on the height of the PS (available only for very high resolution SAR data, like COSMO-SkyMed HIMAGE date).
The product is provided in ESRI shapefile vector format compatible with all proprietary and free GIS software and ASCII format.

Structural statistical models for the analysis of monitoring data (UniPG)

Principles

Structural Health Monitoring (SHM) systems are aimed at the automation of damage detection, localization and prognosis of structures using information provided by sensors installed in the field. These systems can thus provide key information for preventive conservation and condition-based maintenance of civil structures.
Data acquired by both static (i.e inclinometers) and dynamic SHM systems (i.e. accelerometers) are processed by means of statistical methods able to remove the effects of changes in perational and environmental conditions from monitoring data and to detect anomalies in the same monitoring data, possibly related to some developing damage.
After tracking the time evolution of the natural frequencies of vibration of the structure, statistical tools are applied to these time series in order to detect anomalous deviations from normal conditions, such as damages induced by low return period earthquakes**.**

Methodology

Any change in the dynamic behaviour of the monitored structure, possibly related to some developing damage pattern, is automatically detected by application of statistical process control tools to the time histories of identified modal frequencies. For this purpose, the classical techniques of multivariate linear regression (MLR) and Principal Component Analysis (PCA) are combined for removing environmental effects. Then, a technique of novelty analysis is adopted for damage detection. It consists essentially in the use of control charts, which are based on suitable statistical distances.

Input data

Monitoring data, consisting of data directly acquired by the monitoring sensors
Environmental data. This data can be acquired through sensors involved in the monitoring system itself or by weather stations installed near the structure.

Output data

The output data are the results of the application of the statistical procedures to process the monitoring data. The aim of the analysis is to provide evidence of a change in the structural behavior (damage) using a control chart.

Finite Element Models for structural analysis (UniPG)

Principles

The structural behaviour of a building can be studied by the Finite Element Method (FEM), as widely used by the scientific community. More specifically, FEM models allow to predict the response of a structure under prescribed static (e.g. dead load and self-weight) or dynamic (e.g. earthquake, wind) loading conditions, or under imposed displacements at the boundaries (e.g. subsoil movements and settling of foundations).

Input data

Geometrical information. This input can derive by direct architectural surveys and/or by application of photogrammetric techniques, 3D laser scanning, etc.

Material properties. The material properties can be estimated from the literature after an accurate survey of the constituents, or can be estimated by direct non-destructive of partially destructive mechanical field tests.

External loads. This input depends on the analysis that needs to be performed. Static analyses can be carried out under self-weight and/or static external actions. Dynamic analyses can be performed under seismic or gusty wind inputs.

Output data

The output data are represented by the maps of the internal fields computed by the numerical analysis: kinematic fields (e.g. displacements, velocities, and accelerations), stresses and strains, plastic deformations, etc.

Structural monitoring by inverse velocity techniques (Leonardo)

Principles

Structural monitoring by inverse velocity techniques deals with the monitoring and forecasting of structural failures in civil infrastructures (in our case, cultural heritage structures) based on a landslide prediction algorithm. The algorithm is the result of the observation of small landslides recreated in prototype form in a laboratory setting which led to the recognition that, when plotting the inverse velocity versus time, the values of inverse velocity approached zero, as the velocity of surface displacement increased towards final slope failure.

Limits and Potential

The forecasting method has been applied successfully to large instabilities occurring in an extensional stress environment with low in situ horizontal to vertical stress ratio.

Methodology

The inverse velocity approach, as implemented by LEONARDO, is a useful tool to assess the potential time of failure when accelerating creep-type conditions of a structure are involved (as opposed to rapid brittle conditions). In the early stages of failure development, when movement accelerations are relatively low, inverse velocity trends can be used to forecast potential failure time, allowing a certain level of movement rates to be classified as (safe) threshold rates.

Output

The output data are the results of the application of the inverse velocity approach procedures and techniques to the landslide monitoring data in order to assess potential time of failure when accelerating creep-type conditions of a structure are involved.

Climate change and extreme weather conditions modelling

In order to understand the potential evolution of the pressure on cultural heritage cause by the climate change, a collection of numerical results of IPCC climatic simulations has been gathered. This dataset 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 is based on the **EURO-CORDEX** modelling initiative

Methodology for the test beds

The output from the EURO-CORDEX Regional climate simulations (12.5km resolution over Europe) was used to analyse the evolution that can be expected in a future climate. The climate scenarios will be based on the IPCC RCP scenario 8.5 (RCP8.5). The steps of the work was:

- Analysis of historical and future climate periods for the EURO CORDEX modelling grids corresponding to the two test areas of Heraklion and Gubbio.
- Preparation of indicators and criteria for the meteorological parameters of interest for the evaluation of Climate Change on Cultural Heritage (dry day index, wet day index, precipitation day index, tropical day index) based on the results of WP1 (user needs requirements) and the efforts in 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

B. For the investigation of the Pollution scenario:

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.

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 into account atmospheric emissions and their interactions. 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 facades, 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).

Methodology for the Heraklion and Gubbio test beds

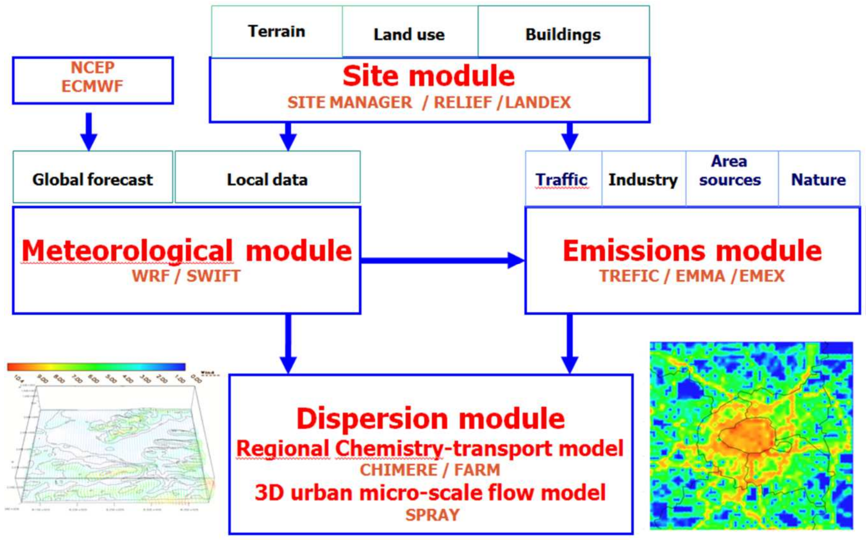
- Detailed emission inventory, including significant emissions
- Development of a continuous 24/7 regional scale simulation system (WRF/CHIMERE) with a 3km resolution refined grid over Heraklion.
- Demonstration testing and validation by running the PMSS high-resolution (3m) air quality models on the selected areas 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

Modelling tools

- Weather Research and Forecasting (WRF) model
- CHIMERE (FARM) model
- PMSS Local scale models
- Parallel Micro-SWIFT meteorological model
- Parallel Micro-SPRAY dispersion model

Input data



Outputs

WRF outputs allows to obtain the following meshed 3D variables under different type of projections (non-exhaustive list):

- Tradewinds and westerlies, boundary layer height
- Temperature, latent and sensible heat fluxes
- Mixing ratio for water and ice, length of Monin-Obukhov
- Pressure, friction speed
- Vertical velocity, roughness height
- Radiative fluxes, albedo
- Field and Land-use

The output files are provided in **Netcdf** format.

The post-treatment of the WRF simulations can further generate **2D maps**, **time series** and **vertical profile graphs** on points configured by the user.

CHIMERE (and FARM)outputs allows us to obtain **3D fields of pollutant concentration** in ppb or µg/m−3. The output files are provided in **Netcdf** format. Post-treatment scripts can generate **2D maps**, **time series** and vertical profile **graphs** for selected points

PMSS outputs:

PSWIFT meteorological model outputs consist in a mass-consistent **wind field** by using data from a dispersed meteorological network. **Temperature**, **pressure** and **humidity** fields can also be interpolated with SWIFT.

PSPRAY 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.

Collection of data for ancillary purpose

Earth Observation Data

Within HERACLES project, the use of multispectral EO sensors serves amongst other for the measurement of parameters useful for climate change and air pollution modelling. The available EO data is structured as follows:

Sensor / Satellite lists the name of the data source;

Product describes the application of the collected data from the sensor.

Air temperature & **LST**: Air temperature and land surface temperature (LST) data are collected to generate designated temperature maps. They serve as an input for stress and erosion parameters computation and for the modelling of local weather conditions.

RH: Relative humidity (RH) data is collected for the generation of RH maps. They serve as an input for erosion parameters computation.

o **AOT**: Aerosol optical thickness (AOT) data is collected to assess air pollution and identify the concentration and type of air pollution.

o **SO2** & **NO2**: Sulphur Dioxide and Nitrogen Dioxide data are collected to measure their concentrations in the atmosphere. They serve to identify degradation factors.

o **Precipitation**: Precipitation data is collected to generate precipitation maps. They serve to identify extreme rainfall rate events and as am input for erosion parameters computation.

Resolution indicated the spatial resolution of the sensor in degrees.

Frequency indicates the temporal resolution of the sensor in days.

Availability in years indicates since when the data is available and downloadable.

Hosting facility lists where the data is located.

Ground Measurement Data

Ground measurement stations in and around the two test sites of Gubbio (Italy) and Heraklion (Greece) allow to monitor the local microclimatic conditions. The scope of those meteorological stations is to assess the local climate conditions and phenomena and estimate the impact on cultural heritage and built environment.

4. TECHNICAL OBJECTIVES IN THIS PROJECT AND THEIR EXPECTED OUTCOMES. POSSIBLE DIFFICULTIES

The aim of this Work Package is to run the application of the depicted models to the project's testbeds and, after that, to analyse the results of the modelling and to present them to the community of the users, through the project's platform.

The second step of the activity regarded the research of correlation between the various factors involved in the risk assessment, as determined both by the modelling results than by the data coming from other sources (ancillary data, geographic data, in situ sensors data, and so on).

At this scope, the analysis focused on two main scenarios: the first one represented by all the factors that may affect CH stability, the second one regarding the effects of pollution and chemical aggressions to the CH.

In both cases, the results coming from the modelling were correlated between them and with data from other sources, in order to observate and point out the most evident correlations between phenomena (i.e. climatic factors and structural displacements).

The scope of this work is to give to the users a scientific guideline in order to perform the analysis of the CH of their interest, through the right correlation of different data.

The correlation guidelines has to be meant as scientific guidelines to be offered to the final users in order to correctly correlate and jointly interpret the results of the various modelling and the data made available by the surveys on the site of interest. The proposed sequences will get out from the validation of the designed workflows, which are on-going at present.

The identified scenarios could become a guideline to be exploited in a larger number of test cases beyond the ones foreseen in HERACLES project, in order to collect a significant number of observations about the correlation events. These collections would be used to statistically define the main correlation trends and events and, finally, to create eventual "super models" able to combine in a mathematical/statistic strategy all the relevant information and outputs (i.e structural deformations and microclimatic factors, ground displacements and temperature trends, and so on).

5. WORK ALREADY PERFORMED TOWARDS THE OBJECTIVES

A. <u>For the investigation of the Stability scenario:</u>

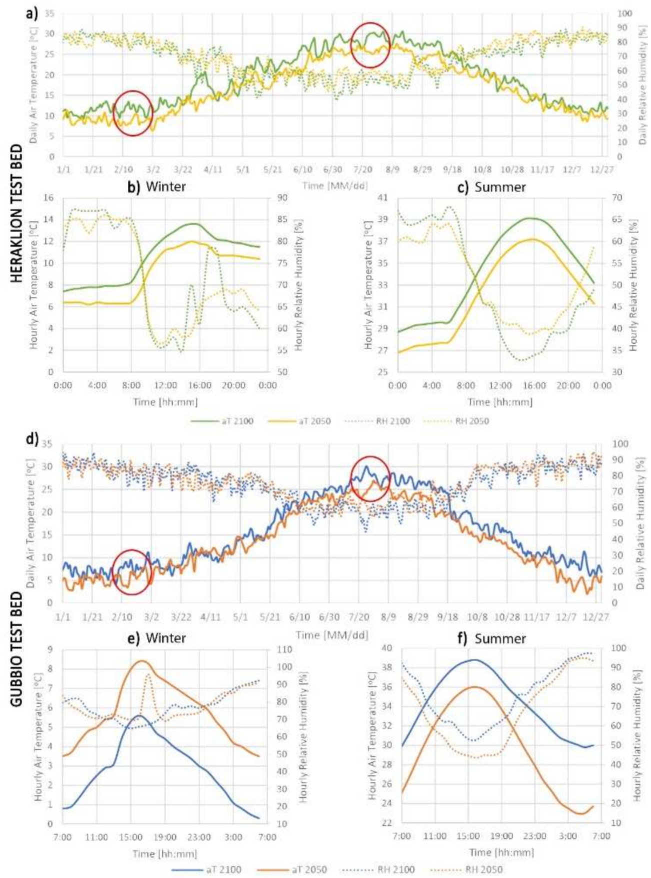
Team first categorized the available data on the project's testbeds and, then, analyzed the main correlation to investigate and to define as general guidelines.

On the basis of these available data, also coming from the models depicted in the previous paragraph,the following correlations was put in place:

- Spatialization of DIFSAR analysis results on a 3D city model basis. The 3D model was realized starting from UAV and TLS surveys' data. This correlation is devoted to allow the final user to get a quick and detailed analysis on the status of the stability of a CH and it could reduce the costs of more detailed investigations by evidencing the most critical situation to keep closely monitored. The 3D model will be also used as a base for the visualization of the TLS results, in terms of cracks and state of conservation of the building's facades or architectonical components. The result of this mesh will be very useful for the comparison with the FEM model output. In particular, it will help the structural experts to validate the model's results in terms of cracks forecasting and structural behavior of the building.

Spatialization of the DIFSAR analysis on Palazzo dei Consoli,

- Comparison between the outputs of climatic models by CIRIAF with the results of ARIA's modelling on a larger scale. This will allow the tuning of the wider area models. The preliminary work about tuning of all the input assumptions and assessment methods between CIRIAF and ARIA complementary models was carried out, while the results combined analysis is in progress.

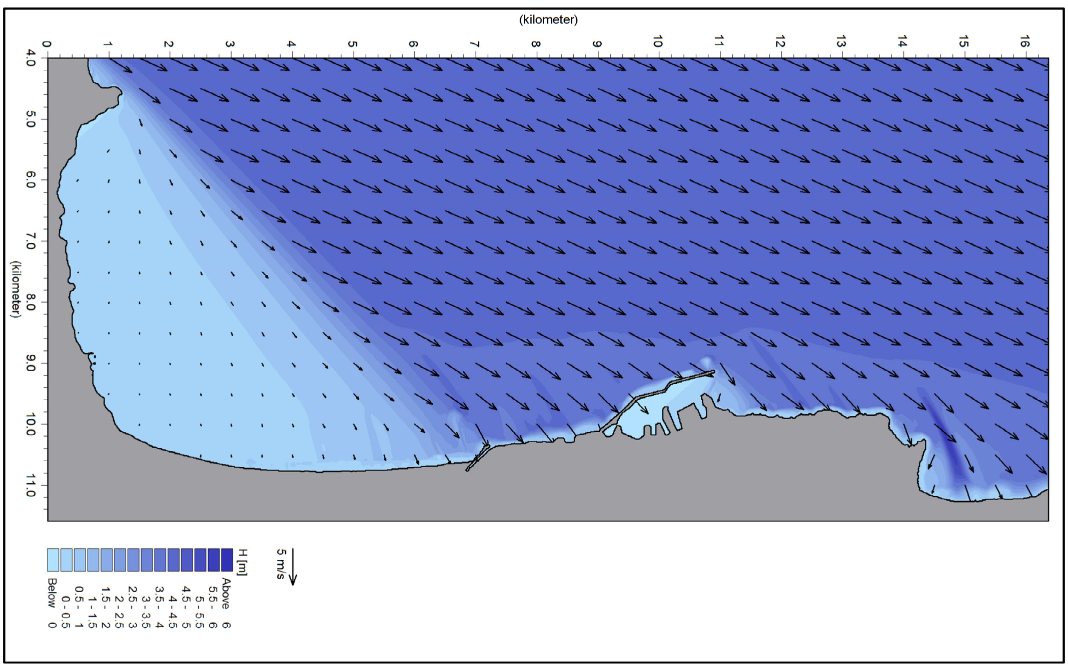


Air temperature and relative humidity daily (a,d) and hourly time-trends of specifically selected winter (b,e) and summer (c,f) days for both the Heraklion (a,b,c) and Gubbio (d,e,f) test beds.

- Correlation between graphical data depicting temperature and displacements trends on a unique database. The temperature and crack width data for the Palazzo dei Consoli in Gubbio are stored on a SensorThings API server. This facilitates the selection of data for a given time period and the analysis of correlation between temperature and displacement using visualizations stored in the Heracles knowledge base.

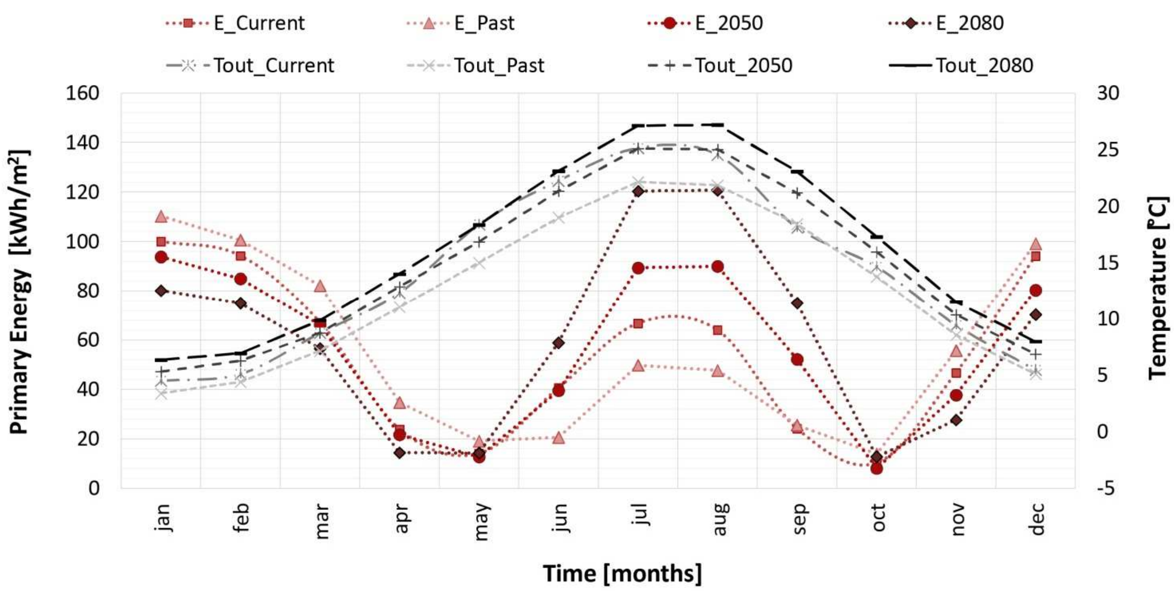
R based HERACLES Data Correlation Analyzer illustrating Gubbio Palace temperature and crack displacement values during a selected time interval on 4th of May 2018

- Correlation of the displacements of the armouring of the coastal site (Koules Fortress) with past wave events. This allows to determine the impact of wave events on the basement of the monument.



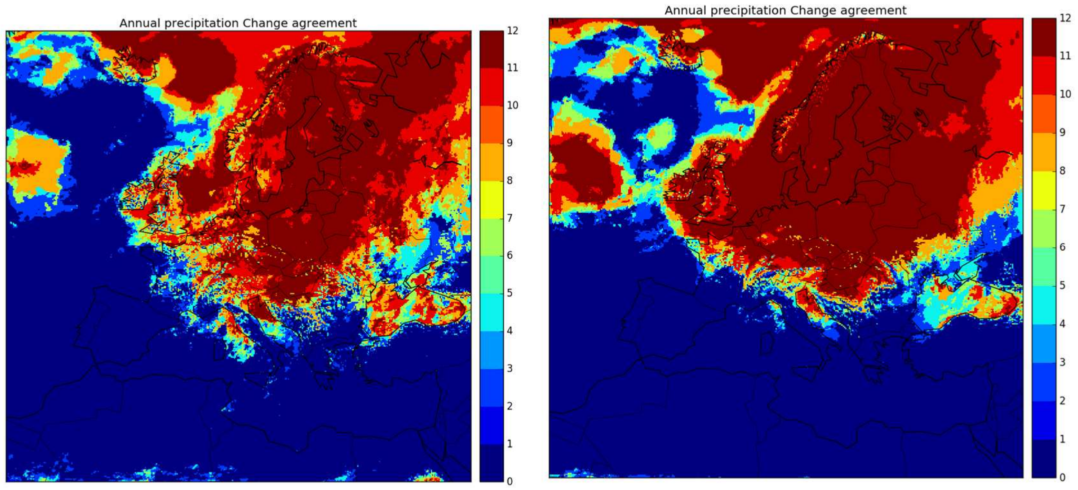
Example of Waves propagation

- Energy model of the building and meteo climatic data (from all sources). Forecasting of the behavior of the building in different meteo climatic trends.



Comparison of monthly primary energy need vs. outdoor dry-bulb temperature in the different scenarios.

- Correlation between DIFSAR data and Time to Failure model
- Projected climate changes over Crete and Gubbio



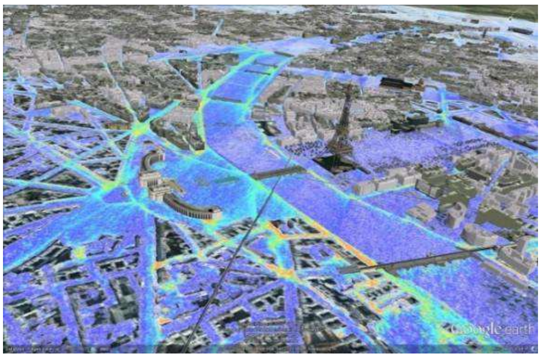
Numbers of models agreeing on the sign of changes for the near future (left) and the far future (right). 12 GCM/RCM combined simulations are used.

B. <u>For the investigation of the Pollution scenario</u>:

The action of the pollution on the exposed surfaces generally involves superficial or even deep damages to the chemical composition of the building materials, also affecting the structural resistance of the artefact.
In some cases the main exposed and vulnerable CH are monitored by dedicated sensors able to monitor the level of pollution and the composition of pollution agents. Unfortunately, most of the CH in Europe do not dispose of such premises and it is therefore out of control.
Furthermore, even in case of in situ monitoring, it is not so easy to simulate the trends of pollution aggressions in the future.
The exact knowledge of the quality and quantity of the pollutants affecting a CH artefact is very important for the planning of restauration actions and for urban planning (i.e. definition of vehicular paths, planning of pedestrian areas and so on).

- Task 2.2 Team, starting from the availability of a dedicated model aimed to simulate the dispersion of pollution agents on site and combining these data with 3D precision city model of the urban area of

Gubbio, developed a method to assess the present distribution of the pollutants on the CH artefact (the two testbeds in Gubbio) and to simulate the future pollution scenarios.



Example of model's output

WP3: DESIGN/DEFINITION OF METHODOLOGIES FOR WIDE AREA SURVEILLANCE AND SITE DIAGNOSIS AND MONITORING

Keywords: Multi-scale monitoring, Remote sensing, In situ-diagnostics, Material characterization, Surface analysis

1. EXECUTIVE SUMMARY

The booklet deals with activities devoted to assess the status of CH assets and involves a large number of technologies with the aim to perform a multi-scale monitoring capable of assuring wide area surveillance and, at the same time, local monitoring and detailed structure diagnosis and material analysis.

In this frame, the available technologies and methodologies are briefly summarized and systematic protocols are defined in order to provide guidelines/procedures for the monitoring, diagnosis and analysis of the monuments/assets by accounting for their structural issues, materials and weathering states. In detail, global protocols are defined for each one of the HERACLES test beds according to its structural and material preservation state.

Specifically, general technical objective are:

- Overview of advantages / limits of the involved sensing technologies;
- Assessment of the available state of art regarding the most recent developments/advances concerning them;
- Design / adoption of innovative devices, methodologies and data processing strategies to improve performances;
- Definition of the systematic protocols for test sites diagnostics and monitoring.

2. INTRODUCTION

The booklet regards the research activities performed in the HERACLES project with the aim to address the analytical steps, from wide-area to local, necessary to assess the status of CH assets. Accordingly, it deals with performance analysis and improvements of many and different sensors and diagnostic instruments (satellite based, airborne based and in-situ technologies), most of them complementary in terms of acquired information type.

The involved technologies operate at different spatial and temporal scales and aim at:

- monitoring the environment where CH assets are located by accounting for both land deformations and meteorological changes;
- performing structural assessments as well as characterizing materials degradation and weathering state.

The research activities involve three different and simultaneous tasks, which are summarized below.

Task 1 Satellite based technologies for wide area surveillance. This task accounts for exploitation of optical and radar satellite technologies suitable to detect and monitor land displacements possibly occurring at the HERACLEs project test beds, and more in general, at the geographical areas where they are located. In this frame, VHR & MR satellite optical data are exploited as complement and integration of airborne technologies. Moreover, VHR radar data collected by Cosmo-SkyMed satellite constellation are processed by patented data processing approaches in order to detect / monitor superficial deformations. Meteorological satellite data are also used to investigate climate changes occurring during the project.

Task 2 Airborne based technologies for monitoring. This task regards the use of airborne optical technologies for an accurate reconstruction of the morphology of the investigated area, with the generation of a Digital Terrain Model (DTM) as well as a 3D reconstruction of the main manmade structures.

Task 3 Non-invasive and non-destructive site diagnosis and monitoring (ground based technologies). This task regards use and optimization of in-situ and laboratory (ex-situ) diagnostic and monitoring technologies providing information on subsoil, structures and materials as well as with indoor/outdoor microclimate sensors. Specifically, it involves both in-situ portable instrumentations, devoted to provide high-resolution images of surface and subsurface features of the investigated objects (i.e., ground, walls, floors, columns, and so on), and laboratory instrumentations, which aim at characterizing materials and their alteration / degradation from a chemical and morphological point of view.

3. TECHNICAL EQUIPMENT AND PROCEDURES USED

The adopted sensors and techniques comprise:

- Satellite remote sensing, including optical, multispectral and radar (SAR) for wide area surveillance;
- Optical/VNIR instruments from airborne and remotely piloted aerial systems for local area sensing;
- In-situ sensing technology including radar technology (ground penetrating radar, holographic radar), electromagnetic methods (ERT), for sub-surface investigation, punctual/micro-local sensors, namely, structural monitoring sensors (accelerometers, LVDT and related environmental parameter sensors), meteorological stations and oceanographic sensors;
- Material characterization methodologies.

Satellite, airborne and in-situ technologies for surveillance and monitoring purposes and their specifics are summarized in Table I, while Table II is referred to the in-situ and ex-situ techniques for material characterization.

Table I: satellite, airborne and in-situ technologies for surveillance and monitoring

SENSORS	PARTNER	SENSED QUALITY	SPATIAL RESOLUTION	Global Coverage	Repeat cycle	Processing	Output
SATELLITE BASED							
Spaceborne optical/VNIR	e-GEOS	mapping and cartography	30-60 cm				
MODIS	SISTEMA	Land Surface Temperature (LST)	1 Km	1-2 days	16 days	Ingestion of data; Data archive population in array database (rasdaman)	Raster data (maps), ASCII data (time series) and statistical elaboration of both data formats (i.e. monthly mean, yearly mean, max value, min value etc.)
AIRS/AMSU (AQUA)	SISTEMA	Relative Humidity (RH)	1 Km	1-2 days	16 days		
MODIS	SISTEMA	Aerosol Optical Thickness (AOT)	10 Km	1-2 days	16 days		
MISR (TERRA)	SISTEMA	Aerosol Optical Thickness (AOT)	17,6 Km	9 days	16 days		
GOME / ERS-2	SISTEMA	Nitrogen Dioxide NO_2	40x320 Km^2	1 week	35 days		
GOME / ERS-2	SISTEMA	Ground-level Ozone O_3	5 Km	1 week	35 days		
GOME / ERS-2	SISTEMA	Sulfure Dioxide SO_2	40x320 Km^2	1 week	35 days		
OMI/AURA	SISTEMA	Nitrogen Dioxide NO_2	13x25 Km^2	daily	16 days		
OMI/AURA	SISTEMA	Ground-level Ozone O_3	13x25 Km^2	daily	16 days		
OMI/AURA	SISTEMA	Sulfure Dioxide SO_2	13x25 Km^2	daily	16 days		
SCIAMACHY / ENVISAT	SISTEMA	Ground-level Ozone O_3	60x30 Km^2	3 days	35 days		
SCIAMACHY / ENVISAT	SISTEMA	Nitrogen Dioxide SO_2	60x30 Km^2	3 days	35 days		
Spaceborne radar COSMO-SK	e-GEOS/CNR (IREA)	regional site and single structure monitoring of deformation	1-3 m			Persistent Scatterers Pairs (PSP) by e-geos and SAR Tomography (TMS) by CNR-IREA	Geo-localized data and deformation measurements. Output is formatted in txt files and shapefiles importable in common Geographical Information System (GIS)
Spaceborne radar SENTINEL	e-GEOS/CNR (IREA)	regional site and single structure monitoring of deformation	4x20 m^2				
AIRBORNE BASED							
Airborne optical/VNIR	e-GEOS	mapping and cartography	10 cm			Photogrammetric approach with the support of the most recent techniques based on multi-view stereo and dense image matching	3D models, orthophoto and geospatial layers related to Geomorphological model, Structural analysis and Climate change and extreme weather conditions
AISA EAGLE II	FRAUNHOFER	mapping and cartography	1m				
Riegl VQ-580 Laserscanner	FRAUNHOFER	3D mapping	1/5 m^2				
IN SITU SENSORS							
GPR	CNR (IREA)	subsoil surveys and vertical structure inspections	10-75 cm subsoil <7,5 cm vertical structures		Data collected during single or repeated measurement campaigns	Microwave Tomography	Spatial reconstructions of the investigated scenarios in terms of dielectric permittivity. These reconstructions are formatted in ASCII files and under the form of images. Output of GPR surveys can be used for structural analysis and health diagnosis and monitoring.
ERT	CNR (IREA)	electrical resistivity for water voids and fractures in the investigated subsoil	1-10 m		Data collected during single measurement campaigns	Res2DInv commercial sof	Spatial reconstruction of the real resistivity distribution formatted in ASCII files and images. Output of ERT surveys is used for ground characterization and monitoring.
Accelerometer	UNIPG	Single point dynamic measurement of acceleration (structural vibration) for structural analysis and monitoring purposes			Data continuosuly recorded at 100 Hz and stored in separate files collecting 30 recording minutes	Ad-hoc developed mathematical procedures for automated output-only modal identification and statistical process control	Output data will be formatted in ASCII files and will be used for structural analysis (FE modelling) and structural health monitoring purposes.
LVDT	UNIPG	Single point static measurement of crack amplitude for structural analysis and monitoring purposes			Data ontinuously recorded with a sampling time of 1 hour		
Temperature	UNIPG	Single point measurement of surface or air temperature			Data continuosuly recorded at 100 Hz and stored in separate files collecting 30 recording minutes.		
Payload monitoring System (E	UNIPG	Hand light portable or payload collecting air temperature, surface temperature, relative humidity, CO, CO2, VOC, PM10, PM5, solar radiation, wind direction and speed, illuminance level					
Meteorological Stations	FORTH - IACM	Fixed installation, 3m. mast meteorological stations, to be installed one (1) on Koules and one (1) in Knossos for measuring Wind Speed and Direction, Temperature, Humidity, Rainfall, Barometric pressure, Solar Radiation and UV Index			The sampling frequency of the measured data is 0.4Hz (1 / 2.5sec). The data are averaged on mean minute values	For every minute recording, a max, min and standard deviation values are provided for the measured quantity. Raw data and time-series report as well as measurement plots are updated and sent to the database at intervals ranging from one to five minutes.	Pointwise information relevant to the location of the installed meteorological stations.
Wave gauge	FORTH - IACM	One in Koules offshore (Wave height, period, sea temperature)			Sampling frequency of the measured data equal to 2Hz		Time series of sea level and temperature

Table II: in-situ and ex-situ techniques for material characterization

Method	HERACLES partner	Analytical capacity of the techniques and its role within the HERACLES
IN-SITU (PORTABLE) TECHNIQUES		
Portable Multispectral Imaging system- IRIS	IESL-FORTH	An imaging technique which combines digital imaging with spectroscopic analysis and may remotely and non-invasively give spatial and spectral information about an object and/or a monument.
Portable Raman spectroscopy system	IESL-FORTH	A non-destructive laser based technique that probes vibrational, rotational and other low-frequency modes (motions) in molecules and materials. Within Heracles Raman is expected to analyse the various types of crusts and weathering forms that are found on the test-beds
Portable Laser Induced Breakdown Spectroscopy (LIBS)-system	IESL-FORTH	Laser based technique that gives information on the elemental composition of the area under analysis. LIBS is fast, has no particular sampling requirements and is ideal for fast screening of materials/areas. Within Heracles LIBS is expected to screen the various types of crusts and weathering forms that are found on the test-beds
Surface/Volume Topography portable prototype	IESL-FORTH	A non-invasive, non-destructive, portable and low cost technique to measure of the topology of a surface and it's variations over time (4D)
In-situ analysis/techniques of mechanical characterization	CNR, UniPG, UoC	A number of techniques that will enable the Heracles consortium to measure the mechanical properties of the lithotypes.
ex-SITU (LABORATORY) TECHNIQUES		
SEM-FIB (with EDS) - Scanning Electron Microscopy not portable	UNINOVA, UoC, CNR-ISMN	SEM gives valuable information regarding the morphology and texture of the archaeological sample tested. This is extremely useful (mostly qualitative) data, because they document the current morphological status of the object under study, but also they can direct and guide consolidation efforts. EDS gives chemical information on the elements present that can be used in addition to other techniques, such as XRD.
X-ray Diffraction (also micro) XRD not portable	UNINOVA UoC CNR-ISMN	X-ray Diffraction is one of the most useful ex-situ characterization techniques. Although it is not a destructive technique per se, it requires sample taken from the site under study. However, it can give definitive information on the mineral phases present in the sample (qualitatively and qualitatively).
X-ray Fluorescence (also micro) XRF not portable	UNINOVA	X-ray fluorescence is a powerful characterization technique for the study of cultural heritage materials: it provides the elemental chemical composition in a non-destructive way, needing almost no sample preparation for qualitative or semi-quantitative results.
TG-DTA and DSC Thermogravimetry, Differential Thermal Analysis and Differential Scanning Calorimetry	UNINOVA, UoC	TGA-DTA offers characterization data of the sample under study regarding its behaviour under thermal stress. It studies mass loss of the sample as the temperature is increased (usually volatile molecules,such as water, are released). Although it can reach temperatures up to several hundred degrees Celsius, the useful range is much lower (eg. up to 120 C).
Micro Raman	UNINOVA	Micro (μ)-Raman microscopy permits to obtain information on inert inclusions, neo-formed crystals and microcrystalline structures of cultural heritage assets, being a non-destructive method.
Confocal Laser Scanning Microscop	UNINOVA	The confocal laser microscopy generates accurate three-dimensional imaging revealing detailed information regarding structures in the samples. This technique is particularly well suited for cultural heritage materials since it is non-destructive and non-invasive, while allowing surface topography of samples.
Stereo microscopy, not portable	UNINOVA	Stereo microscopy using reflected light is a particularly useful technique for surface observation of cultural heritage materials. It offers several modes of observation leading to different applications, high resolution topographic contrast and structural contrast.
FTIR - Fourier Transform Infrared Spectroscopy	UNINOVA, INSTM (Third Party), UoC	FT-IR is a useful ex-situ technique that supplements the material characterization by studying the vibrational modes of chemical groups present in the sample. It is extremely useful in characterizing organic consolidants used for stone/material consolidation.
Ellipsometry	UNINOVA	Spectroscopic ellipsometry provides accurate measurements of materials optical and structural properties of a broad range of materials allowing for the determination of surface chemistry features, constituent and void fractions roughness, indexes of refraction and area mapping
AFM - Atomic Force Microscopy, not portable	CNR-ISMN UNINOVA, UoC	AFM is mainly used in surface characterization and can be useful in ageing, conservation and cleaning effects studies of materials surfaces for the assessment of coatings and protective layers behaviour and measurement of the size of aggregates. It allows the characterization of the surface of samples taken from the site, showing degradation for the study of the decay mechanisms.
Spectrophotometry (UV-Vis-NIR)	UNINOVA, UoC	UV-vis spectroscopy is a technique that studies electronic transitions in materials (either in liquid or solid form). Although it finds limited application in archaeology, it can be applied on solid samples to enrich characterization.
Porosimetry (Archimedes) and helium picnometry	UNINOVA, INSTM (Third Party)	The determination of porosity and density of materials from the three test-beds will allow for a cross-correlation among materials used in the different monuments, building techniques and state of conservation.
4.4.2-13 X-ray photoelectron spectroscopy (XPS)	CNR-ISMN	XPS is a unique analytical technique in providing chemical state information of the detected elements. XPS can be used to analyse the surface chemistry of a material and is routinely used to analyze a wide range of materials from inorganic compounds, glasses, ceramics, stones, etc.
Non-linear Microscopy	FORTH-IES	A type of laser scanning microscopy, which within HERACLES project will investigate materials with emphasis to selenite with the aim to discriminate the thickness between the different layers of these multi-layer structures at microscopic level and eventually assess the effectiveness of the new materials to be developed.
DSC Differential Scanning Calorimetry, not portable	INSTM (Third party), UNICRETE	Same as ThermoGravimetry-Differential Thermal Analysis (TG-DTA) and Differential Scanning Calorimetry (DSC)
Analyses/techniques concerning the mechanical, thermo-physical characterization of concrete, mortars, binders and stones	INSTM (CVR-Third party), UniPg	They include analyses/techniques concerning the mechanical, thermo-physical characterization of concrete, mortars, binders and stones.

These technologies are exploited for assessing and facing the different risks affecting cultural heritage assets (specifically the test sites considered in the HERACLES project), for evaluating the climate change impact and risks, and for analysing the related vulnerability according to the overall holistic approach summarized in Figure 1

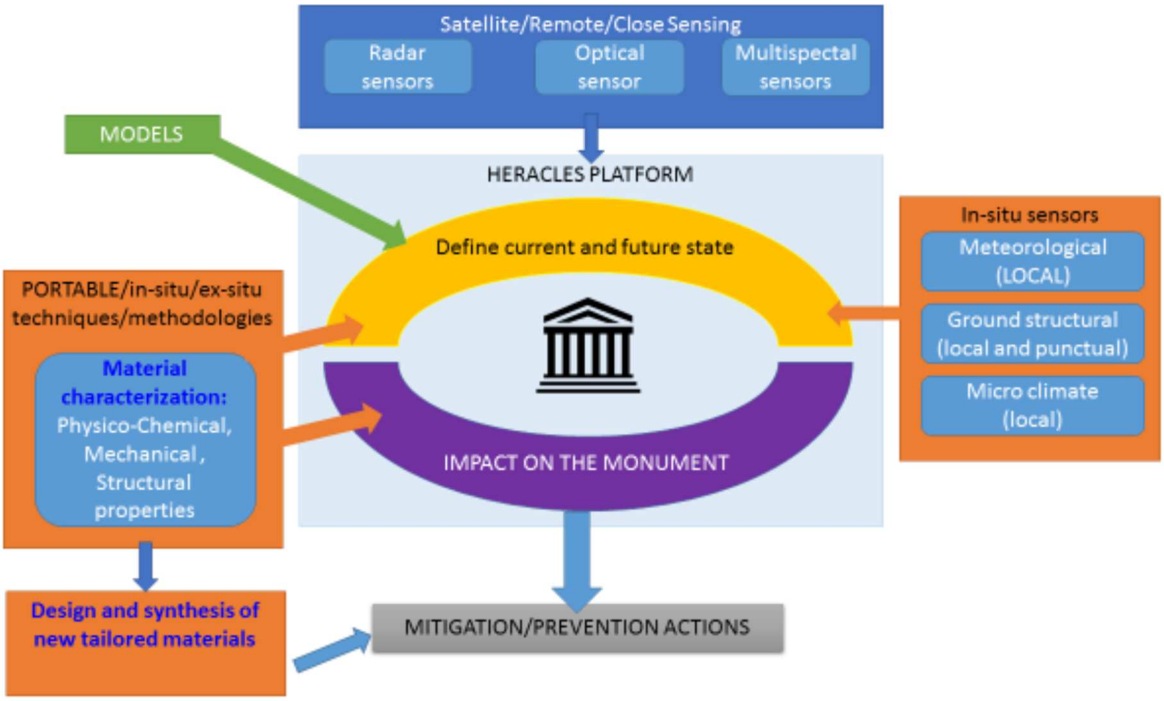


Figure 1: Schematic representation of the holistic HERACLES approach

4. TECHNICAL OBJECTIVES IN THIS PROJECT AND THEIR EXPECTED OUTCOMES. POSSIBLE DIFFICULTIES

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

- Brief summary of the state-of-art application in the frame of CH assets monitoring for each one of the considered techniques;
- Identification, development and validation of strategies aimed at improving measurement and diagnostics performances of the considered techniques, when required;
- Analysis of the experimental aspects related to the use of the considered technologies and to the interpretation of their results with specific reference to the HERACLES project test-beds. This analysis has been useful to describe the potentialities and limitations of the different technologies and the possibility of the measurements assimilation of the HERACLES models.
- Development of protocols for in situ-diagnostics aimed at assessing and monitoring the weathering state of the CH assets of interest into the HERACLES project as well as of analytical protocols for laboratory analysis devoted to characterize materials and their alteration.

Specific objective and expected outcomes are listed below.

- Full integration of optical aerial and satellite data, which are geometrically processed to fit the same reference map provided by airborne sensors.
- Use of SAR persistent scatterer interferometry and SAR tomography to obtain accurate 3D reconstructions (point clouds) suitable to provide surface deformation maps.
- Exploitation of meteo-climatic data for a local-scale characterization of meteorological conditions and climate change effects, including pollution levels and all phenomena having a potential impact on CH assets

- Availability of information (for the HERACLES test sites) to be integrated with satellite data in order to estimate 2D and 3D physical parameters useful to define morphological changes occurring at the areas of interest
- Survey of the potentialities offered by each one of the considered in situ and ex-situ technologies, by taking into account their state of art development and further improvements in terms of devices, installation / measurement procedures and data processing approaches

5. WORK ALREADY PERFORMED TOWARDS THE OBJECTIVES

The first performed activity regards the definition of global protocols accounting for structural issues, materials and weathering states of the HERACLES test beds. Figure 2 shows these protocols.

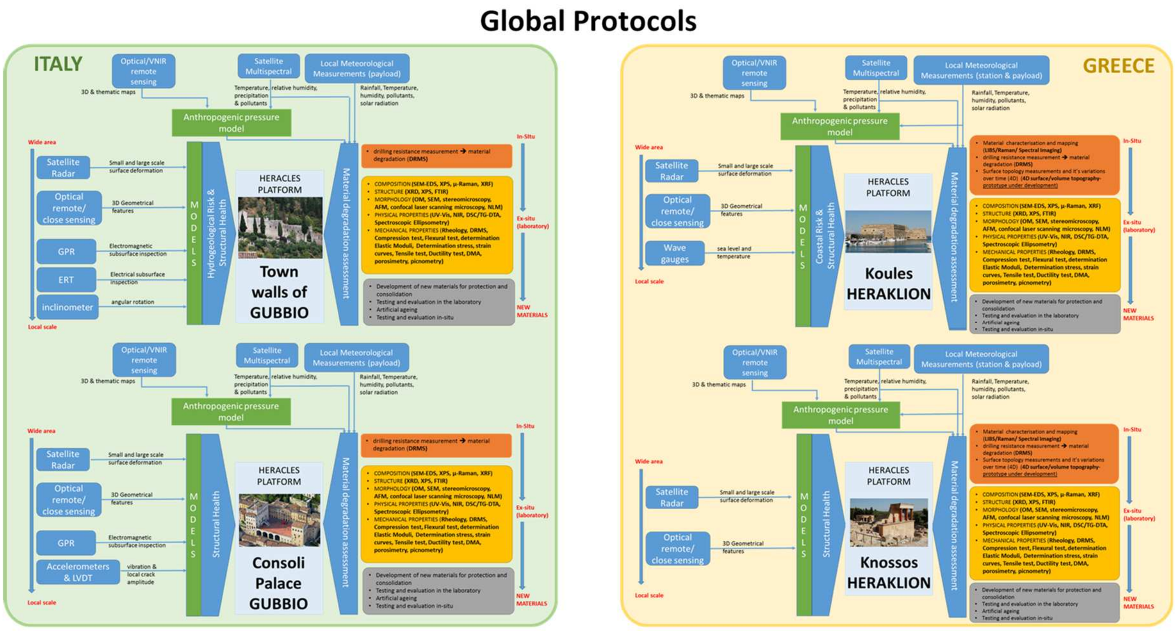


Figure 2: Global protocols for each one of the HERACLES test sites

Further carried out works and related reached progresses are summarized below with respect to three tasks recalled into the introduction.

As far as task 1 is concerned, indications about the development and testing of possible advanced data analysis strategies for data provided by satellite technologies have been considered, where possible. Moreover, experimental aspects associated with the use of satellite technologies and the result interpretation, tuned on the HERACLES test-sites, have been considered in order to describe potentialities and limitations of the different technologies. In this frame, the main results are:

- Availability of Digital maps of the test beds for surface, terrain and buildings model extractions
- Improvement of available DInSAR approaches in term of computational efficiency and accuracy of their products
- Statement of the limits of DInSAR approaches with respect the peculiarity of the Heracles test beds (vegetated areas, areas with significant slope -> selection of ascending of descending pass)
- Identification of the satellite multispectral sensors for the acquisition and collection of atmospheric and climatic data and collection of the satellite multispectral sensors data on two web data platforms exposing an OGC standard WCS interfaces. The two web platforms have been implemented with the scope to make the raster data easily accessible.

As far as task 2 is concerned, a survey of the state of art photogrammetry approaches based on airborne optical technologies has been performed as well as strategies devoted to improve the achievable information on the morphology of a landscape and variations occurring within a certain time range have been defined / identified. In this frame, it was decided to complete / integrate data provided by aerial surveys by means of terrestrial laser scanner surveys (not foreseen at proposal time) in order to gain more detailed information, with higher resolution, about vertical structures as façades and walls. Accordingly, accurate 3-D reconstruction of objects have been obtained by merging data collected with photographic cameras (from UAV and ground) and laser scanner (from ground).

As far as task 3 is concerned, the developed activities, beyond the survey and the performance analysis of all the in situ and ex-situ (laboratory) available diagnostic and monitoring technologies, are design / development / validation of methodologies devoted to improve the accuracy of the achievable results ("methodologies" includes devices, data processing approaches and measurement or installation procedures). In addition, specific diagnostic protocols combining in a synergic way the set of different technologies have been designed. Figure 3 and Figure 4 show the defined systematic protocols for in situ diagnostics protocol and laboratory analysis, respectively.

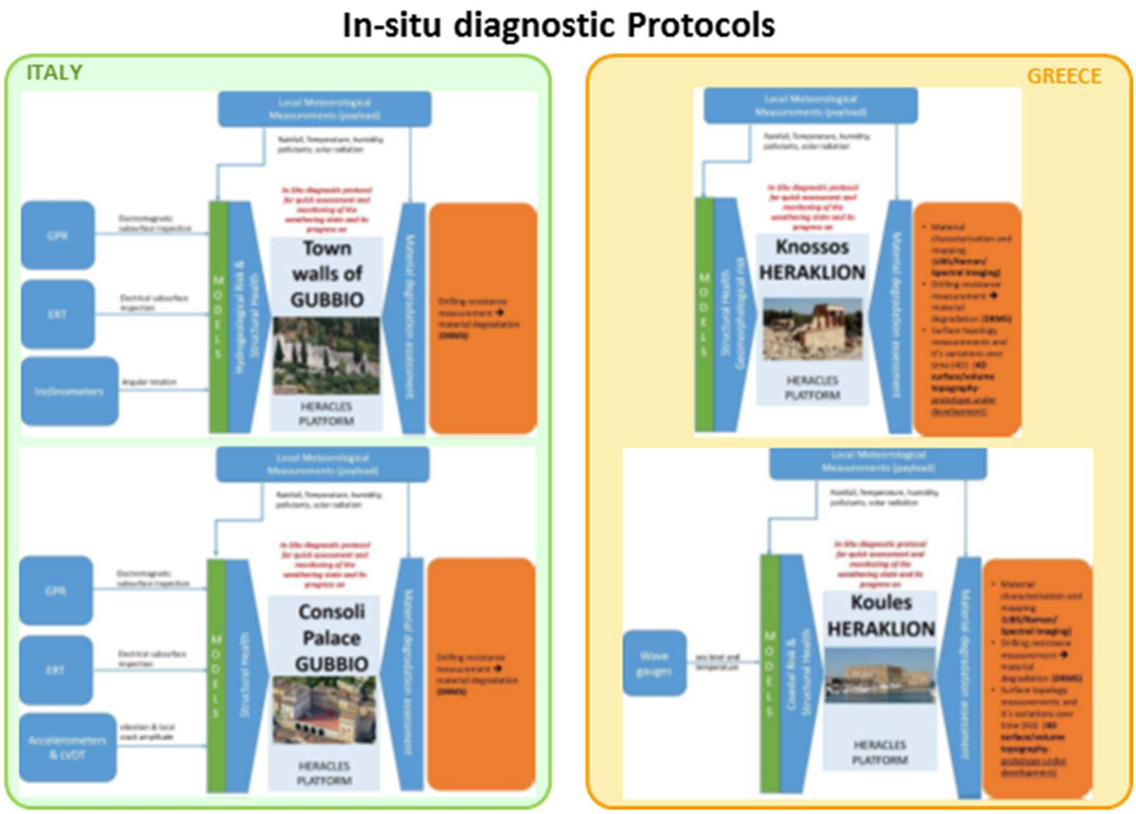


Figure 3: In-situ diagnostic protocols for each one of the HERACLES test sites

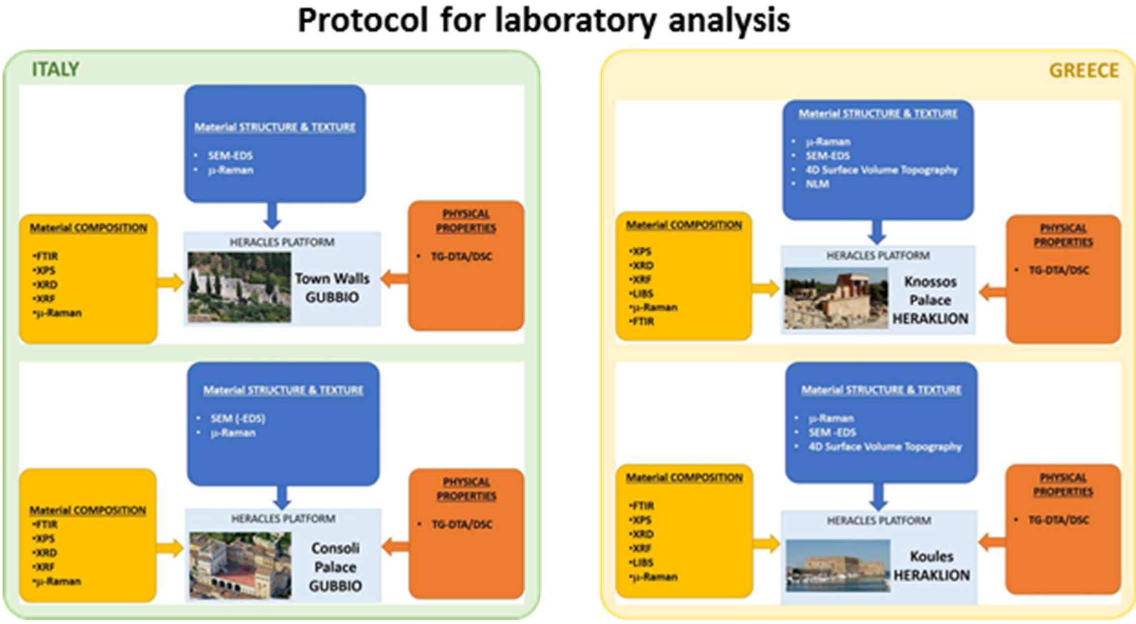


Figure 4: laboratory analysis protocols for each one of the HERACLES test sites

Further valuable results are:

- Definition of a radar imaging strategy, based on a model based procedure, designed to process GPR data and its adoption to improve the results of a survey carried out at Consoli Palace.
- Generation of time series data for deformation monitoring and temperature profiles at specific points inside the Consoli Palace
- Proofs of concept of a drone mounted microclimate weather station capable of gathering spatial profiles of air temperature, relative humidity, global solar radiation, wind speed and CO_2 concentration performed at the Gubbio Town Walls and at the Knossos Palace
- Use of portable instrumentation, based on optical and laser spectroscopic analysis for the fast, reliable and in-situ analysis and monitoring of the weathering state of the HERACLES test-beds
- Development of a prototype instrument of 4D surface volume topography for the monitoring of the evolution and progress of weathering states on HERACLES test-beds.

A transversal performed activity, partially still on-going, regards the cooperative / integrated use of two or more sensing technologies in order to provide a complete assessment, from wide-area to a local one, of the state of CH assets. In this frame, the current available results are:

- Tomographic SAR images referred to the Consoli Palace (Gubbio) have been interpreted on the basis of the information provided by structural deformation monitoring sensors and correlated with temperature distribution.
- GPR and ERT results referred to Gubbio town walls have been compared visually in order to verify their coherence
- Integrated use of in-situ techniques for monitoring decay products due to environmental impact, f.i. salt accumulation

Conversely, on going activities are:

- Integration of meteorological and microclimate data collected by using technologies providing information at different spatial scales. In this case the main issues are: synchronization of the different monitoring devices; b) necessity to select the large scale provisional procedures and forcing them for running with microscale data; c) need to compare experimental and modelled results for large- and local-scale data in order to interpret their consistency.

- Cross-correlation of the results of the in-situ surveys for material characterization and meteorological data. In this frame, the main effort regards the correlation among climatic conditions and possible changes in the chemical composition and spatial distribution of the deposits affecting the surface of monuments

Cross-correlation of information provided by structural monitoring sensors with those provided by GPR surveys. The related main issue regards the Integration of different type of data regarding visible cracks, in order to improve the amount of information useful to better assess the structural integrity of a monument.

WP5: DESIGNING THE HERACLES PLATFORM AND CREATING A COMMON LANGUAGE (ONTOLOGY)

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1. EXECUTIVE SUMMARY

The HERALCES project aims at implementing an information and communication platform able to provide a timely up-to-date situational awareness about the site, thus supporting decision makers to plan the actions necessary for long term and short-term maintenance, intervention and risk management against the threats of the climate change.

This work package addressed all aspects necessary for the specification of a system architecture and user interfaces for the HERACLES platform. From bottom up these are: the data collection via sensors and open sources, semantic data integration, data processing and fusion, visualisation and decision support.

Therefore, it includes the following specific objectives:

• The definition and realisation of a decentralized architecture for HERACLES as a System-of-Systems. This ensures that the information of existing systems can be integrated (e.g. Sensor Networks).

• The design of a generic concept for Data processing and Fusion

• The Specification of services to be used in the HERACLES platform

• The design and implementation of a user interface for decision support (incl. Mobile Solutions)

Furthermore, all experts contributing to the platform come from different domains and use their own terms, which are not connect. No attempts have been undertaken so far to model the risks and effects of climate change with regard to CH buildings and monuments, the caused damage and potential materials for restauration. Therefore, a new Ontology has been designed integrating all necessary aspects for improving the resilience of cultural heritage on site. This ontology combines the following topics: Cultural Heritage Assets, Stakeholders and Roles, Climate and Weather Effects, Risk Management, Conservation Actions, Materials, Sensors, Models and Observations. Furthermore, the ontology can be used as a basis for new research projects, which need to tackle the problems of climate change effects and involve a set of heterogeneous sensors and processing algorithms.

The available output of this work package consists of the architecture of the HERACLES ICT platform and the HERACLES ontology, which forms a common language for all participating domains. This output forms the basis for implementing the HERACLES ICT platform, which is implemented in work package 6.

2. INTRODUCTION

The UNESCO cultural heritage (CH) sites in Europe are almost 400, located in different Climatic European Regions. Environmental factors, worsened by the increasing climate change impact, represent significant threats to CH assets as monuments, historic structures and settlements, places of worship and archaeological sites.

An information and communication platform able to provide a timely up-to-date situational awareness about the site, thus supporting decision makers to plan the actions necessary for long term and short-term maintenance, intervention and risk management against the threats of the climate change.

The approach will benefit from a multidisciplinary methodology, which will bridge the gap between the two different worlds: the CH stakeholders and the research/technological experts since protecting cultural heritage assets and increasing their resilience against effects caused by the climate change is a multidisciplinary task. Experts from many domains need to work together to meet their conservation goals.

3. TECHNICAL EQUIPMENT AND PROCEDURES USED

For the management of available data two systems are put in place: FROST for managing sensor data and WebGenesis for managing the semantic knowledge.

The **Fraunhofer Open Source SensorThings API Server – FROST** – is used to store and provide all time series data in HERACLES. Fraunhofer IOSB has been working successfully with OGC standards for many years and realized the importance of the SensorThings API standard at a very early stage. This standard, developed with the experience of the OGC, combines well-established ideas of time and geo-referenced sensor data with a modern and lean interface concept.

FROST Server

With regard to the requirements coming from numerous applications in the mega-trend topic "Internet of Things", Fraunhofer IOSB decided to develop a server for the SensorThings API. The aim of the development was to achieve high performance with a low consumption of resources and at the same time an openness to facilitate usability in research as well as in commercial applications. The requirement for openness motivated the decision to design the implementation as an open source software from the start, and thus to clear the way for innovation as far as possible.

The software is certified by OGC and is one of the first implementations of the standard and as far as known, it is the only Open Source Implementation. The FROST Server is freely available as open source software under the GNU Lesser General Public License 3.0. LGPL 3.0 is a license that enables commercial applications on the one hand, and on the other hand ensures that further developments of the FROST Server will be available to all users: https://github.com/FraunhoferIOSB/FROST-Server

The implementation of the knowledge is based on the WebGenesis Framework (https://www.iosb.fraunhofer.de?21107). WebGenesis is a layered framework for building semantic web applications. It provides tools to modify the ontology, dynamically create input and search forms for instances and visualizes parts of the semantic graphs via a web-based interface. Furthermore, a programming interface is available for batch updates of the ontology instances. This can be used by algorithms, which analyse sensor data or weather prediction models to publish their results.

4. TECHNICAL OBJECTIVES IN THIS PROJECT AND THEIR EXPECTED OUTCOMES. POSSIBLE DIFFICULTIES

The specification of the system architecture is organized according to the five viewpoints defined by the Reference Model of Open Distributed Processing (RM-ODP, ISO/IEC/IEEE 42010, Systems and software engineering – Architecture description). These are the enterprise viewpoint, the information viewpoint, the computational viewpoint, the technological viewpoint and the engineering viewpoint. The utilization of different viewpoints, each one focusing on a particular aspect of the system, facilitates design and comprehension of complex systems.

The designed ICT platform is able to integrate heterogeneous data from multiple sources, analyses the data to evaluate the state of the Cultural Heritage (CH) assets and related risks, integrates predictive models, and supports decision makers to plan long and short term maintenance and restoration actions with the aim to mitigate the effects of climate change.

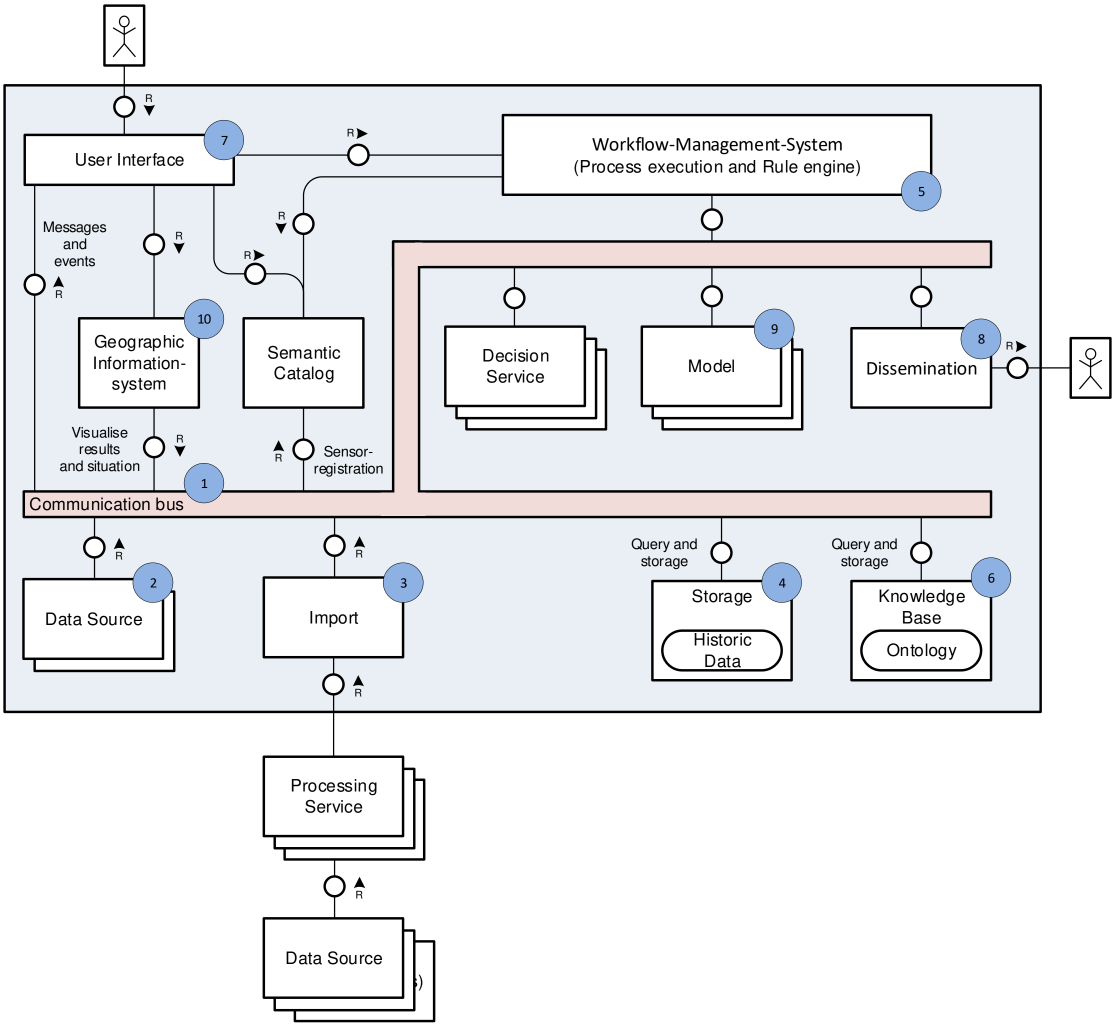
To provide these features the platform consists of different components. The basis consists of two data stores: The BigData store and the Knowledge Base (KB). The BigData store handles the raw and pre-processed sensor data and will be useful for the sensor data storage in view of subsequent (more sophisticated) processing and to learn more about the possibility to correlate outputs from different sensors by looking at past events. The purpose of the KB is twofold: on one hand, the KB provides facts in machine readable form to be used by other services of the platform; on the other hand, it provides information for end-users that can be navigated and visualized through a graphical user interface (GUI).

The models used by the ICT platform operate in different ways: some of these models are continuously in operation and produce updated results on a regular basis or when new input data, e.g. sensor measurements, are ingested in the models. Other models require explicit activation in order to be run and produce results. The Open Geospatial Consortium (OGC) defines a number of widely adopted standard APIs that can be used to expose geo-referenced data and models to other components of the system.

The management of workflows and standard operating procedures (SOPs) is another important component of the platform. Workflows enable site managers and domain experts to systematically deal with the onset of a potentially hazardous event impacting CH structures. They guide the users in the tasks, which need to be carried out during different phases: 1) the initial identification of the problem, 2) the evaluation of its severity and possible causes, 3) the design of mitigation and remediation actions, and 4) their implementation and the final evaluation phase.

5. WORK ALREADY PERFORMED TOWARDS THE OBJECTIVES

In the following figure the HERACLES system architecture is depicted.



A central element in the figure is the communication bus (indicated by number 1), allowing different components exchanging messages and data in a decoupled and decentralized way. This allows to easily add new components to the platform.

The bottom of the picture shows the available data sources and storage components. One category of the data sources are sensors (number 2). Another part of data sources are results of external model runs as well as laboratory examinations, brought to the platform using an import component (number 3). All those structured data will be stored in the sensor data storage (number 4). All document-like objects will be stored inside the document storage, which will be integrated with the workflow component (number 5). Further interpretation of this documents need to be done by a human and might result in findings that can be added to the Knowledge Base (number 6) in a structured way. All content in the Knowledge Base is organized in an ontology, which is described in more detail in Section 3 Information viewpoint.

The management of workflows and standard operating procedures (SOPs) is another important component of the platform (number 5). Workflows enable site managers and domain experts to systematically deal with the onset of a potentially hazardous event impacting CH structures. They guide the users in the tasks, which need to be carried out during different phases: 1) the initial identification of the problem, 2) the evaluation of its severity and possible causes, 3) the design of mitigation and remediation actions, and 4) their implementation and the final evaluation phase. This guide also integrates the decision support functionality of the platform.

As presented in the architecture there are two interfaces for user interaction. On the one hand the User Interface (left upper part, number 7), which is launched by the user (e.g. site manager/domain expert) to work with the HERACLES platform. On the other hand, there is a dissemination component (right in the middle, number 8) which can alert one or more users in case an event occurs. To allow the integration of existing or further developed dissemination components, we make use of the Common Alerting Protocol (CAP) which is standardized by OASIS. Since CAP is specialized for warning systems, we extend it to be applicable in the context of CH, too. Within the HERACLES project these CAP messages can be received by a mobile app.

For integrating those models two interaction aspects need to be regarded. The first one is how to activate those models and the second how to integrate the results of them. On the one hand, the model can be run synchronously when the client (i.e. the HERACLES platform) makes a request through an API offered by the model owner. The model is run and, when the request is complete, the results are available. On the other hand, the model can be run by an asynchronous activation. E.g. this can be done through a web API or an e-Mail. In contrast to the synchronous option, the process finishes before the result is available. After computing the results, they need to be integrated to the platform by a separate process.

The design process of the **HERACLES ontology** included the research and analysis of existing ontologies. One of them is the CIDOC Conceptual Reference Model (CRM), which provides definitions and a formal structure for describing the implicit and explicit concepts and relationships used in cultural heritage documentation. CIDOC CRM can be extended with additional models, such as the CRM scientific observation model, or the CRM model for archaeological buildings. In our view, while these models provide very valuable input, they are not well suited to be directly adopted in HERACLES. Our main concern is that trying to extend such in-depth models with the missing pieces, such as weather phenomena, risk analysis and crisis management elements would result in a model that is overly complex and non-intuitive.

The approach followed in HERACLES has been to create a new model from scratch trying to keep it as concise as possible, while incorporating elements from all the domains that are relevant for the application. Other sources that have been used as reference material are the SWEET ontologies developed at the NASA Jet Propulsion Laboratory, the materials ontology from Ashino and OGC standards such as the SensorThings API.

To identify the ontological classes and relations a workshop was held, which brought together the different stakeholders of the project with their different re-search and domain knowledge backgrounds. This group consisted of about 20 people. For a workshop, this number is considered too large but was necessary due to the different required domains. Regardless the interdisciplinary meeting brought many new insights into the domain since it was a disciplined discussion.

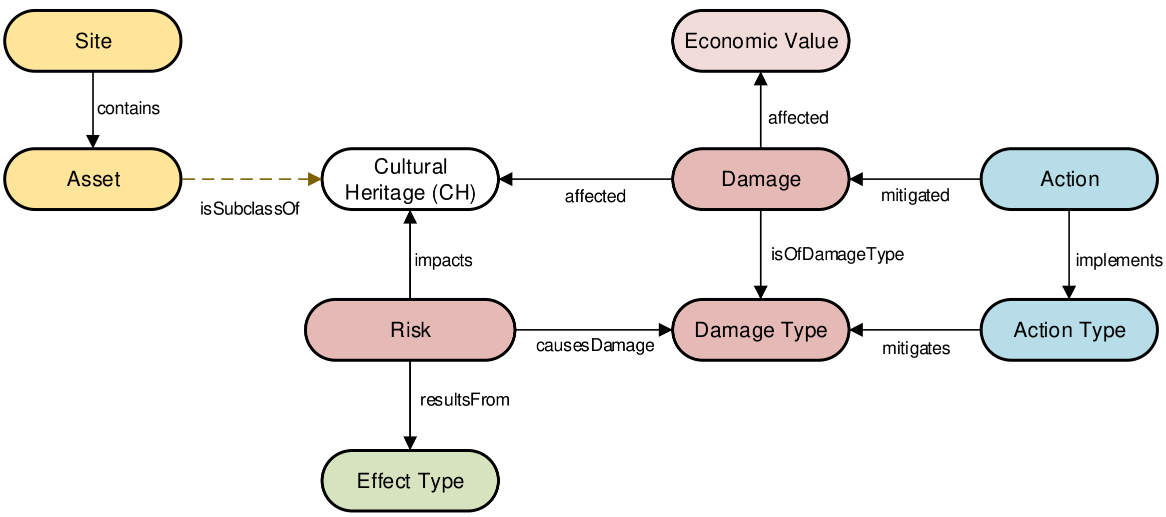


Figure: The main concepts and their object properties of the HERACLES ontology

WP6: HERACLES PLATFORM IMPLEMENTATION AND INTEGRATION

1. EXECUTIVE SUMMARY

The HERACLES project aims at implementing an information and communication platform able to provide a timely up-to-date situational awareness about the site, thus supporting decision makers in planning the actions necessary for long term and short-term maintenance, intervention and risk management against climate change threats.

Based on the System-of-Systems architecture defined in WP5, WP6 addressed the development of the Heracles platform, as the result of the integration of existing components relatively advanced in terms of maturity as well as of newly developed HERACLES ones.

In detail, the objectives were:

- o Development for improvement and adaptation of the Heracles platform components dealing with: Sensing and Storage; Data fusion, Data analytics; Workflow and Knowledge Management; Services.
- o Development of new components dealing with:
    - ➢ A presentation layer with operator console for real time signalling and intervention
    - ➢ The user interface to populate data bases and manage usage workflows to achieve call-requested functions.
- o Delivery of the HERACLES integrated platform.

2. INTRODUCTION

Heracles WP6 consists of the four tasks listed in the Title section.

The technical equipment and procedures used for the whole work package are briefly illustrated in the following section and regard: sensors installed at the two Gubbio test beds, sensors installed at the two Heraklion test beds, equipment used for remote monitoring of all four test beds and the newly developed Heracles Integration Environment, relying on LEONARDO's Cloud Automation Infrastructure.

Subsequently the objectives, difficulties encountered in trying to achieve them and the results obtained so far are described separately for each task

3. TECHNICAL EQUIPMENT AND PROCEDURES USED

A. <u>Gubbio Sensors :</u>

Integration within the Heracles platform of sensors data related to the two Gubbio CHs has been achieved in a variety of modes:

- The first integration mode requires installation and use of IOSB's FROST server (instance of a SensorThings API server) on the Heracles platform. This is the chosen mode for transferring in-situ sensor data stored in ASCII files at UNIPG servers to the Heracles platform. In most cases, the sensor data is transferred on an hourly basis from the UNIPG server to the Heracles platform.
- Weather and air quality data such as Localized Significance Thresholds (LST), Relative Humidity (RH), Air temperature, Precipitation, Aerial Optical Thickness (AOT), Sulphur Dioxide (SO_2), and Nitrogen Dioxide (NO_2) are provided by Sistema through a Web Coverage Service.
- Weather and air quality data are also provided by Sistema by accessing a repository through PL/SQL, which stores data collected from the ARPA UMBRIA weather monitoring stations network.

There are also a number of off-line sensors installed on the two Gubbio sites or used in the Gubbio environment, which register data in ASCII files stored on UNIPG servers. Data from these servers can manually be loaded into the FROST server.

Several off-line sensors data are also supplied by E-Geos at the Gubbio sites. The deployed sensor types are:

- ground-based synthetic aperture radar (SAR) - a radar-based terrestrial remote sensing imaging system);
- terrestrial laser scanning (TLS) deployed to obtain 3D point clouds of object surfaces by laser rangefinding;
- aerial and terrestrial photographs;
- drone survey data.

CNR provides processed data related to the use of a ground-penetrating radar (GPR) - a geophysical method that uses radar pulses to image the subsurface. This non-destructive method uses electromagnetic radiation in the microwave band (UHF/VHF frequencies) of the radio spectrum, and detects the reflected signals from subsurface structures. It is especially used when searching for subsurface objects, changes in material properties, voids and cracks.

B. Heraklion Sensors :

Two meteorological stations were installed near the two Heraklion test beds. Both stations are equipped with sensors used to measure meteorological parameters such as speed and direction of wind, amount of rain, temperature, relative humidity, barometric pressure and ultraviolet light.

Further offline sensors perform topographic and bathymetric surveys and side scan sonar imaging. The resulting data is stored in ASCII format text files on a FORTH-IACM server. A wave gauge sensor registers wave data every minute and a download to a text file, in time series format, is stored on a FORTH-IACM server every three months.

At the time of writing, four offline sensors, are provided by FORTH-IESL. The first sensor will initially be ex-situ and consists of laser-based analytical instruments for material analysis to be performed in the laboratory on selected samples. In a second phase the laser-based analysis will be performed in-situ. Another sensor will perform remote spectral imaging. Still another sensor will perform 4D surface volume topography. A temperature-humidity sensor data logging system will also be implemented with the aim of acquiring data every five minutes to be stored in ASCII-format text files in the logger's internal memory. Every six months, the data will be downloaded to a FORTH-IESL local storage system.

Integration within the HERACLES Platform of sensors data related to the two Heraklion test beds under investigation is achieved in a variety of modes:

- The first integration mode requires the installation and usage of a FROST server installed on the Heracles platform. This is the mode chosen for the storage to the Heracles platform of sensor data collected by the two meteorological stations installed at Knossos and Koules and managed by FORTH-IACM. Every minute, sensor data regarding parameters such as speed and direction of wind, amount of rainfall, temperature, relative humidity, barometric pressure and ultraviolet light are collected and stored at the station and every five minutes the data are transferred to the SensorThings API server installed on the Heracles platform.
- Weather and air quality data such as LST, RH, Air temperature, Precipitation, AOT, SO_2, NO_2 are provided by Sistema through Web Coverage Services (WCS).
- Local weather data is also provided by Sistema by accessing a repository through PL/SQL containing data collected from the ARPA UMBRIA weather monitoring stations network.

There are also a number of off-line sensors installed on the Heraklion sites which register data in ASCII files stored on FORTH – IACM/FORTH-IESL servers. Data can be loaded manually to the SensorThingsAPI server.

Several off-line sensors data are also provided by E-Geos both at Gubbio and Heraklion sites in order to evaluate deformation measurements. E-geos sensors deployed at HERAKLION are:

- terrestrial laser scanning (TLS) deployed to obtain dense 3D point clouds of object surfaces by laser range finding
- aerial and terrestrial photographs.

Thales provided examples of sensor data integration through both the Gubbio HMI and the Heracles HMI by implementing display of WCS data published by E-Geos for both CHSs.

See HERACLES D6.1 for further tecnical details regarding the sensor data.

C. Integration Environment :

In order to check the different HERACLES platform components are suitable for their purpose and consistent for an integrated use in accordance to the architecture specification, an integration environment was setup relying on LEONARDO's Cloud Automation Infrastructure.

The access to the integration environment was granted to the involved partners through VPN connections.

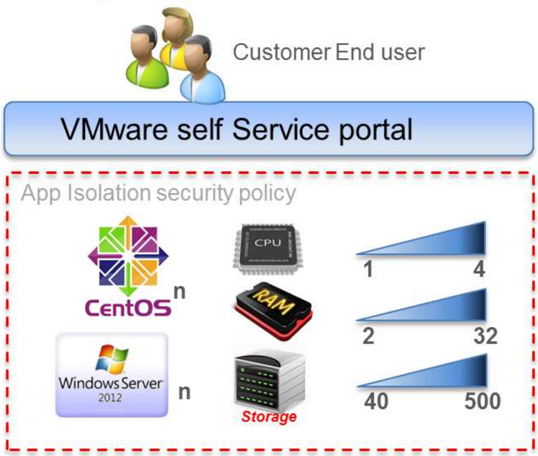


Figure 1 - LEONARDO's Cloud Automation Infrastructure

At the time of writing two virtual machines have been deployed with the following specifications:

- VM#1 : Windows Server 2012, 4 CPUs, 32 GB RAM, 1TB HD
- VM#2: CentOS7, 4 CPUs, 32 GB RAM, 1.5TB HD

4. TECHNICAL OBJECTIVES IN THIS PROJECT AND THEIR EXPECTED OUTCOMES. POSSIBLE DIFFICULTIES

Based on the architecture defined in WP5, WP6 addresses the development of the Heracles platform, as the result of the integration of existing components relatively advanced in terms of maturity (Technology Readiness Level (TRL) 5-6) and new HERACLES developed ones.

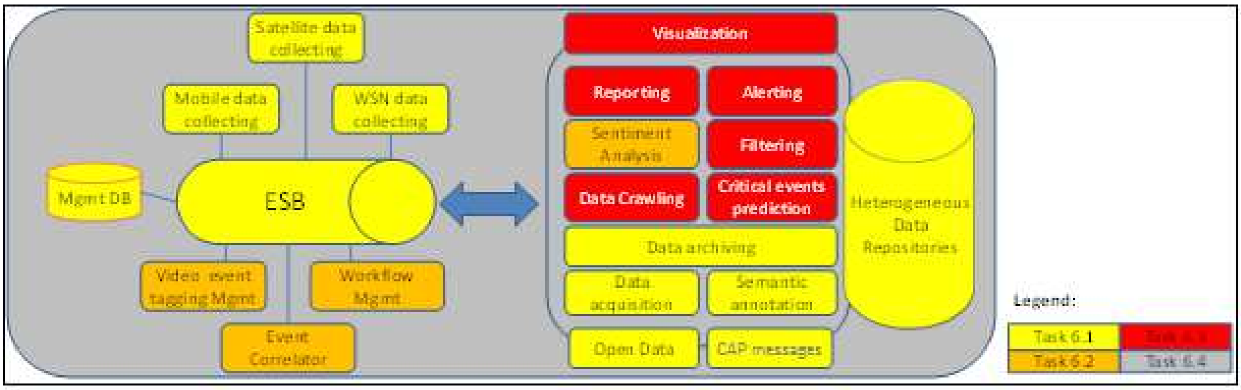
This WP includes the following specific objectives:

- Development for improvement and adaptation of the Heracles platform components dealing with:
  - Sensing and Storage
  - Data fusion
  - Data analytics
  - Workflow and Knowledge Management
  - Infrastructure Services.

- Development of new components listed below:
  - Decision Support System (DSS): a presentation layer with operator console for real time signaling and intervention. DSS processes and integrates heterogeneous data, and is triggered by the right pattern of events in order to require the right human intervention when situations are critical.
  - Multi-user dedicated Information services: the mobile app enabling different users to receive standardized alerts from many sources and configure their applications to process and respond to the alerts as desired.

- Delivery of the final HERACLES integrated platform.
  The integration environment was setup relying on LEONARDO's Cloud Automation Infrastructure.
  At the time of writing the status of components' development /deployment is summarized as follows:
  - SensorThingsAPI Server deployed in the LDO cloud – T6.1
  - **K**nowledge Base deployed in the LDO cloud – T6.1 & T6.2
  - Workflow management backend logic in progress, first version deployed in the LDO cloud – T6.2
  - CAP alerting messaging application deployed in the LDO cloud – T6.3
  - Decision Support System development is in progress, first version deployed in the LDO cloud – T6.3
  - Multi-user dedicated Information services in progress – T6.3
  - Communication Service Bus deployed in the LDO cloud – T6.4
  - Single Sign On integration in progress – T6.4

Overview of WP6 objectives:



During the the project, we have encountered the following difficulties :

- The CEP rule engine is available in the platform but we are missing the expert domain knowledge required to identify well-known patterns in the in-coming sensor data thus allowing configuration of CEP rules.

The Risk assessment tool (see WP2 - Task 2.3) is not integrated in the platform. The user will manually introduce the result of the tool in the platform.

5. WORK ALREADY PERFORMED TOWARDS THE OBJECTIVES

A. Task 6.1

Integration of the in situ and ex situ sensor data within the HERACLES platform was achieved by using the FROST Server, an open-source implementation of the OGC SensorThings API standard developed by Fraunhofer. It was chosen in place of the OpenIoT platform because of the popularity of the SensorThings API standard sponsored by the well-known Open Geospatial Consortium (OGC). The metadata of the sensors are modelled in the IOSB Knowledge Base and linked to a SensorThings datastream. Several instances of IOSB's FROST Server have been installed and receive data from the running sensors in Gubbio (Consoli Palace) and Heraklion. In addition, IOSB implemented not only manual but automatic import of data coming from a number of Gubbio sensors. The SensorThingsAPI servers are available over the public Internet (https://94.127.86.132/SensorThingsService/v1.0/) and expose REST web services for retrieving stored data. Sensor data are currently displayed by charts and diagrams available through the Decision Support System developed within Task 6.3.

Fraunhofer also setup a knowledge base based on IOSB's WebGenesis system. The system allows the import of an ontology from which a full information system can be easily configured, e.g. you can automatically create input forms. This was done with the first version of the HERACLES ontology.

Information can be added to the Knowledge Base and, once stored, can be accessed through REST APIs (endpoint: https://94.127.86.132:8081/servlet/is/rest/) and through SPARQL queries (endpoint: https://94.127.86.132:8081/servlet/is/Entry.5075.SPARQLEndpoint/).

The communication model based on a Service Oriented Architecture, designed for the Heracles Platform, was implemented by means of ActiveMQ, a Message Oriented Middleware. In addition, the document management tool based on Alfresco was tested and is used for implementation purposes within Task 6.3.

The online availability of the sensor data has started but is still on-going since not all sensors have been integrated.

Integration of several cartographic and modelling products generated by the WP2 models has been performed. Among these, the PS interferometric data on Gubbio has been preliminarily made available on an OGC compliant service (Geoserver) in order to be integrated into the Web Interface. Other 2D/3D data are on their way to being integrated as OGC services or using similar web services. Automatic loading procedures have been developed to sustain the continuous updating of such data. The server is currently hosted in e-GEOS and a public end-point (http://share.egeos-services.it/mapping_service2/wfs?request=GetFeature&version=1.0.0&typeName='+layer+'&BBOX='+bbox+',EPSG:4326&&outputFormat=application/json) has been made available for the integration with web interfaces and third-party processors supplying other models.

B. Task 6.2

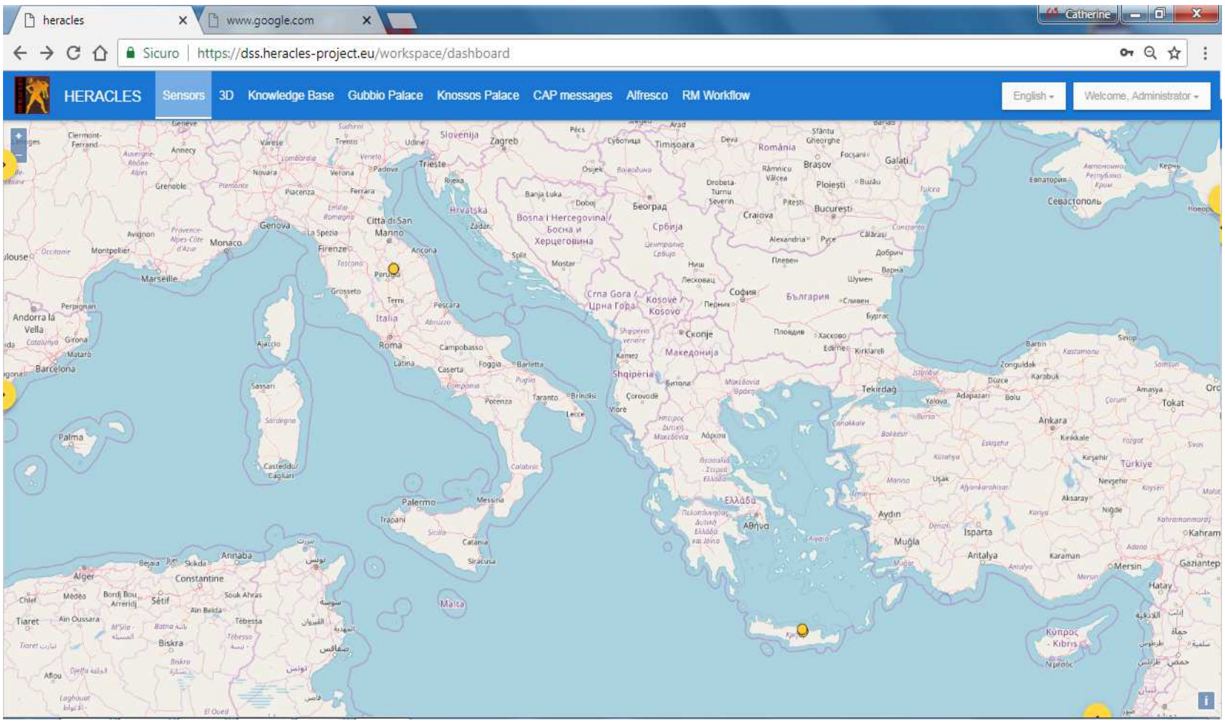
The new Heracles Risk Management workflow was designed by WP6 partners with the support of TIEMS by using BPMN notation. The tool used for BPMN modelling was Camunda BPMN. Subsequently, integration within the DSS and development of this new functionality, involving LEONARDO, THALES and IOSB within T6.3, was begun.

In addition, work in task 6.2 involved :

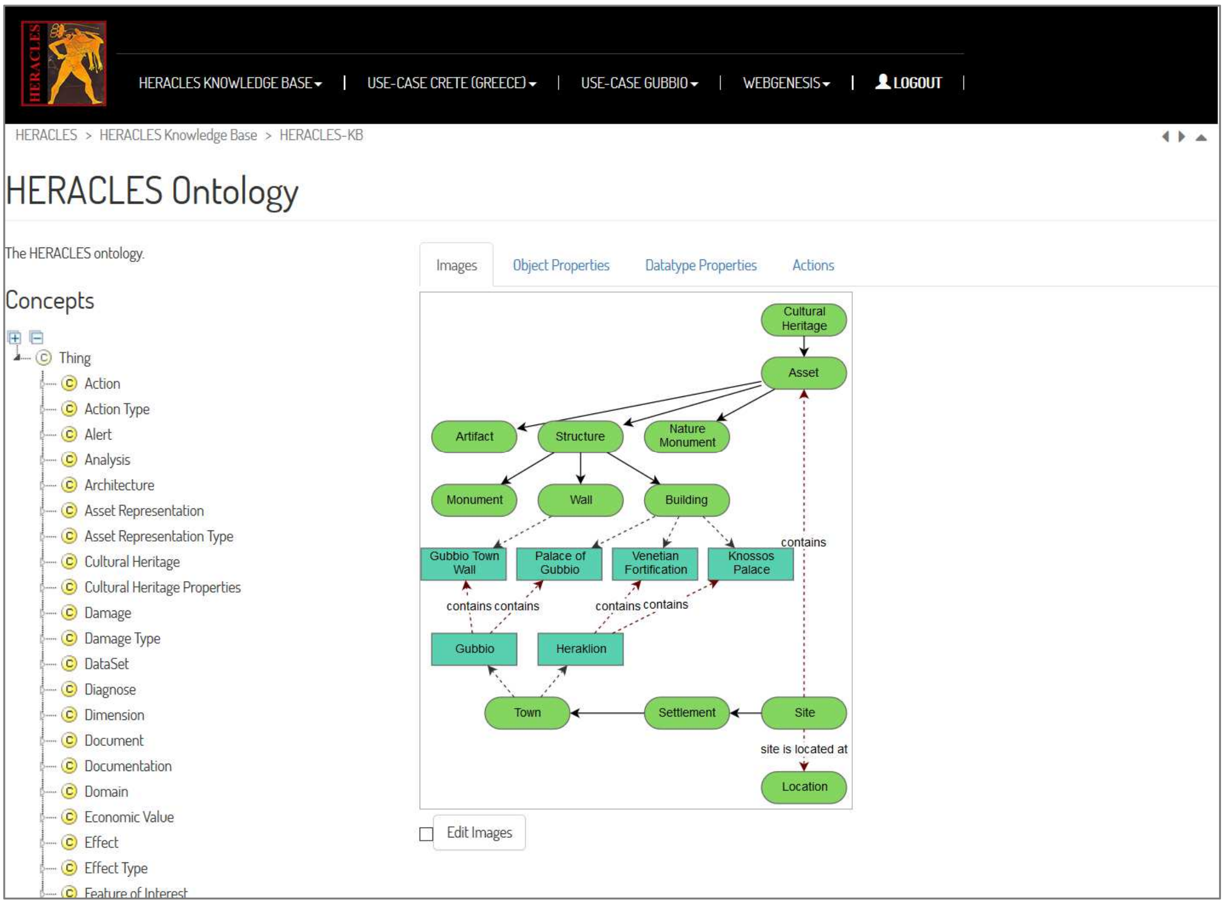
- Fusion/processing of incoming sensor data by the platform thus allowing decision makers the possibility to view valuable information through the platform.
- A risk assessment tool displaying data coming from the models involved in risk assessment where the results must be manually entered into the platform by the domain experts.
- A CEP rule engine available for configuration by domain experts. If configured, it can raise alerts that can be visualized through the Heracles layered georeferenced web interface thus informing platform users regarding the actual risks that are occurring in selected areas.

C. Task 6.3

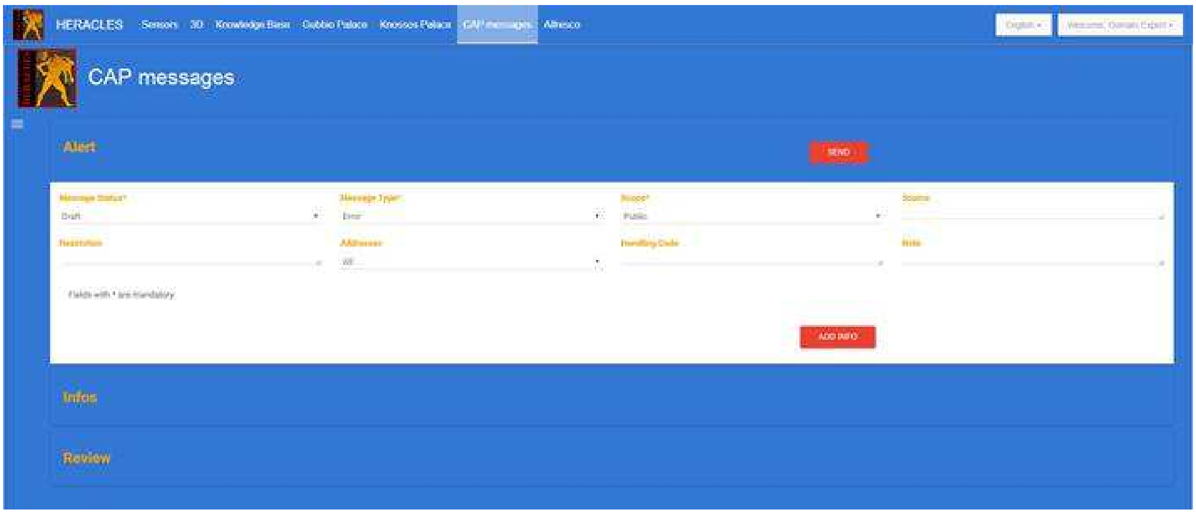
Thales integrated the Knowledge Base (KB) from IOSB within the DSS.



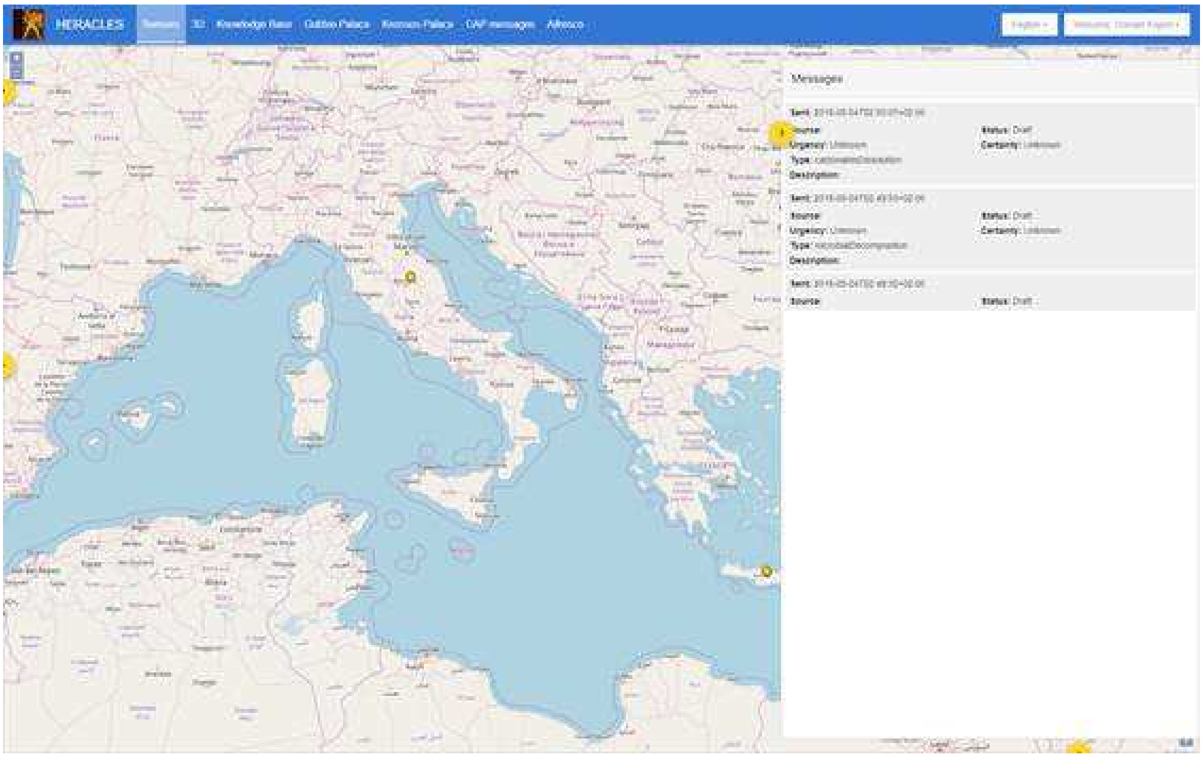
The Heracles user can now access the Heracles Ontology through a dedicated tab of the main DSS GUI.



The CAP web application has been developed by Leonardo and integrated by Thales within the HERACLES Decision Support System. Through a dedicated tab of the main DSS GUI, users can access and use the capabilities offered by the CAP web tool, sending and managing messages compliant with the Common Alerting Protocol. CAP messages are routed by means of ActiveMQ, the Message-oriented Middleware used by LEONARDO as the communication bus for the HERACLES DSS.



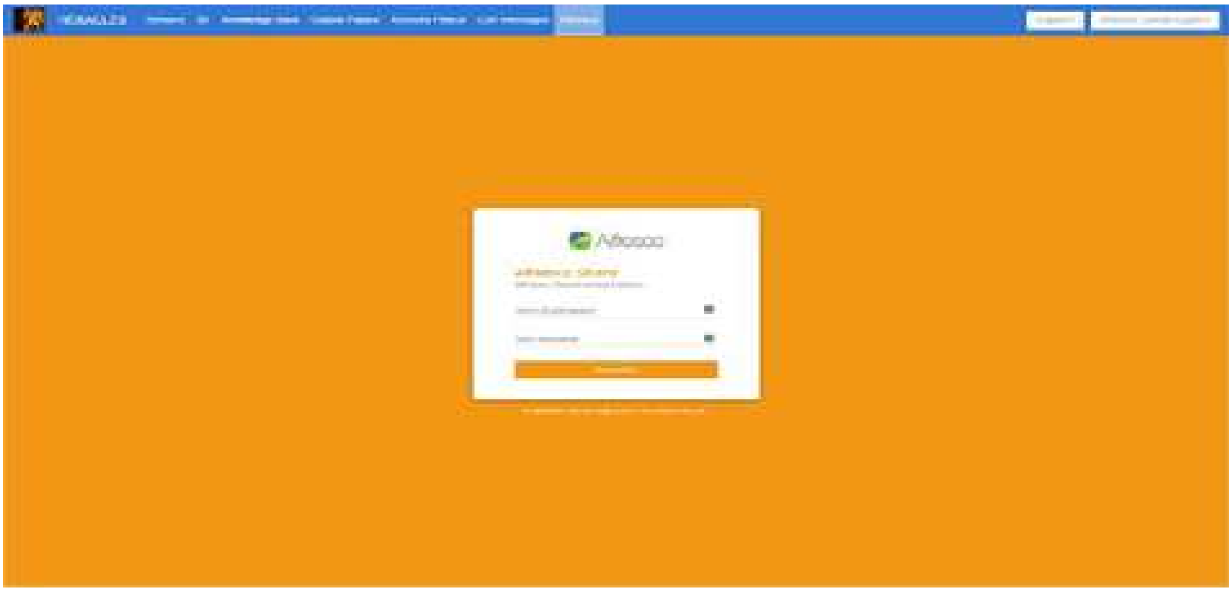
Note : All received CAP messages are also displayed in the messages sub-panel of the DSS MMI Sensors tab (GIS 2D view).



Mapping between the CAP message fields and the ontology concepts defined in the Knowledge Base were performed by Leonardo together with IOSB. The web-based CAP Messaging Tool was then developed by Leonardo and tested in conjunction with IOSB.

After the CAP web tool, IOSB subsequently developed a mobile application able to receive CAP messages.

The Alfresco document management tool was integrated within the DSS GUI developed by THALES by means of a dedicated tab. However, it was not possible to integrate Alfresco with KeyCloak, i.e. Alfresco can not be accessed through Single Sign On and requires its own login page. In any case, for ease of use, the DSS Administator will keep the Alfresco user accounts and the DSS ones aligned for the whole duration of the project. The Alfresco login page can be seen below.



The Risk Assessment Workflow has been implemented after the design stage performed in T6.2. LEONARDO has adopted Flowable, a light-weight open source business process engine for implementation purposes. The Flowable engine has been embedded within the HERACLES platform and is designed to interact with

ActiveMQ and the DSS GUI developed by Thales. Flowable REST APIs are being used to communicate over HTTP by means of the GET and POST methods with the Heracles platform-integrated GUI. Integration tests between the DSS GUI, the Flowable engine and ActiveMQ are forthcoming.

D. Task 6.4

The objective of T6.4 "Platform Integration" are three-fold:

- to integrate the platform modules with the design and development of web services according to a SOA (Service-Oriented Architecture) model in order to make the architecture interoperable and modular ;
- to investigate tool and service interface definitions, checking that these are suitable for their purpose and consistent for integrated use and in accordance to the architecture specification ;
- to check the integration between the utility services and tool implementations in order to provide feedback to the technical work concerning changes, which may be necessary to identify technical issues that must be solved in the previous WPs.

In order to fulfil the above mentioned objective the requirements for each software component were gathered and an integration environment was setup relying on LEONARDO's Cloud Automation Infrastructure. Two virtual machines were deployed and the access to the integration environment was granted to the involved partners through VPN connections.

Several software modules were developed, installed and deployed by WP6 partners within the HERACLES integration environment built and maintained by LEONARDO.

Specifically, the following modules are currently available and integrated with each other:

- the DSS GUI developed by THALES
- SensorThingsAPI service specifically configured for Heracles needs and deployed by IOSB
- the Knowledge Base specifically configured for Heracles needs and deployed by IOSB
- Heracles ontology visualization developed by IOSB
- Time series sensor data visualization developed by IOSB
- ActiveMQ, the communication bus customized by LEONARDO
- the CAP web application implemented by LEONARDO.
- Workflow Management engine, based on Flowable and customized by LEONARDO
- Alfresco, the Document Management tool customized by LEONARDO.

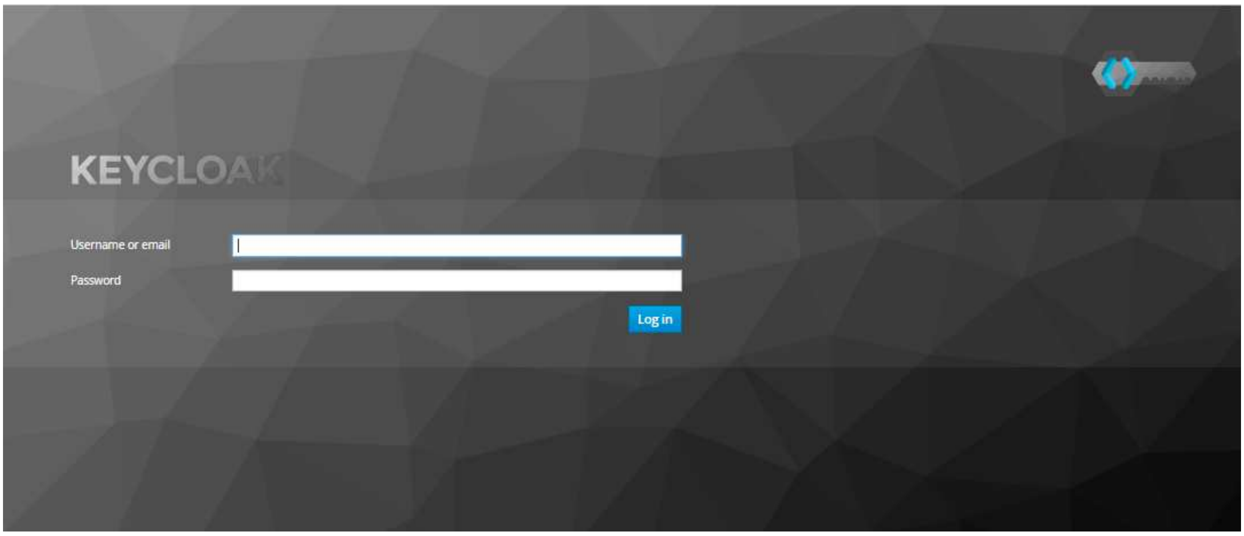
Moreover IOSB and LEONARDO assessed several technologies for the implementation of a Single Sign On mechanism. The discussion was finalised by choosing the KeyCloak technology. IOSB and LEONARDO installed the tool within the HERACLES shared environment where the DSS software components have already been installed.

KeyCloak as a Single Sign On technology (performing user authentication and authorization) was installed by IOSB with the support of LEONARDO. Tests were performed to verify if the Heracles platform applications could be integrated with KeyCloak in order to allow DSS Single Sign On. The results of the tests were that only Alfresco could not be integrated.

However, the user accounts configured in KeyCloak will be used by the DSS for user authorization of all DSS-integrated applications whether they can be integrated with KeyCloak or not.

Integration between KeyCloak and all other DSS tools (CAP Message Tool, Knowledge Base, RM Workflow, etc.) is on-going.

Below the KeyCloak login page :



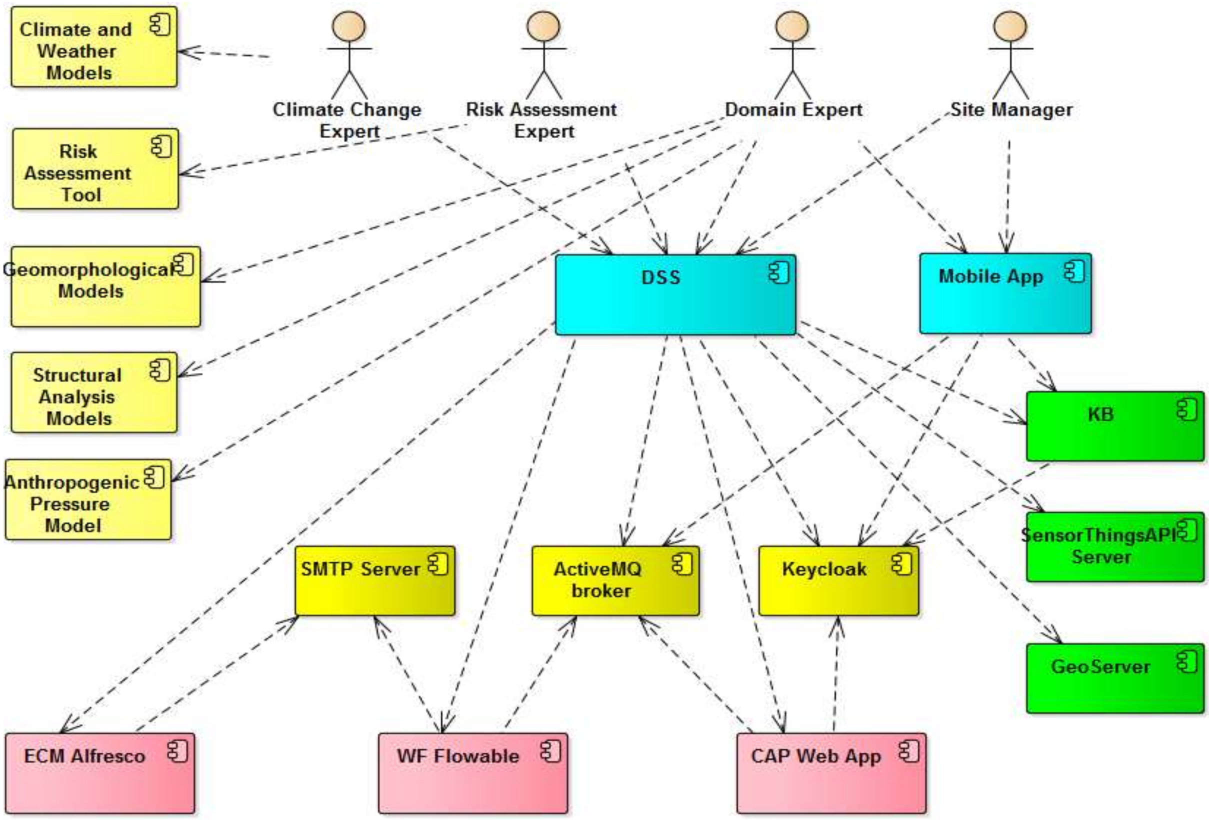
Based on HERACLES requirements, users can be grouped according to the site they belong to (e.g: Consoli Palace, Gubbio Walls, Knossos Palace, Koules Fortress) and also according to their expertise (e.g.: Administrator, Domain Expert, Site Manager…).

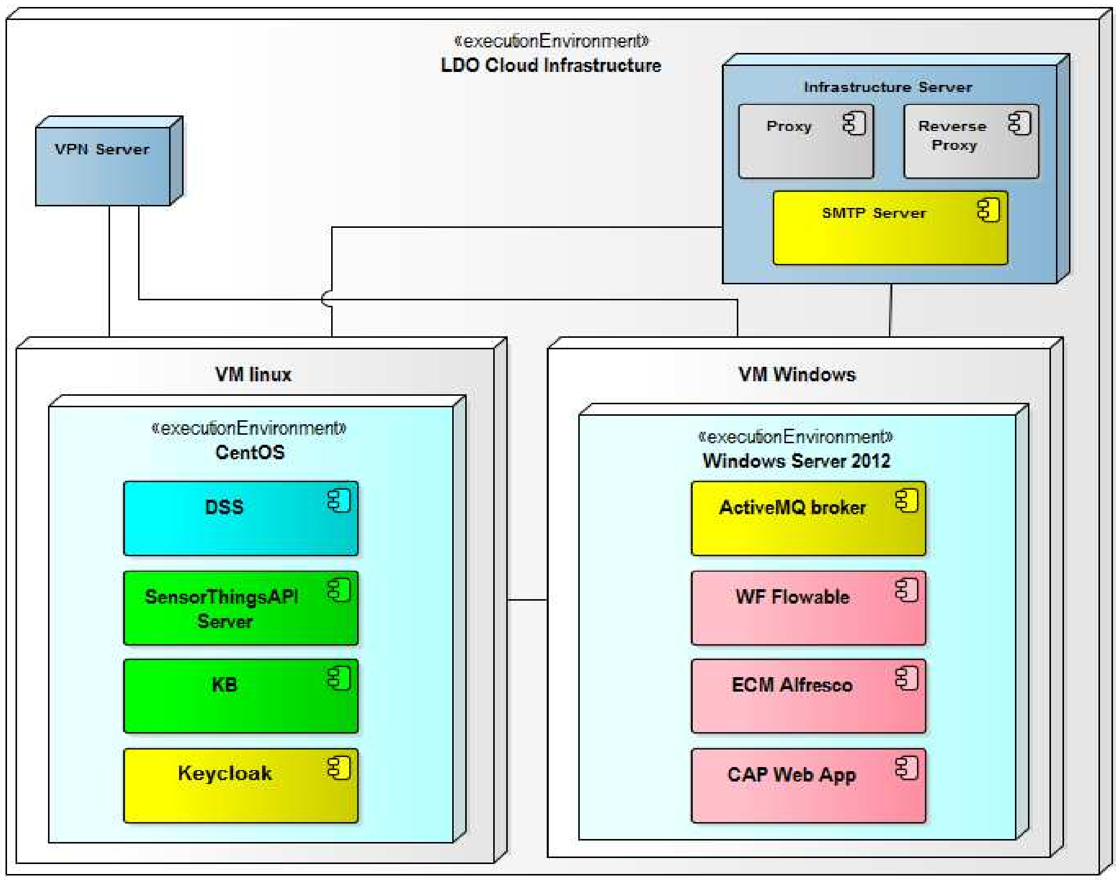
Each user has been configured in Keycloak using values from two role sets :

- **Expertise-role-set**
- **Site-role-set**.

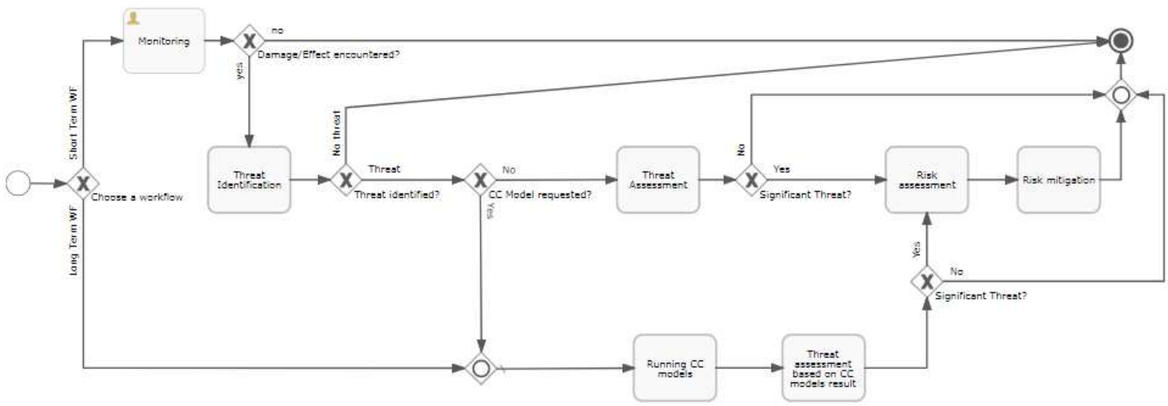
The DSS GUI implements the "first filtering level" of granted functionalities (e.g. only a Site Manager for Consoli Palace can view/access the Cap Message Tool Tab for the given site, only a Site Manager for Koules can start a workflow for the given site,….) .

Overview of current system actors and components :





Risk Management (Main) Workflow diagram



WP7: RISK MANAGEMENT, MAINTENANCE, RESTORATION, ADAPTATION POLICIES AND PROCEDURES FOR END USERS

1. EXECUTIVE SUMMARY

With the aim to protect and support Cultural Heritage (CH) Monuments and assets from the threats of the climatic change HERACLES project investigates on the development of a number of examination and diagnostic methodologies allowing careful and systematic inspection and monitoring of monuments from different inspection levels and points of view (satellite, in-situ sensors, laboratory analysis etc.). For the responsible coordination of these actions an information and communication platform is designed and implemented.

This work package aims at delineating the procedures and activities that will enable/ensure the proper operation of the HERACLES platform. It develops in close collaboration with the design and implementation of the platform itself (through WPs 5 and 6 respectively) and communicates with most of the other work-packages (WP1 on end-user requirements, WP2 on modelling vulnerability and risk, WP3 on satellite, airborne and in-situ monitoring). Finally, through the demonstrations that will take place within WP8 these operational procedures will be critically revised, refined and updated.

The main objectives of WP7 are:

- The description of a methodological approach and guidelines for the design and implementation of maintenance and restoration actions in order to ensure reliable and cost-effective conservation practices.
- The definition, design and update of the operational procedures that must be followed to ensure disaster preparedness, risk management and mitigation. These strategies must be effective for long-term scenarios as well as for emergency quick Damage Assessment, Mitigation, Remediation, and Restoration after crisis.

2. INTRODUCTION

To ensure the responsible safeguarding and longevity of a CH monument a methodological approach must be followed. Carefully designed maintenance and restoration actions must be developed which through preventive and routine actions will result into a reliable and cost effective preservation plan for the monument. In parallel, and in agreement with the development of the HERACLES platform (WP5 and WP6), an operational procedures (OPs) framework for disaster prevention, risk mitigation and management is designed on the basis of the end user requirements (WP1), vulnerability and risk models (WP2), data from satellite, airborne, and site-based monitoring (WP3) and the behavior of new materials designed through WP4. These OPs, as well as whole framework, will be critically tested through the demonstration activities of WP8 in order to be carefully adjusted and refined with the operational requirements. Thus, OPs will be modified according to what is learned from critical results analysis in WP8, while they will allow for expansion and further refinement.

Last but not least, a number of actions for quick damage assessment, mitigation, remediation and restoration after a crisis, both due to natural causes and man-induced are also foreseen to be developed within WP7

3. TECHNICAL EQUIPMENT AND PROCEDURES USED

For the design and development of operational procedures for disaster prevention, risk mitigation and management effective both for long term strategies, as well as after a crisis, and cautiously adjusted for the monuments under study through the HERACLES project, all actions referring to maintenance, conservation, and restoration activities must be carefully described and defined. Thus a number of generic, as well as specific, good practice guides, protocols and methodologies related to the monitoring, analysis, restoration interventions and procedures followed by the site managers and specialists for the safeguarding of the monuments is taken into account. Generic data was collected from world-wide important organisations and initiatives such as the ICCROM (International Centre for the Study of the Preservation and Restoration of Cultural Property), the ICOMOS (International Scientific Committee for Stone), a number of COST Actions and the CEN (the European Committee for Standardization). These broad data must be then carefully adjusted for the specific requirements and needs of the HERACLES monuments taking into account local environmental conditions, specific materials, historic data and other socioeconomic factors.

The operational view (OV) diagrams developed in the HERACLES project are primarily used to describe the main components of the system of interactions between end-users and the HERACLES Platform. The interactions are related to the disaster prevention, risk mitigation and management for adaptation strategies considering longer time periods, up to the year 2100. OVs are designed on the basis of internationally recognized enterprise architectures (i.e. the US Department of Defense Architecture Framework (DoDAF) with activity model implemented using BPMN 2.0 notation and are continuously aligned with the HERACLES platform development and refined with the HERACLES test-beds requirements.

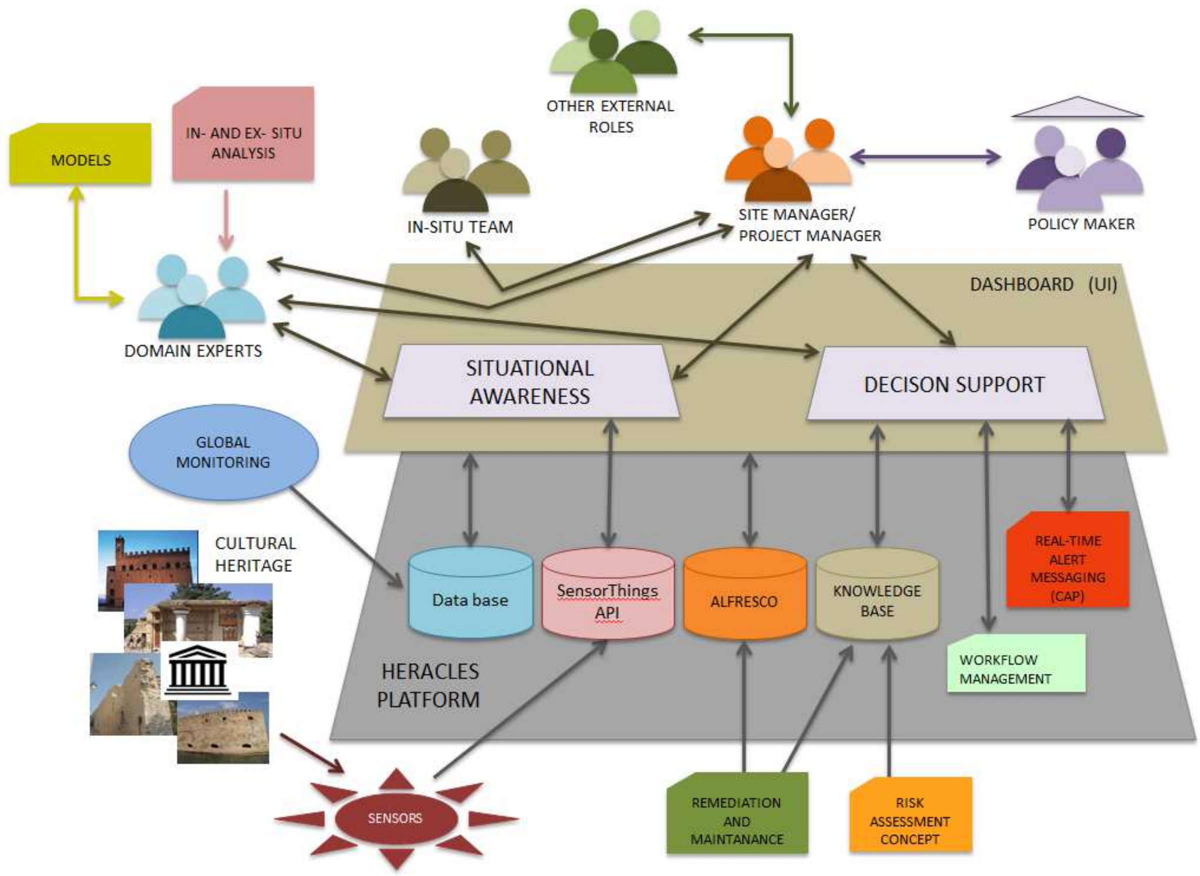
Three types of view diagrams have been developed and used for creation of operational procedures: a high-level concept, organizational charts and an operational activity model.

- The high level concept, a starting point of the system description providing a general overview of the main actors and activities, is used to generally describe how end-users will use the Platform's functionalities. It is a graphical presentation of the system's architecture summary accompanied with textual explanation where needed and it's final version is reached after other system's elements are defined and described.
- The organizational structure defines relationships that can exist between organisation that manages CH and its sub-organizations. The organisational structure is decomposed to a degree that allows correlating specific human roles within the organization to the Platform functionalities.
- The activity model is the operational view that describes the operations usually performed by the organization aiming at achieving business goals. It describes operational activities, input and output flows between them, as well as input and output flows to/from concepts that are outside the organisation.

The BPMN 2.0 notation [http://www.bpmn.org] limited to the subset which fits the project's purpose is employed for the purposes of HERACLES. The activity model is depicted in BPMN notation implemented in Camunda Modeler [https://camunda.com/download/modeler/].

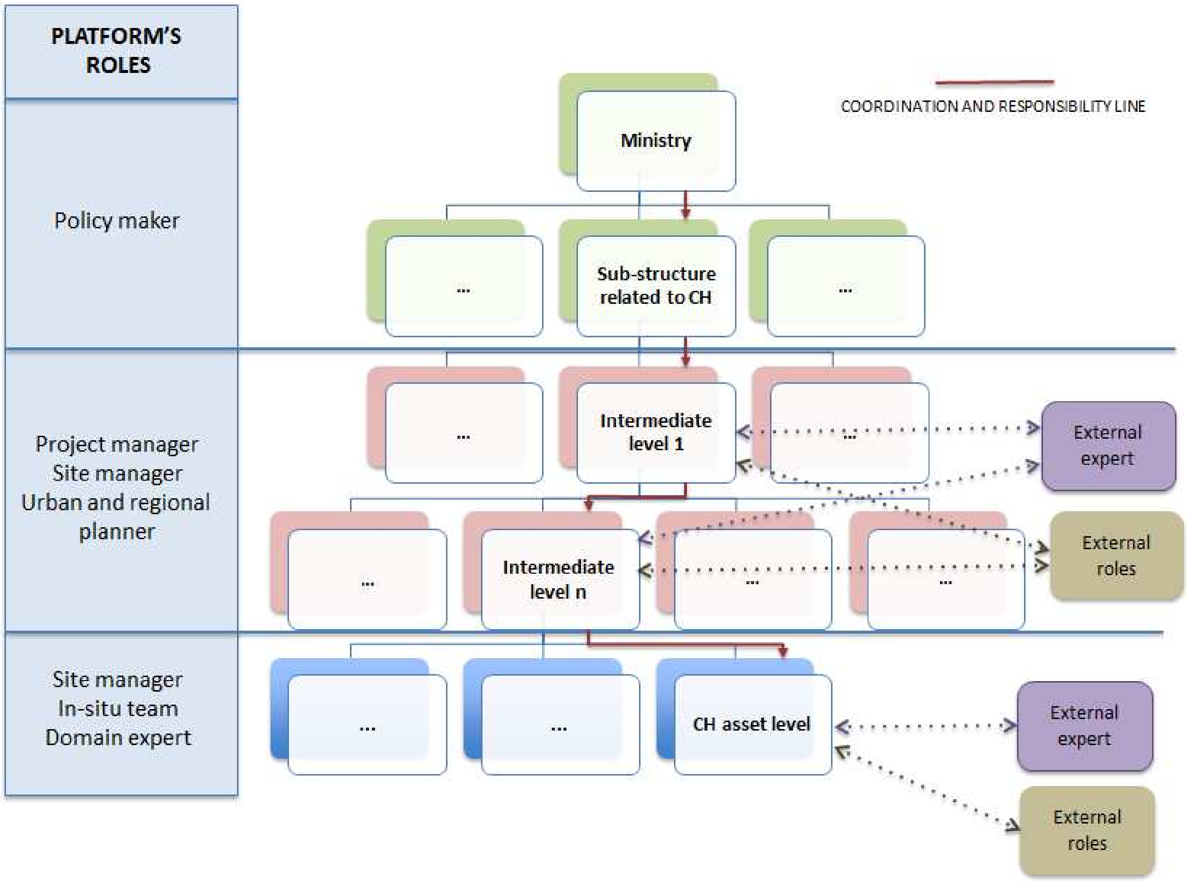
4. WORK ALREADY PERFORMED TOWARDS THE OBJECTIVES

The general overview (OV-1) of HERACLES activities, as discussed in detail in D7.1, is shown in the following figure:



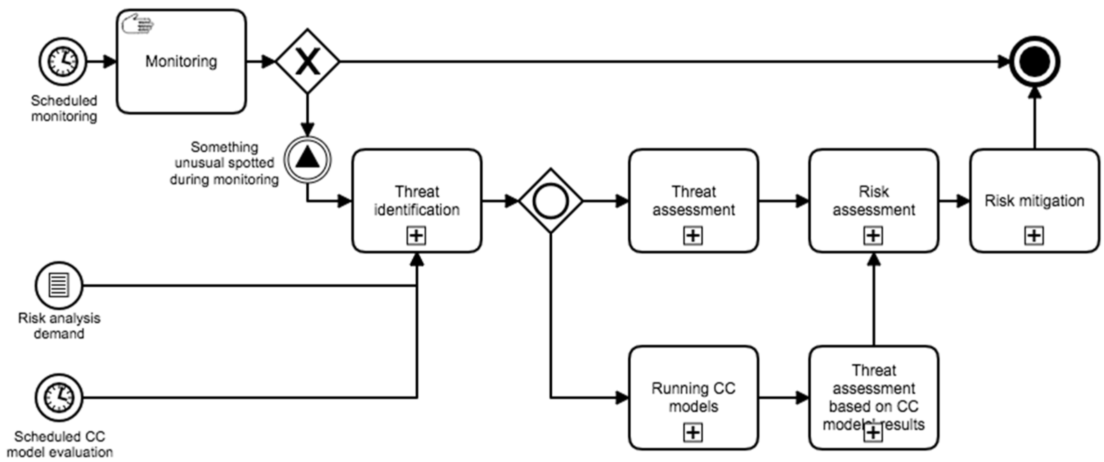
In this schematic it is attempted to present and link/associate all relationships between organisational structures, responsibilities and predefined HERACLES platform's roles and functionalities, as defined in WP5, with reference to the two HERACLES test beds. The central element of this OV is an integrated Dashboard (ID), a special purpose user interface used by the users to interact with the Platform. The dashboard is further functionally divided into Situational Awareness (SA) and Decision Support (DS) blocks. Each block undertakes certain functionalities of the system as described in the Deliverable 5.8.

A crucial point towards this end was also to define in detail all actors that are important for the responsible organisation of the HERACLES platform and thus a generic organisational structure showing informational channels and responsibility's paths from the CH owners to the ministries was presented, also shown in the following figure.



Furthermore, the activity model refers to risk assessment scenarios describing the most possible situations how end-users will perform risk management and interact with the Platform. The activity model may be modified as the Platform's development continues and synchronization with end-users' good practices evolves.

"Risk management" is the main, starting workflow and is depicted in the following **Erreur ! Source du renvoi introuvable.**. The Risk management workflow starts with three events, which correspond to two risk management scenarios. The first scenario starts with the requirement to run CC models, while the second scenario has two variants: first when the threat is identified during the monitoring and the second when the threat identification and assessment are performed on-demand. The other activities are also elaborated in detail using BPMN 2.0 notation and implemented in Camunda Modeler.



WP8: DEMONSTRATE AND PROVE IN AN OPERATIONAL ENVIRONMENT THE SERVICE FUNCTIONALITY AND VALIDATE THE PROPOSED SERVICE BY THE END-USER.

1. EXECUTIVE SUMMARY

The objective of the WP8 is to demonstrate the effectiveness of the HERACLES approach at four test beds; two in Heraklion and two in Gubbio. As a result of the demonstration activities it is expected that specific knowledge will be gained based on Critical Results Analysis. Future upgrades will be defined in order to improve the HERACLES solution and establish best practices and recommendations.

The activities have been carried out bringing together end-users and techno-providers to assess the overall functionality of the HERACLES platform with respect to project goals. In the next period, HERACLES will identify Best Practices based upon operational procedures elaborated during the project course. HERACLES will also summarize recommendations from the analysis of the demonstrations, as to how best practices might evolve as the HERACLES Platform is improved. Recommendations for platform improvements, based upon operational considerations, are considered

2. INTRODUCTION

Four sites are identified as the field of experimentation for the HERACLES platform. The four sites are the followings:

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

Koules Fortress: The "Castello a Mare" (or "Koùles") is a fortress located at the entrance of the old port of Heraklion, Crete. The fortified enclosure of the Venetian Candia (today Heraklion) of the 15th century, which is still preserved today, is one of the most significant monuments of its kind in the whole Mediterranean basin. Another important monument of the period is the imposing fortress of "Koules" which is dominating at the edge of the Venetian NW breakwater of the old harbour. It was built by the Venetians before the construction of the new Venetian fortification, in order to protect the pier and the port. It took its last shape in the years 1523-1540, replacing another construction destroyed by an earthquake. The violent waves of the sea have been constantly causing damages to its stonework and foundation, thus it has been continuously repaired.

Town Walls: in the province of Perugia rises Gubbio, one of the most ancient medieval towns of the Umbria region, Italy. 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.

Consoli Palace: Palazzo dei Consoli is a medieval building in Gubbio. The Consoli Palace was built between 1332 and 1349. The main façade is made of ashlar stone and stands for over 44 meters up to the top of the bell tower. Since 1901, the building hosts the town museum. 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.

The four sites exhibit enough similarities but also differences to allow defining procedures, processes and techniques that could be widely deployed without needing heavy revision.

The techniques, equipment and procedures are summarized in the following section

3. TECHNICAL EQUIPMENT AND PROCEDURES USED

The HERACLES platform uses a large set of sensors to analyze the sites environmental conditions that the sites are facing. The sensors and data sources are described here after along with their utility for site analysis.

Geometric monitoring

Spaceborne radar COSMO-SKYMED: Allows IFSAR analysis aimed to detect the relative displacements of the relative scattered points. This methodology is carried on starting from HR SAR data from COSMO SKY-MED constellation. The IFSAR analysis helps to monitor instability phenomena affecting the interested structures and their surrounds and gives back subsidence maps, whose information, combined with the susceptibility maps coming from the geomorphological analysis, give an exhaustive overview of the criticism related to the stability of the asset and of its surrounding elements. This methodology allows detecting terrain displacements with millimeter/centimeter accuracy. The IFSAR analysis uses the remote sensing SAR data. The fundamental principle is that the phase difference between two SAR images acquired at different times and with slightly different view angles is related to the topography of the observed scene as well as to its terrain/structure displacements.

UAV-Drone geometrical survey: UAV surveys are used on Knossos Palace in order to realize a quick and complete optical survey of the whole archaeological settlement. The results of the survey used together with the laser scanner survey results produce a detailed 3D representation of the archaeological area at the scale of the single building. The two surveys (UAV and terrestrial laser scanner) are integrated by optical remote sensing information, thanks to the exploitation of archives of digital aerial ortophotos and, if necessary, by VHR optical satellite images.

The drone, equipped with an optical high precision camera, is manned in order to obtain both a nadiral and oblique survey with a final resolution close to the cm.

Terrestrial Laser: Terrestrial Laser Scanning (TLS) is an imaging technique that performs distance measure at nearly equidistant sampling steps along vertical and horizontal directions. The laser scanner acquisition produces cloud of 3D points, whose density is of 10.000 points per sqm. The clouds of 3D points are completed by radiometric information RGB. The surveys are applied to the buildings of the archaeological area. Together with the TLS survey, the UAV nadir-oblique photogrammetric survey of the whole area is used to generate an integrated survey obtained by the combination of aerial and TLS surveys.

Climatic data monitoring

Weather monitoring - local station NETWORK: Weather monitoring is achieved thanks to a 3m mast meteorological station measuring Wind Speed and Direction, Temperature, Humidity, Rainfall, Solar Radiation and UV Index. The monitored parameters are SO_2, NO_2, CO, O_3, PM_{10}, $PM_{2.5}$.

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

Oceanographic sensors: The RBRduet T.D. wave gauges allow measuring water level and sea temperature. They are deployed in the sea bottom in front of the test-bed of Koules. Their small compact size allows to be installed in a base near the sea bottom. The RBRduet has two channels submersible temperature and depth logger that allow long term deployments. The wave gauges provide raw data (time series of sea level and temperature). All data are accessible via the HERACLES web page after acquisition and processing. All parameters are recorded at 2Hz intervals. The RBRduet is calibrated to an accuracy of ±0.002°C (ITS-90 and NIST traceable standards) and accuracy of 0.05% full scale for pressure (between -5°C and 35°C).

Drone measurement of climatic parameters: This equipment is a portable environmental payload device for the monitoring of local microclimate parameters (i.e. dry bulb temperature [°C], relative humidity [%], surface temperature [°C], air quality in terms of CO2, CO, and VOC [ppm], wind speed [m/s] and direction [°], global radiation [W/m2], and lighting [lux]) in time and space. It is carried out by means of a dedicated newly developed geo-referenced payload consisting of miniaturized environmental sensors. The system is also equipped with visible and infrared cameras to detect superficial temperature [°C] of the surrounding environment.

Temperature - Relative Humidity (RH) sensor data logging system (portable): The punctual monitoring of the main environmental parameters, i.e. air temperature [°C] and relative humidity [%], is carried out by means of a TGP-4500 device. Such device is able to monitor temperatures within -25 and +85°C and all the spectra of relative humidity (i.e. 0-100%). The data collected by this system, coupled with the data acquired by the weather station installed on site, are used to validate the numerical microclimate model of the area. Parameters monitored by TGP-4500 sensor are: (i) air temperature and (ii) relative humidity. The operative ranges of the devices are -25 ÷ +85°C and 0 ÷ 100% for temperature and relative humidity respectively.

Temperature - Relative Humidity (RH) sensor data logging system (fixed): The Temperature and Relative Humidity loggers are compact sized sensors, integrating a battery and a built-in memory. In such a way, they can autonomously operate and periodically store data. The loggers allow users to download data acquired and schedule the measurements. Relative humidity measurement specification: 0 to 100% ± 2% RH.

Material analysis

Infrared Thermography: The infrared thermography uses a thermographic camera. The aim of this monitoring is to detect specific inner structural diseases and non-homogeneities.

Multispectral remote sensors: Multispectral remote sensing is defined as the collection of reflected, emitted, or backscattered energy from an object or area of interest in multiple bands of the electromagnetic spectrum. By means of the combination of spatial and temporal resolution features, multispectral sensors provides 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 meteo parameters are: precipitation, air temperature, relative humidity and land surface temperature; the air quality parameters are: Aerosol Optical Thickness (AOT), SO2 and NO2 concentrations.

Portable Raman spectroscopy system: The Raman process represents inelastic scattering of light by matter. Light in the visible, near-IR or near-UV, typically from a laser source, interacts with molecules by depositing part of its energy to chemical bonds that vibrate at characteristic resonance frequencies. Raman spectroscopy provides an accurate look into chemical bonding, thereby enabling identification of various types of materials, both inorganic and organic. Spectral analysis of the inelastically scattered light yields the Raman spectrum, which is a plot of the intensity of scattered light as a function of the frequency difference between the incident and scattered radiation. The frequency difference Δ√, is called the Raman shift, expressed in wavenumbers (cm-1). The spectral bands in the spectrum correspond to characteristic bond vibration in the molecule.

Portable LIBS: Laser-induced breakdown spectroscopy provides information about the elemental composition of materials. Briefly, focusing a pulse from a nanosecond laser onto the surface of an object, under analysis, a transient micro-plasma is generated, which emits light upon relaxation. Recording the plasma emission on a spectrometer produces the LIBS spectrum, which features sharp atomic emission peaks leading to the identification of the elements contained in the sample. The peak intensity or the integrated intensity of the atomic emission peaks is related to the number density of each emitting species in the plume and this, in turn, with the concentration of specific elements in the ablated material.

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

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

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

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

The post-processing of data provides information related to:

- In SI, spectral fringes are captured using an imaging sensor, with each frame corresponding to a complete measurement of the surface profile along a line. Since no moving parts are present, it is possible to carry out high repetition rate measurements (>100 Hz) with sub-wavelength precision (<λ /70). There is a maximum height difference that can be measured (typically ~ 200 λ).
- In WLSI, a series of interferograms of varying path delay are captured using an imaging sensor. The 2D surface topology is retrieved by analysing, pixel by pixel, the intensity variation of these images. The WLSI technique is optimal for in depth, sub-wavelength precision (<λ/50) measurements of the surface topology without practical limits on the surface height.

Drilling Resistance Measurements System (DRMS) (in-situ): The application of the drilling resistance measuring focusses on two distinct targets:

- The evaluation of the stone current state preservation of the building and architectural elements of the Knossos Palace.
- The sampling of the drilling residue (dust) from distinct interval depths for further physicochemical analyses of selected stones, highly affected by salt efflorescence, in Knossos Palace.

The materials are tested and evaluated in-situ. By drilling the materials with special diamond type drilling bits, the system can measure continuously: the penetration force, the actual drill position, the rotational speed and the penetration rate.

Stone, mortar, weathering crusts and concrete samples analysis: The analysis for the Knossos materials refers to the monitoring and analysis of the original materials as well as those ones used for reconstruction but also crusts and accumulations due to pollution and climate change. Particular attention is given to:

- The unique feature of selenite, which is particularly sensitive to a number of factors, humidity being the most important.
- The mortars, ancient as well as historical ones (from the Evans reconstruction works and more recent ones), with the aim to evaluate their performance against weathering and other effects of climate change
- Efflorescence salts in sheltered areas due to incompatibility of adjacent materials that have been applied in different periods and conditions
- Concrete (used by Evans and more recent ones)

The aim is to monitor degradation phenomena progresses, trying to prevent them. Special attention is paid to the correlation of increasing pollution and extreme weather conditions.

Modelling systems implemented on the test beds

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 is gathered. This allows 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 is based on the EURO-CORDEX modelling initiative.

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

4. WORK ALREADY PERFORMED TOWARDS THE OBJECTIVES

A large set of actions have been achieved on both sites to deploy, start collecting data and experimenting. These actions are summarized for both sites here after as well as criticalities that have been encountered in some cases.

Heraklion

Synthetic Aperture (SAR) data has already been acquired in order to perform the Differential Interferometric SAR (DInSAR) analysis on the Palace of Knossos and Venetian Fortress “Koules”. The aim is to monitor the displacements of the assets of interest for stability analysis of the sites. The data processing is under current development. A drone survey on the two sites has been also achieved, allowing achieving a detailed 3D geomorphological modelling, requested to run the Air Pollution model.

Remote sensing data source have already identified and the data collection has started. For what regards the local measurements, the National Greek Meteorological web portal is exploited and provides data on local weather stations as well as the METAR network stations. METAR is the worldwide network of airport weather stations.

Demonstration tests by thermographic analysis on both Koules and Knossos sites have been carried out. The monitoring activity has been achieved using the portable wearable environmental station in Knossos and Koules. This allows the characterization of the case studies microclimate in Crete. The portable station (i.e. payload) consists of miniaturized environmental and microclimate sensors which may be installed over a drone and/or over a pedestrian's helmet. Those measurements were performed under hot weather conditions, by helmet and drone in the Knossos Palace and only by helmet in Koules, due to the strong wind which impaired the use of drone. Therefore, the only criticality consisted in the impossibility to fly the drone over the Koules test-bed due to a strong wind.

Meteorological stations were installed on test-beds as well as T (temperature) and RH (Relative humidity) sensors. A first in-situ campaign with the multispectral imaging system has been performed to investigate the most critical areas and surfaces to be further studied for the material component.

Sampling and studying the material issues of Knossos and Koules have been carried out. The results collected are used as control /baseline data for the evaluation of consolidants performance.

Data sets were collected from 12 different models included in the EURO-CORDEX modelling initiative which allows analysing the differences between current climatology (<2020) and the future climate (> 2050) for the modelling grids corresponding to the two HERACLES test-beds (Gubbio and Heraklion). The preparation of indicators and criteria for the meteorological parameters of interest for the evaluation of Climate Change on Cultural Heritage (dry day index, wet day index, precipitation day index, tropical day index) has been achieved.

Feasibility/integration trials among the different sensors present in the HERACLES platform have been carried on.

Gubbio
All the activities about installation of sensors, surveys (i.e. through satellites and drones, georadar, etc.), and material sampling have been planned and carried out.

First of all, all the possible relevant past interventions already done on the Town Walls have been retrieved in the Gubbio archives, thus representing the “historical data”.

At the test cases of Gubbio, the remote sensing data collection has started. The access to local environmental data is matter of negotiation with the local environmental regional agency in order to have direct access to the public database. In any case, most part of the data concerning weather and air pollution parameters are published in the regional open data web portal.

Remote sensing data sources have been identified and the data collection has started. For what regards the local measurements, the Heracles team is in contact with the regional environmental protection agency (ARPA UMBRIA) for local meteorological and air pollution data collection. The regional open data portal for meteo-climate archive data collection and for the ancillary data collection (i.e. inventory emission) is identified to be used as input of local air quality model. The data necessary to be collected for the air pollution modelling has been defined. Most of the information is being put together; still there is a concern about the emission inventories for the two test-beds: a detailed emission inventory for Umbria (including Gubbio) exists at the local/regional environmental agency (ARPA). If ARPA will not provide its emission inventory data, a more simplified approach would have to be used.

The Cosmo SkyMed DInSAR data on the Gubbio test-beds, suitable to detect subsidence and general displacements on the ground have been collected. In June and July 2017, surveys by laser scanner on Consoli Palace and on the Town Walls have been carried out, in order to build up a detailed 3D model of the two test-beds and to feed the structural models. A further action was the building (using aerial images) of a 3D rough city model on Gubbio area, with the aim to give input to the Air Pollution modelling. For the environmental assessment of the Gubbio case study, a microclimate monitoring campaign has been achieved on both the

Consoli Palace and the Town Walls by means of environmental portable payload installed on a pedestrian's helmet. The main microclimate parameters such as outdoor air temperature and relative humidity, air quality, solar radiation, wind speed and direction were collected with a frequency of 2 seconds in order to (i) characterized the local microclimate conditions of the area and (ii) calibrate and validate the numerical model. Moreover, a thermographic analysis of the Consoli Palace and the ancient Town Walls was performed in order to detect any surface materials criticality due to extreme microclimate and weather events. No peculiar criticality was detected during such experimental campaigns.

An analysis is being undertaken in cooperation with Comune di Gubbio toward the material characterization and the evaluation of the structural, in terms of material weathering state, risks and vulnerability assessment for both Town Walls and Consoli Palace. Characterization and study of Town Walls and Consoli Palace materials are concerning the mortars, stones and weathering/pollution degradation products, and inspection and sampling campaign have been carried out (June 2017) to identify and collect the most significant material samples.
Also the terrestrial laser scanner survey (TLS) (July 2017), provides information about the status of conservation of the structures and materials of the Town Walls and the Consoli Palace. This information would be used in the evaluation of structural behavior and in the validation of the polluting agents' distribution.

A georadar and electric resistivity tomography measurement campaigns at Town Walls of Gubbio have been carried out. Georadar data have been also collected at Consoli Palace to perform both foundation investigations and structural surveys. Among the investigated areas of the Consoli Palace, georadar measurements have been performed at the area known as Loggia where an out-of-plane rocking mechanism is becoming evident by a widespread crack pattern and where an extensimeter has been installed.

On the basis of the architectural, degradation and damage inspection, a structural monitoring system was installed on the Consoli Palace. It consists of static and dynamic sensors connected to a gateway on site providing input for the HERACLES platform. More in detail, two Linear Variable Displacement Transducers (LVDTs) have been installed across two major structural cracks to monitor their evolution in time; two temperature sensors (thermocouples) have been installed in the proximity of the LVDTs to characterize temperature effects on the structural response. Three high sensitivity uni-axial accelerometers have been installed on top of the building, with the purpose of continuously measuring the micro-tremors of the structure and to process such data to continuously extract the natural frequencies of the structure for diagnostic purposes. Few preliminary tests have been also performed on the Town Walls, to identify the position of inclinometers sensors, which have not yet been installed. In this context, a criticality is represented by the complicate logistics at the Town Walls, where neither electrical power protection from environmental conditions nor internet connections are available.

From mechanical testing perspective, In-situ mechanical tests on different mortars have been also carried out.