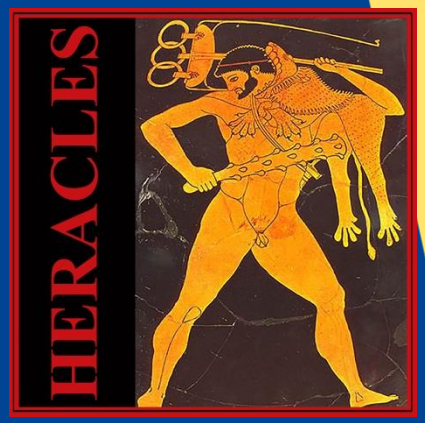
CLIMATE CHANGE IMPACTS ON CULTURAL HERITAGE:
FACING THE CHALLENGE

International Conference
June 21-22, 2019
Athens, Greece



Project coordinator:
Giuseppina Padeletti
(CNR, Italy)

HERACLES Project: Mission and Vision to face the CC challenge

GA number 700395

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

OUR HERITAGE:
WHERE THE PAST
MEETS THE FUTURE

2018 EUROPEAN YEAR OF CULTURAL HERITAGE
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The integrity of monuments, historical centers and archaeological landscapes and sites is nowadays increasingly threatened by the climate change, the related extreme meteorological phenomena and by the natural hazards.

The Cultural Heritage monuments are exceptionally vulnerable to these threats : for their cultural importance as a source of information on the past and a symbol of identity, any loss or deterioration of these outstanding assets would negatively impact on local and national communities, also for their socio-economic value (tourism and satellites activities, etc)

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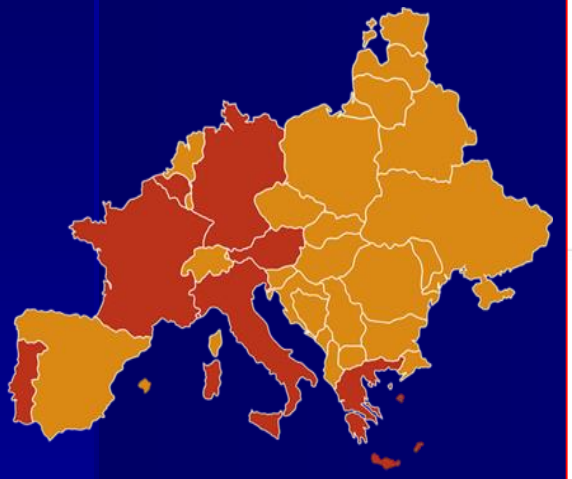
The HERACLES Consortium is made of 16 partners from 7 countries



- The Project received funding from the *European Union's Horizon 2020 research and innovation programme* under Grant Agreement No 700395
- **Funding:** *6.564.313,75 Euro;* *Starting date: May 1°, 2016*
- CNR coordination

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Countries object of the study: ITALY and GREECE

- **The majority of the worldwide cultural heritage is in these two Countries.**
- **Their ancient civilisations are considered world Heritage.**
- **On the basis of their similar risk exposure.**

THE SITES: *we focused on living areas representing the essence of the European Countries, often not greatly taken into account but constituting the* ***essence*** *of our* ***Countries,*** *our* ***Culture,*** *our* ***Identity,*** *our* ***Economy,*** ***where people live,*** *and* ***work***

Living area

Archaeological site

Greece, **Heraklion** : ***Minoan Palace of Knossos***, *centre of the first civilization of the Mediterranean basin, namely the Minoan civilization .*

*The **Sea Fortress of "Koules"** symbolises all monuments facing the risk of hazards from climatic change, such as **significant impact from the sea**, (sea level rising, increasing intensity of extreme weather phenomena that combined with the air and land associated hazards together with increased salinity are accelerating corrosion and deterioration of materials and structures, etc)*

Living town

Italy, Umbria, Gubbio *wants to represent **all the historical monumental towns in Italy and in Europe**, that were conceived and built in the past following criteria when the climate conditions were very different from nowadays and that suffers at present the effects of climate changes, that would endanger their safeguard, particularly the **hydrogeological risk (heavy rains, flood, landslides)**. Moreover on the Apennines chain: seismic area*

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Threats to heritage monuments/assets deriving from Climate Change and natural risks

- ✓ floods, storms, sea waves, extreme weather phenomena, etc
- ✓ effects linked to temperature variation, humidity/air composition
- ✓ environmental pollution
- ✓ others….

- ❖ structural instability
- ❖ material degradation
- ❖ corrosion
- ❖ *others*…

➢ **Governmental budget constraints limit mitigation strategies**

Need for effective management tools for cost-effective maintenance and restoration – defining priorities:

the HERACLES project

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Greece/Heraklion (Koules Fortress + Knossos Palace):

On the basis of the end users requirements (Ephorate of Antiquities of Heraklion) and on the investigations performed on-site, was found that one of the fundamental elements is to have available:

- **Monitoring Integrated Technologies** -

HERACLES solution: starting from a wide area observation (satellite) till the observation on-site of the single element constituent the monument, including the surrounding territory.

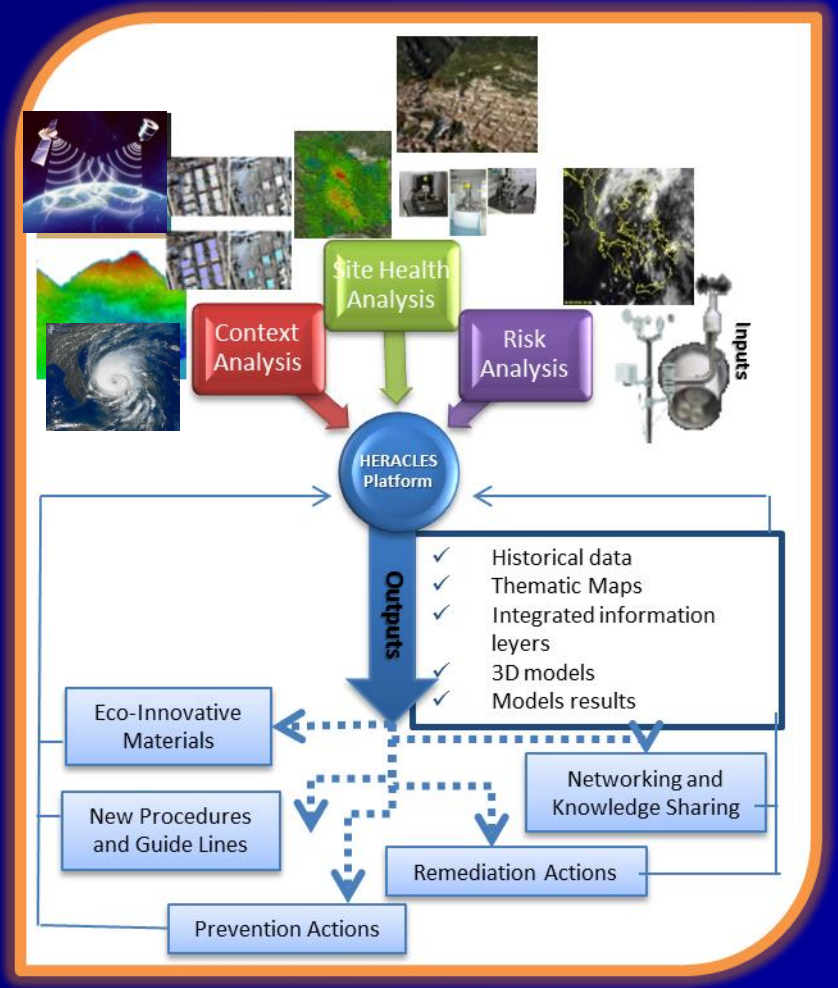
HERACLES holistic-multidisciplinary vision/approach & ICT Platform concept

HERACLES methodology

Need of NEW INSTRUMENTS to OPTIMIZE the present MANAGEMENT of CH:

HERACLES ICT PLATFORM DEVELOPMENT

HERACLES Platform :
Multirisks →
multi-source data →
Many useful info available for the end-users



Flexible, general applicability

HERACLES project concept

Wide area
(*satellite*)

Data and Info on different aspect of the built heritage

Ex-situ
(*in laboratory*)

In-situ
(*in loco*)

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THE HERACLES TARGETS

- ✓ **Context and Site Analysis / Risk Assessment**
- ✓ **Related answers** in terms of :
  - **Monitoring/preservation *actions* contributing to best practices and guidelines**
  - **New materials and eco-solutions for restoration and conservation *(binders, Gypsum consolidant, mortars)***
  - **Safeguard & valorization of cultural heritage, promoting the social and economical values of the Communities *(aspects related to RRI) - education/training/events involving civil society***

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What we are studying in Greece

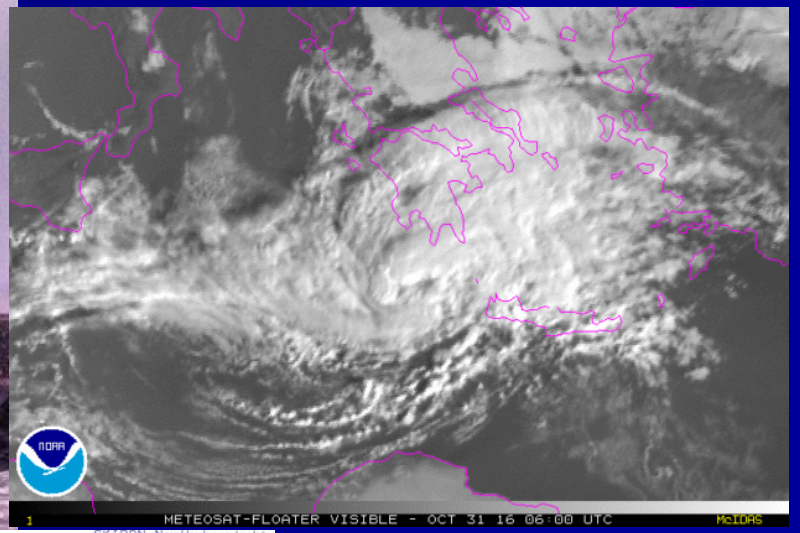
Study Cases:

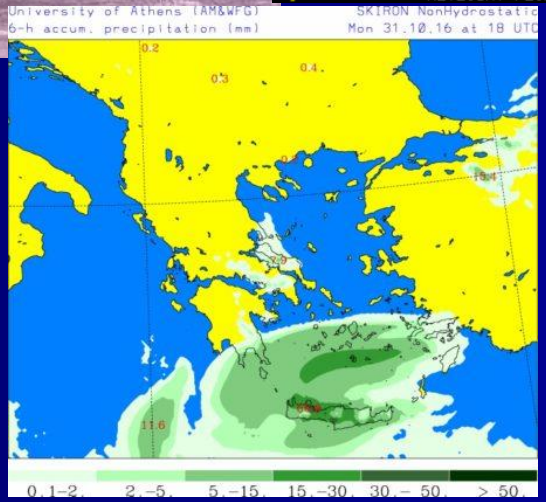
- *Koules Fortress*
- *Knossos palace*

Climate Change Effects

Koules Fortress - Heraklion

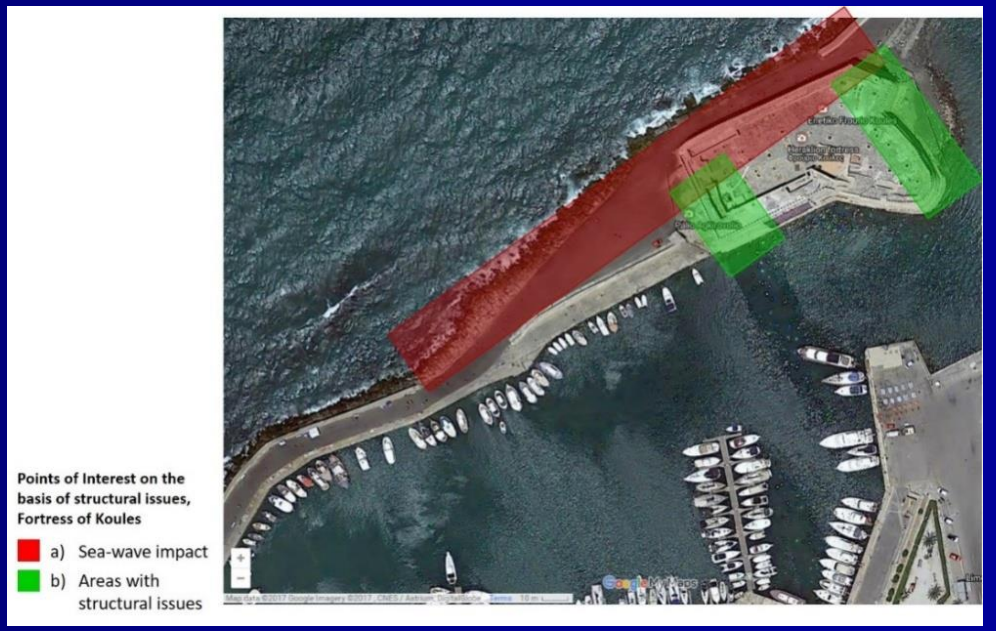
Climate Change (Storm) risk
Επιπτώσεις Κλιματικής Αλλαγής :
Crete, October 2016





Climate Change Effects

Example of structural risks due to the impact of big pieces of rock (highlighted in the yellow circle) from the breakwater structures upon intense wave events



Climate Change risk effects
Επιπτώσεις Κλιματικής Αλλαγής:
Koules fortress

Oceanographic sensors:

Wave gauges measuring water level and sea temperature, deployed under the sea in front of the Koules fortress

Figure 26: RBRduet sensor (left) and example of an installation base (right).

Crete island (GR)

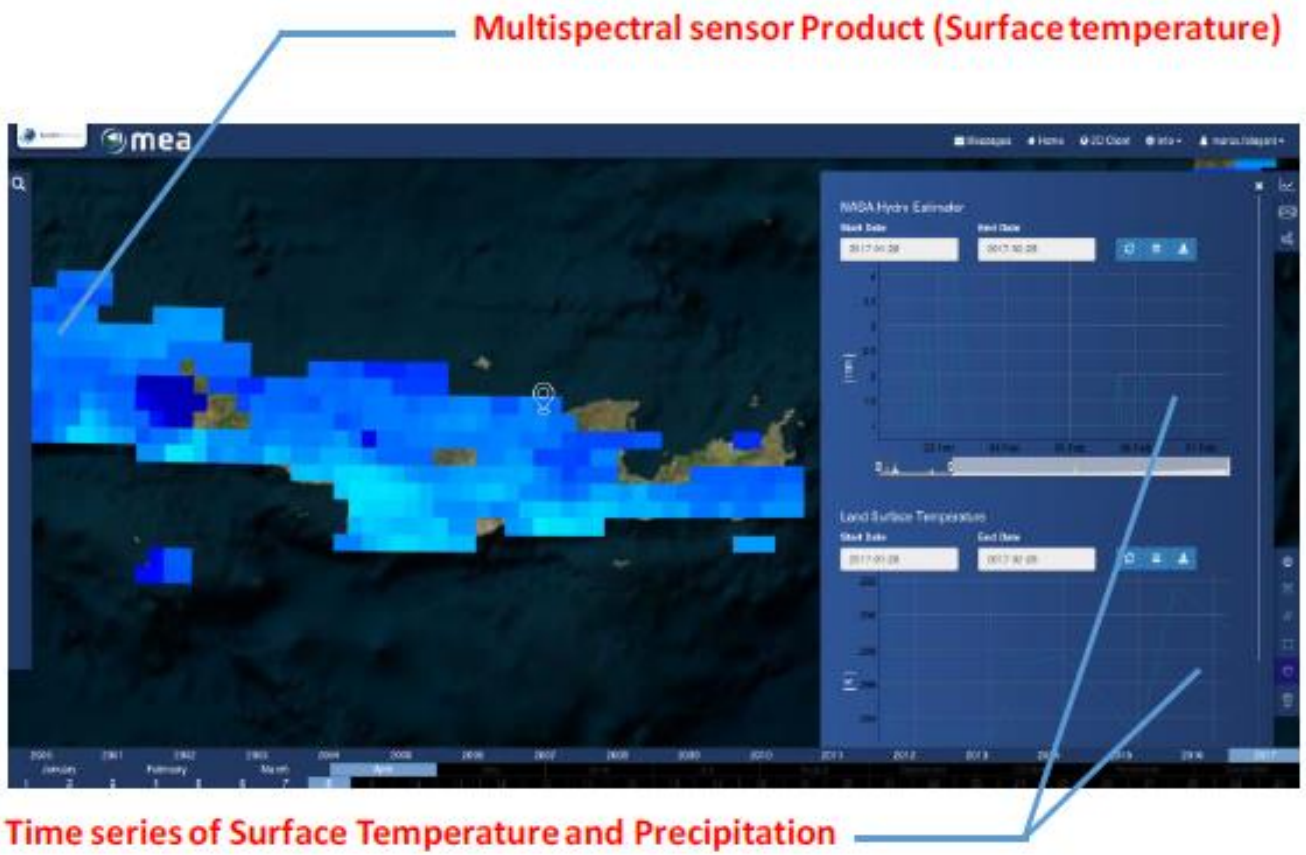


Figure 3: Meteo-Climate data platform with precipitation image product and time series of precipitation and surface temperature

ARIA , SISTEMA, egeos

Crete island (GR)

ARIA , SISTEMA

Multispectral sensor Product - Image (Air temperature)

Multispectral sensor Product – Time series (Air temperature)

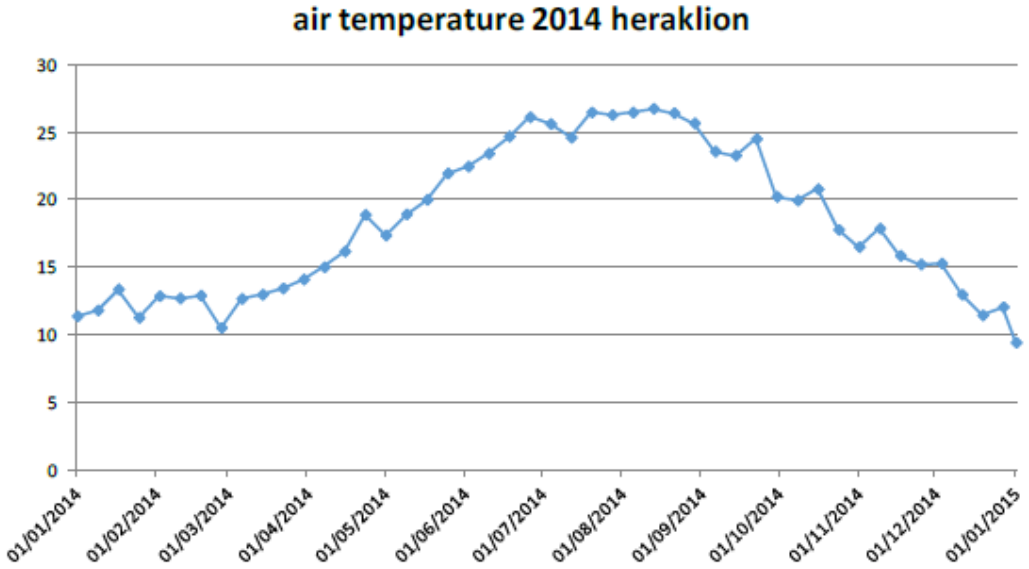
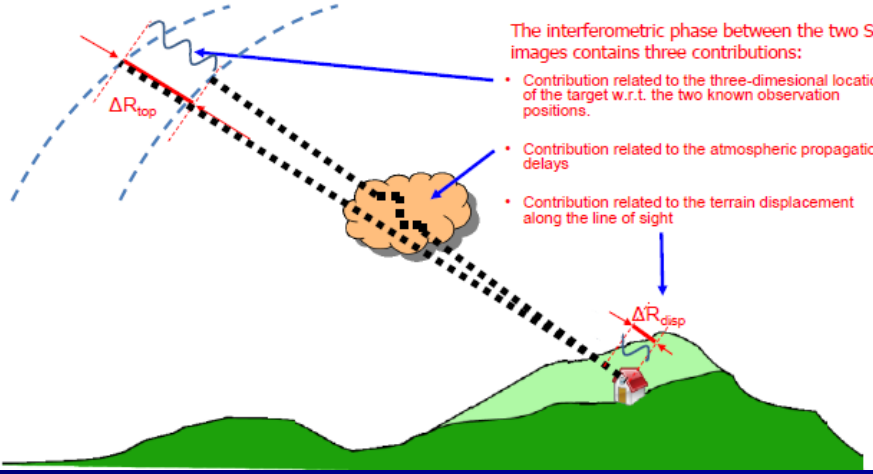


Figure 4: Downloaded image (colours are indicative of the spatial distribution of the temperature) and time series products of air temperature

Monitoring from Satellite

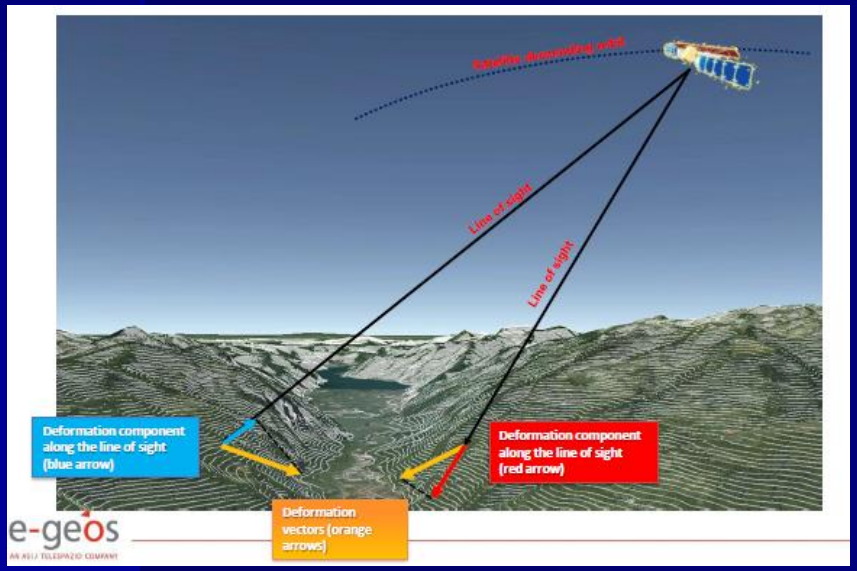
SAR interferometry basic principles

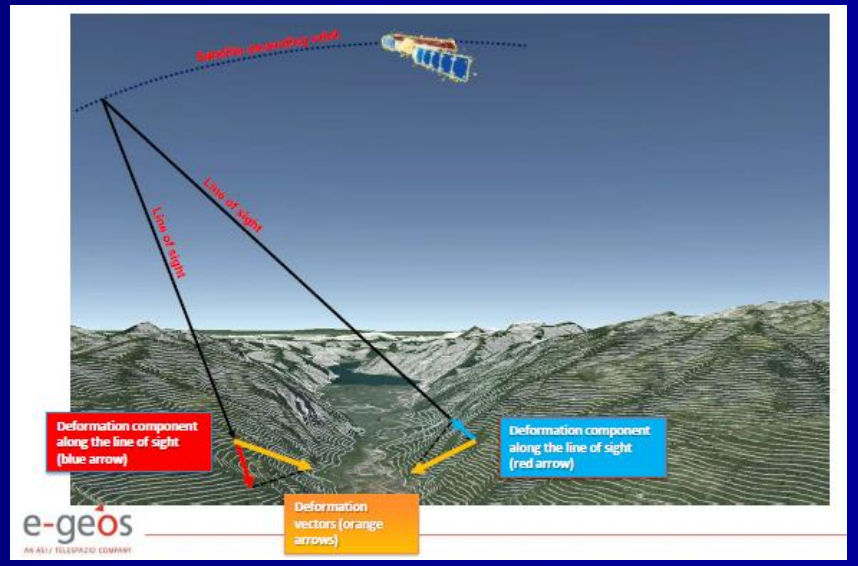
Synthetic aperture radar (SAR) interferometry is a powerful technique to determine the topography of the observed scene and possible slow surface movements due to subsidence, landslides, seismic and volcanic phenomena.



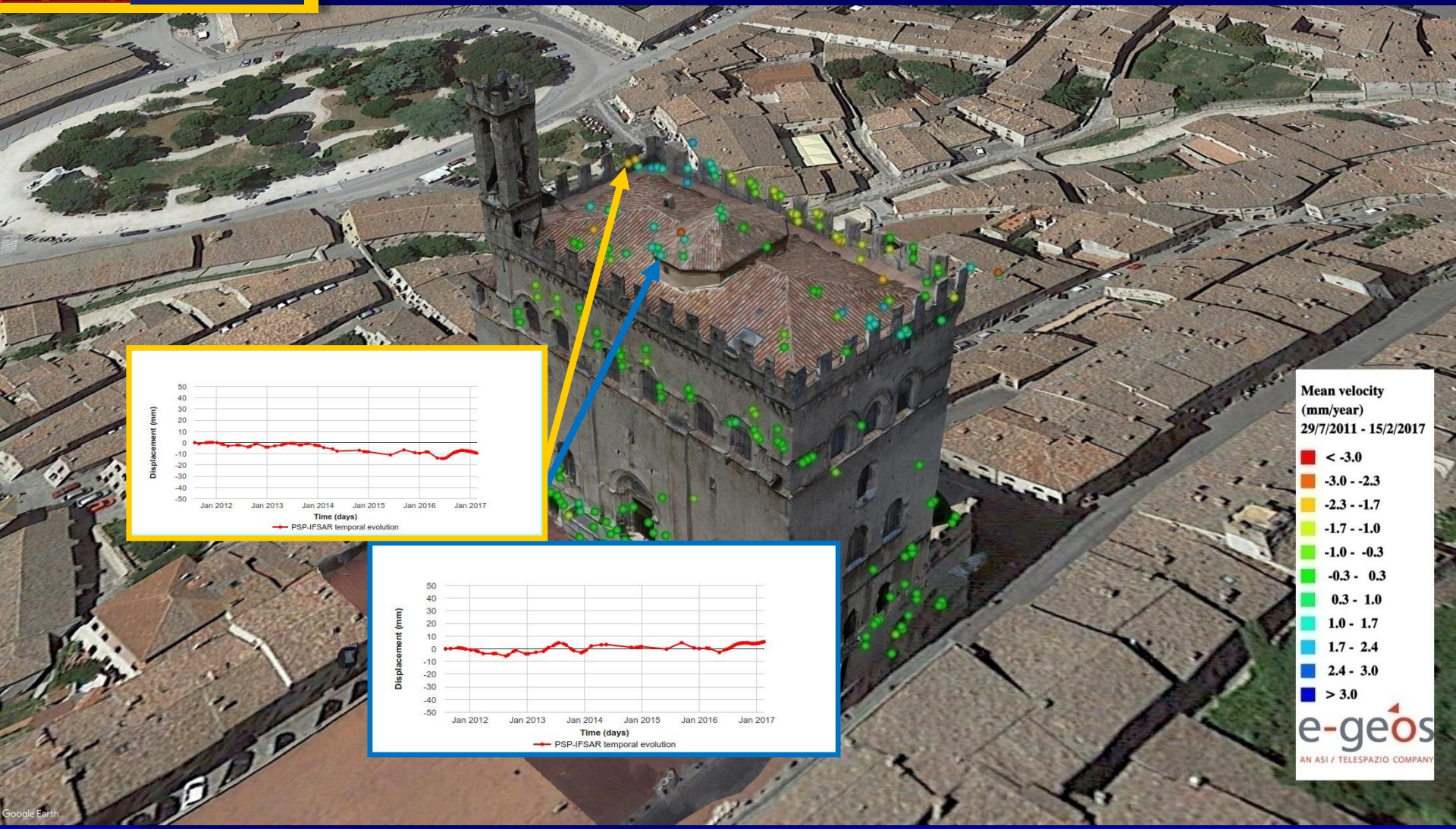
The interferometric phase between the two SAR images contains three contributions:

- Contribution related to the three-dimesional location of the target w.r.t. the two known observation positions.
- Contribution related to the atmospheric propagation delays
- Contribution related to the terrain displacement along the line of sight





Consoli Palace, Gubbio, PSP-IFSAR analysis
COSMO-SkyMed descending dataset (07/2011-02/2017)

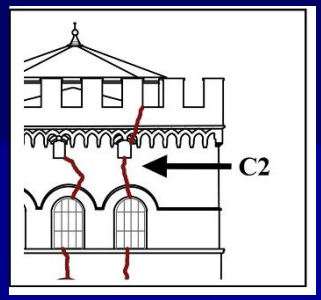


Monitoring a structure

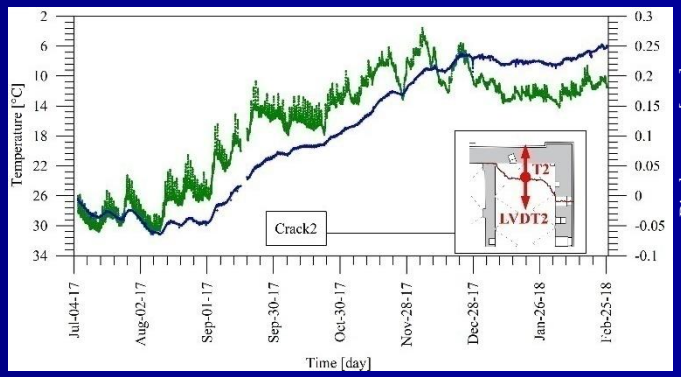
Interferometric Analysis

In-situ data and SAR analysis Comparison Crack 2

In-situ data monitoring



Opening of crack in Autumn/Winter season

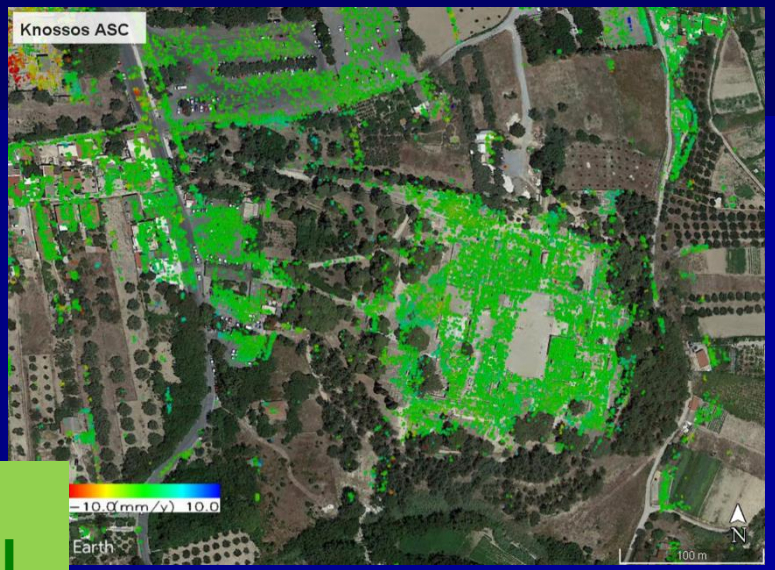


W – West side of crack

E – East side of crack

Maps of displacements in time

Knossos

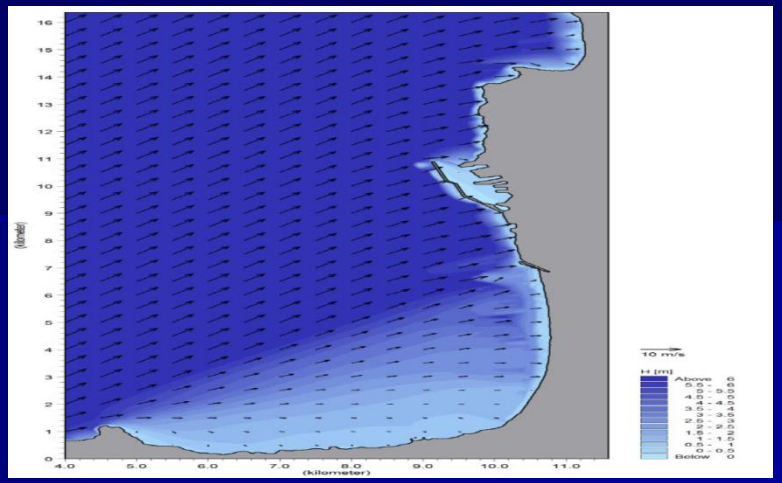


These surveys show an overall stability of the areas/structures

Koules

Koules Fortress - Heraklion

Displacement of breakwaers in the Koules area



Wave propagation of NW waves

Correlation of displacement with wave heights

e-geos, FORTH-IACM

Over Crete: +2.2°C in the near future and + 4,2° far future and decrease of annual precipitation (-12,3% till 2065 and – 28,7% till 2100). Due to changes in frequency and directions of wind and waves in the area, the displacement of the break water and salt spray,are expected to increase

Materials degradation phenomena
Φαινόμενα υποβάθμισης υλικών

Climate Change effects
Επιπτώσεις Κλιματικής Αλλαγής :
Koules fortress

Structural issues - Στατικά ζητήματα

Climate Change effects
Επιπτώσεις Κλιματικής Αλλαγής :
Knossos palace

Example pictures highlighting **insufficient bonding between stone blocks in masonry elements** (left) and **major cracks** most likely associated to settling of the foundations (right)

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Materials degradation phenomena
Φαινόμενα υποβάθμισης υλικών

Climate Change effects
Επιπτώσεις Κλιματικής Αλλαγής:
Knossos palace

Climate Change effects
Επιπτώσεις Κλιματικής Αλλαγής :
Knossos palace

85

Figure 85:Disintegration; Loss of cohesion between gypsum crystal aggregates leading to crumbling. Selenite block located near the "West Magazines", Knossos Palace.

Figure 86: Erosion; Typical formation of microkarst cavities on the surface of secondary gypsum from Knossos. Dissolution pits, grooves and runnels, collectively called karren.

developed materials
αναπτυγμένα υλικά

Σταθεροποιητικά υλικά - **Consolidants:** A consolidant material is intended to restore the mechanical integrity of deteriorated stones by binding the grain boundaries and fracture surface, both physically and chemically.

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Example pictures highlighting **rebar corrosions in reinforced concrete** elements built during the restoration by Sir Arthur Evans

Climate Change effects
Επιπτώσεις Κλιματικής Αλλαγής :
Knossos palace

Materials degradation phenomena
Φαινόμενα υποβάθμισης υλικών

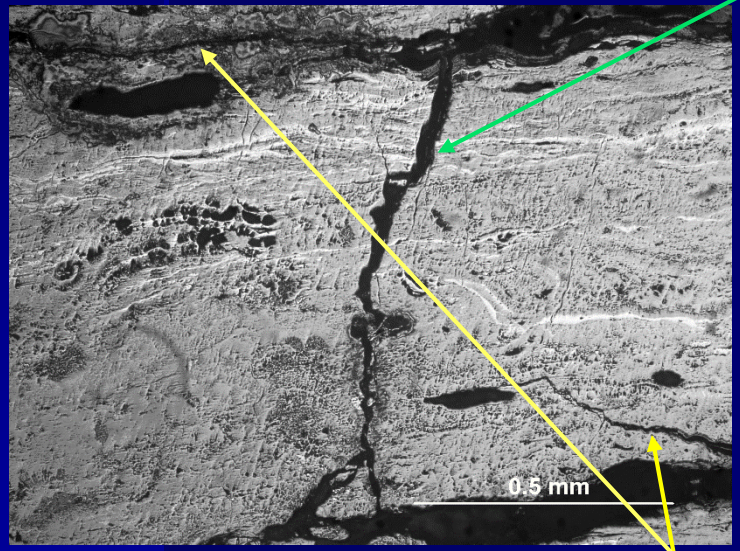
Example pictures highlighting **corrosion of iron beams supporting a floor** with masonry vaults

Climate Change effects
Επιπτώσεις Κλιματικής Αλλαγής :
Knossos palace

Knossos Palace: Iron bars delamination

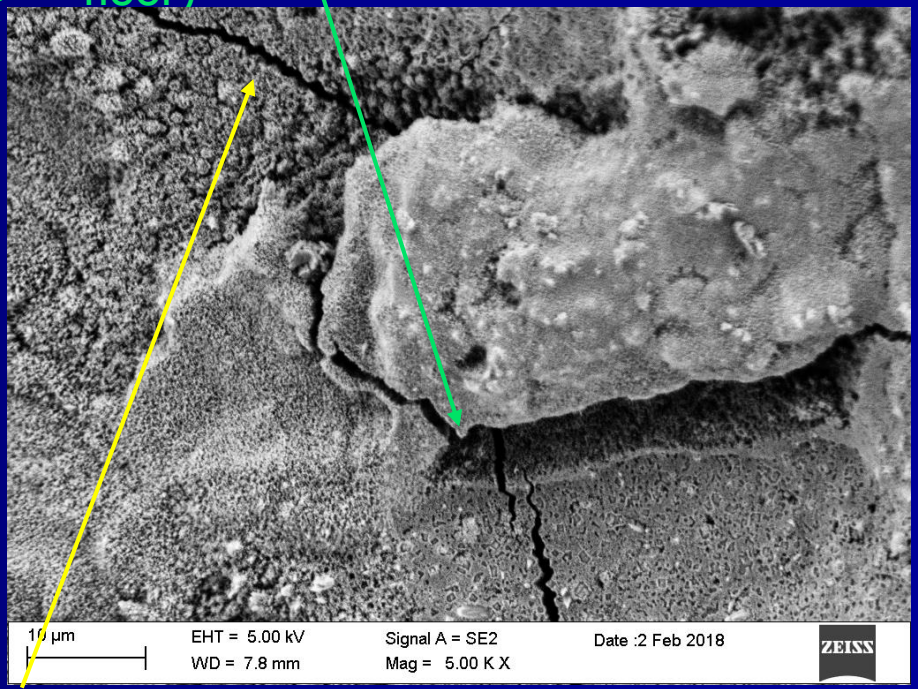
CNR, INSTM, CVR

Vertical cracks (from the upper floor)



Optical microscope

Orizontal cracks (from corrosion)

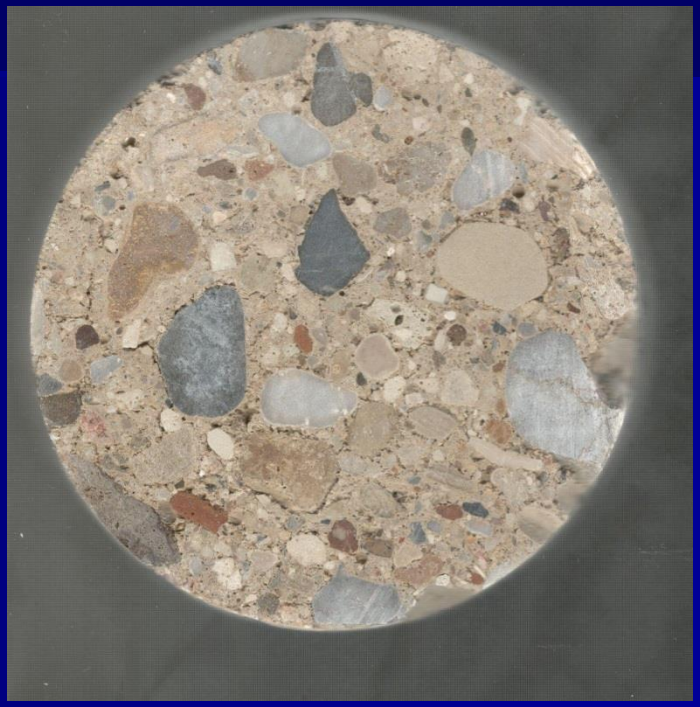


Electron Microscope

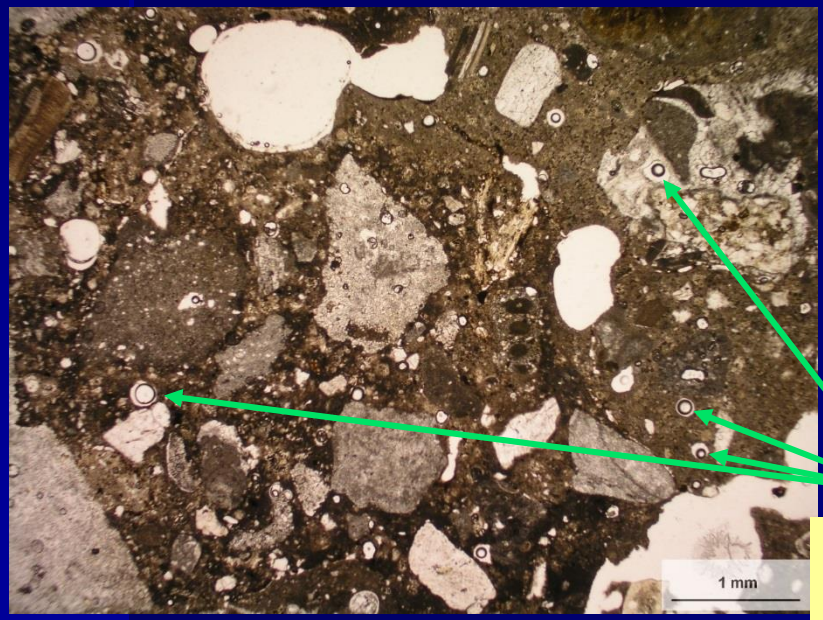
Knossos Palace: Concrete

CNR, INSTM, CVR

Concrete has been cored in different points



Thin layers (30 μm) were prepared and observed under a polarized microscope

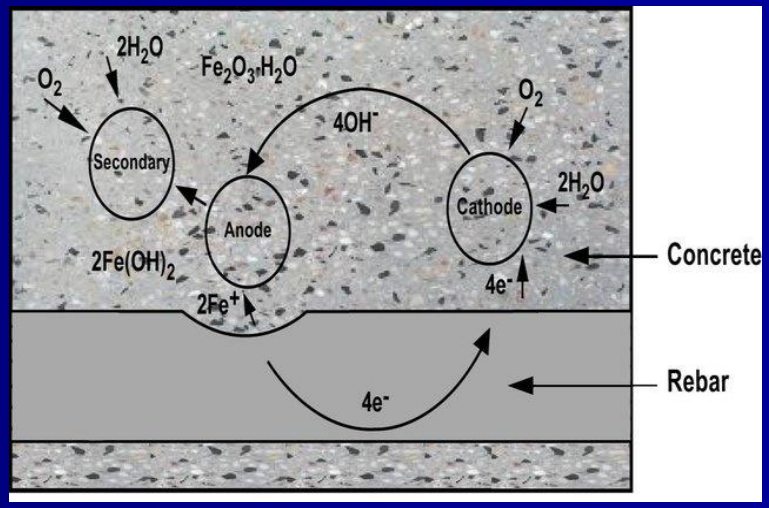


Porosity

- main components are **calcite ($CaCO_3$) and quartz (SiO_2)**
- **a low mechanical strength, both in tension and compression.**

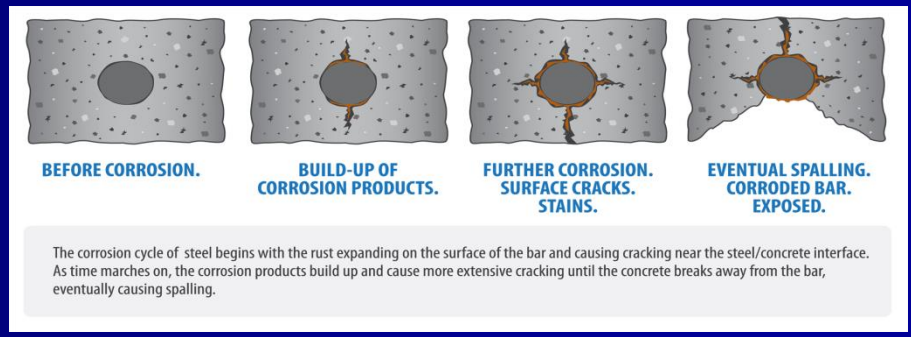
D 3

D 4



- **evaluate the thickness of the carbonated layer with phenolphtalein test.**
- for the studied cases the carbonated layer resulted **almost 5-6 cm thick**, evidencing a higher carbonation level esposing the internal bars to corrosion.

Carbonatation: 5-6 cm !!



CNR, INSTM, CVR, UniPG

Measurement campaigns

Samples of corrosion products were also taken (i.e. crusts and efflorescences) achieve a better understanding of erosion mechanisms and environmental factors (**FORTH-IESL, CNR, UNINOVA**).

Measurement campaigns

At the same time measurements were carried out using portable instruments: Multispectral Imaging system, LIBS, Raman (**FORTH-IESL**)

Measurement campaigns

Special attention is given to mineral gypsum (selenite): Research is focused on the design and development of an innovative consolidant, which will guarantee highest durability, reversibility and compatibility for gypsum (**UoC**).

New proposed Solutions – Cement Mortar

Figure 23 – HERACLES developed technical mortar for concrete

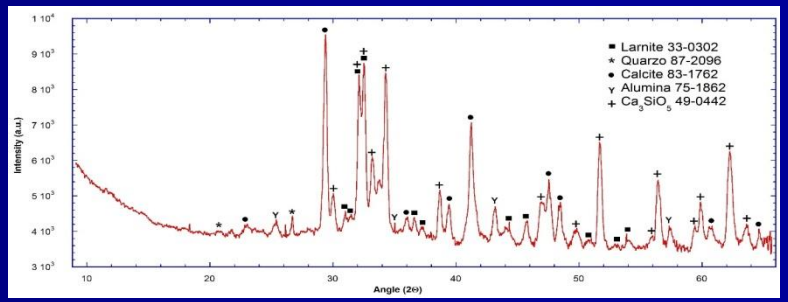
selfcuring TECHNOLOGY CVR

- ✓ *Cement mortar, reo-plastic, polymer modified, formulated with sulphate resistant cement (SRC) binders*

- ✓ *Cement mortar with high compressive strenght, adequate elastic modulus*

- ✓ *Cement mortar with reduced CO_2 permeability*

- ✓ *Expressly developed to restore old structures in reinforced concrete, also showing an advanced deterioration degree*



Bulk density of set dried mortar 1850 kg/m ^{3}
Average flexural strength at 28 days ≥ 8 N/mm^2
Average compressive strength at 28 days ≥ 40 N/mm^2

Shear adhesion strength on concrete f_h ≥ 1.5 N/mm^2
Shear adhesion strength on concrete f_h after freeze cycles - thaw ≥ 1.5 N/mm ^{2}
Compressive modulus of elasticity E ≥ 25000 N/mm^2
Soluble chloride content ≤ 0.01%

CNR, INSTM, CVR

New proposed Solutions – Cement Mortar

Trials

Climate Change effects
Knossos palace

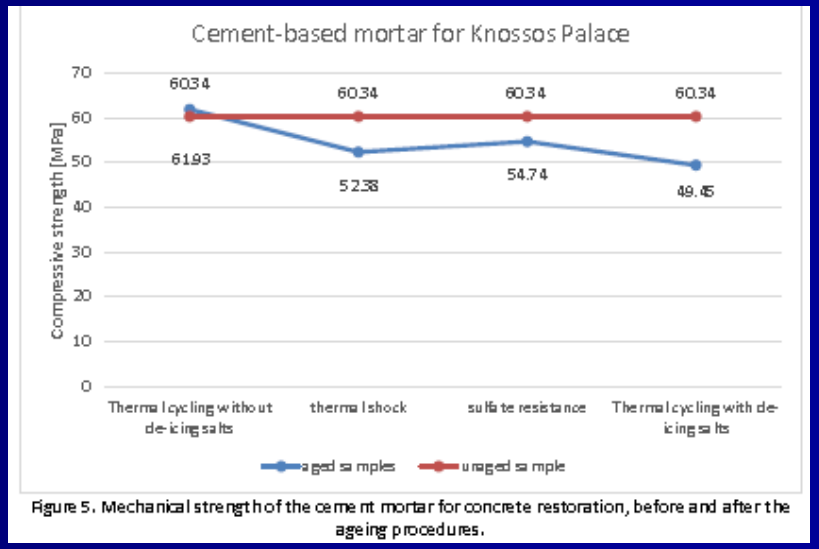


Figure 5. Mechanical strength of the cement mortar for concrete restoration, before and after the ageing procedures.

CNR, INSTM, CVR

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New proposed Solutions – Ancient masonry Mortars

Roman Cementum – pozzolanic material + hydrated lime

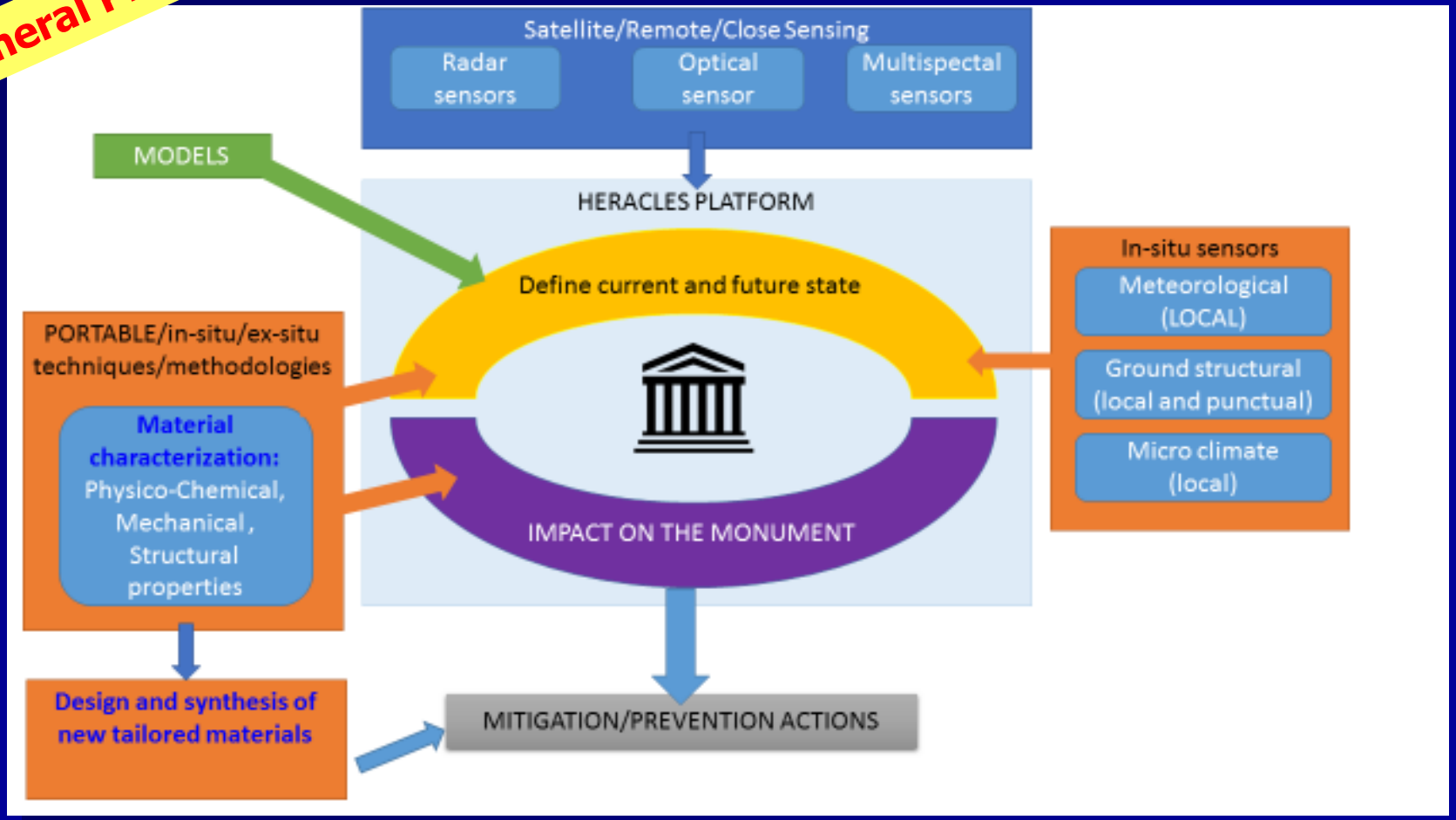
Different develope types– different performances

MORTAR A	Mortar for bedding	Calce idrata CL90 Calce idraulica NHL 3.5 bianca Ossido di calcio Nanosilice colloidale amorfa bianca Allumina Bagnanti	0 – 4.0 mm		
MORTAR B	Mortar for the protection and coverage of the top of the walls	Calce idraulica NHL 3.5 bianca Nanosilice colloidale amorfa bianca Allumina Polimero acrilico in polvere Idrorepellente silanico Fibre di cellulosa	0 – 6.0 mm		
MORTAR C	Mortar for grouting of the joints of walls (coarse grained)	Calce idrata CL90 Calce idraulica NHL 3.5 bianca Nanosilice colloidale amorfa bianca Allumina Idrorepellente silanico Amido addensante	0 – 4.0 mm		
MORTAR D	Mortar for masonry consolidation injections	Calce idraulica NHL 3.5 nocciola Nanosilice colloidale amorfa grigia Ossido di calcio Superfluidificanti	0 – 0.5 mm		
MORTAR E	Mortar for grouting of the joints in buildings (fine grained)	Calce idrata CL90 Calce idraulica NHL 3.5 bianca Nanosilice colloidale amorfa bianca Allumina Idrorepellente silanico Amido addensante	0 - 2.0 mm		

CNR, INSTM, CVR

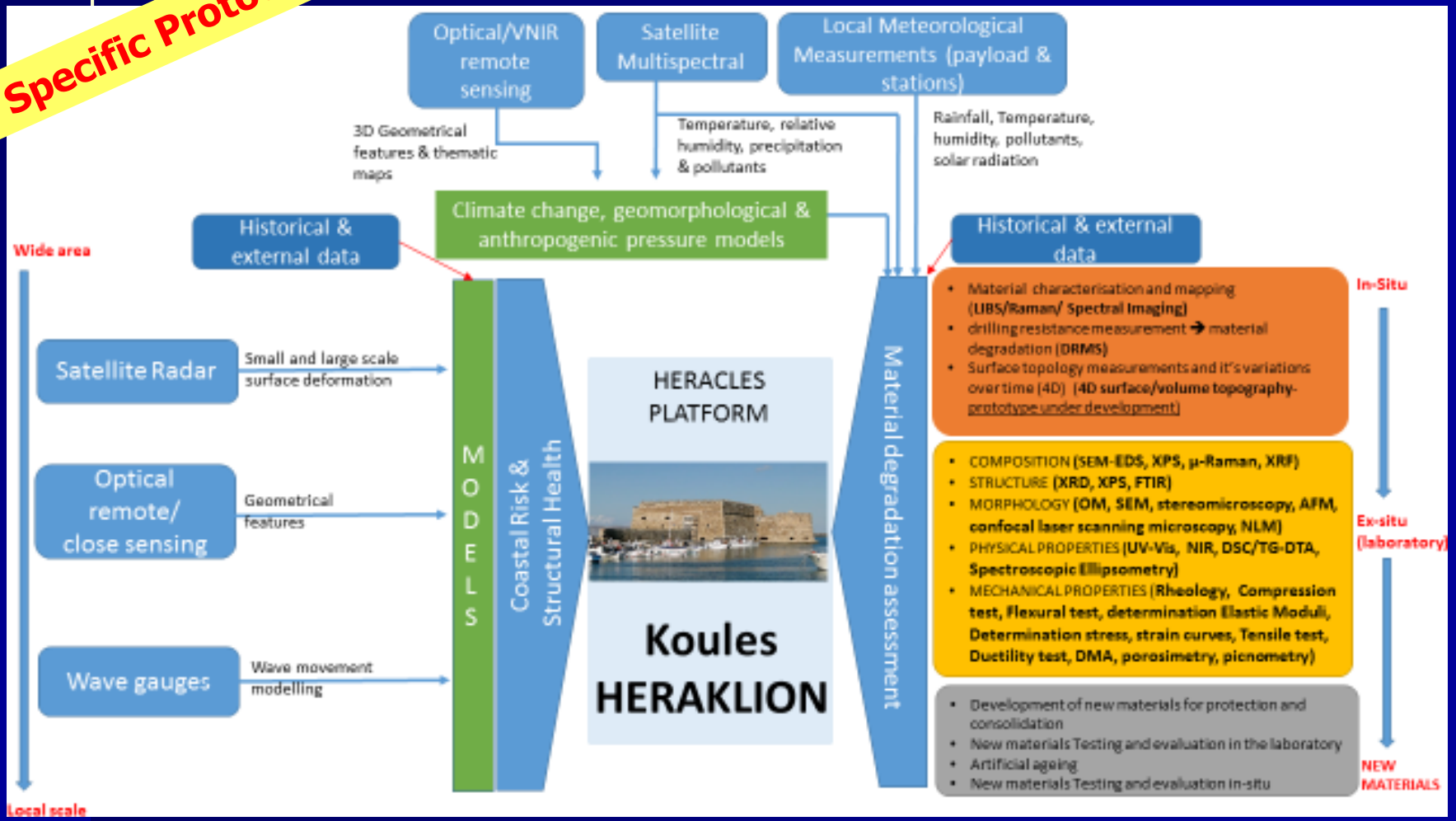
General Protocol

Schematic representation of the HERACLES general protocols approach as regards the sensing, diagnostic and analytical strategies.



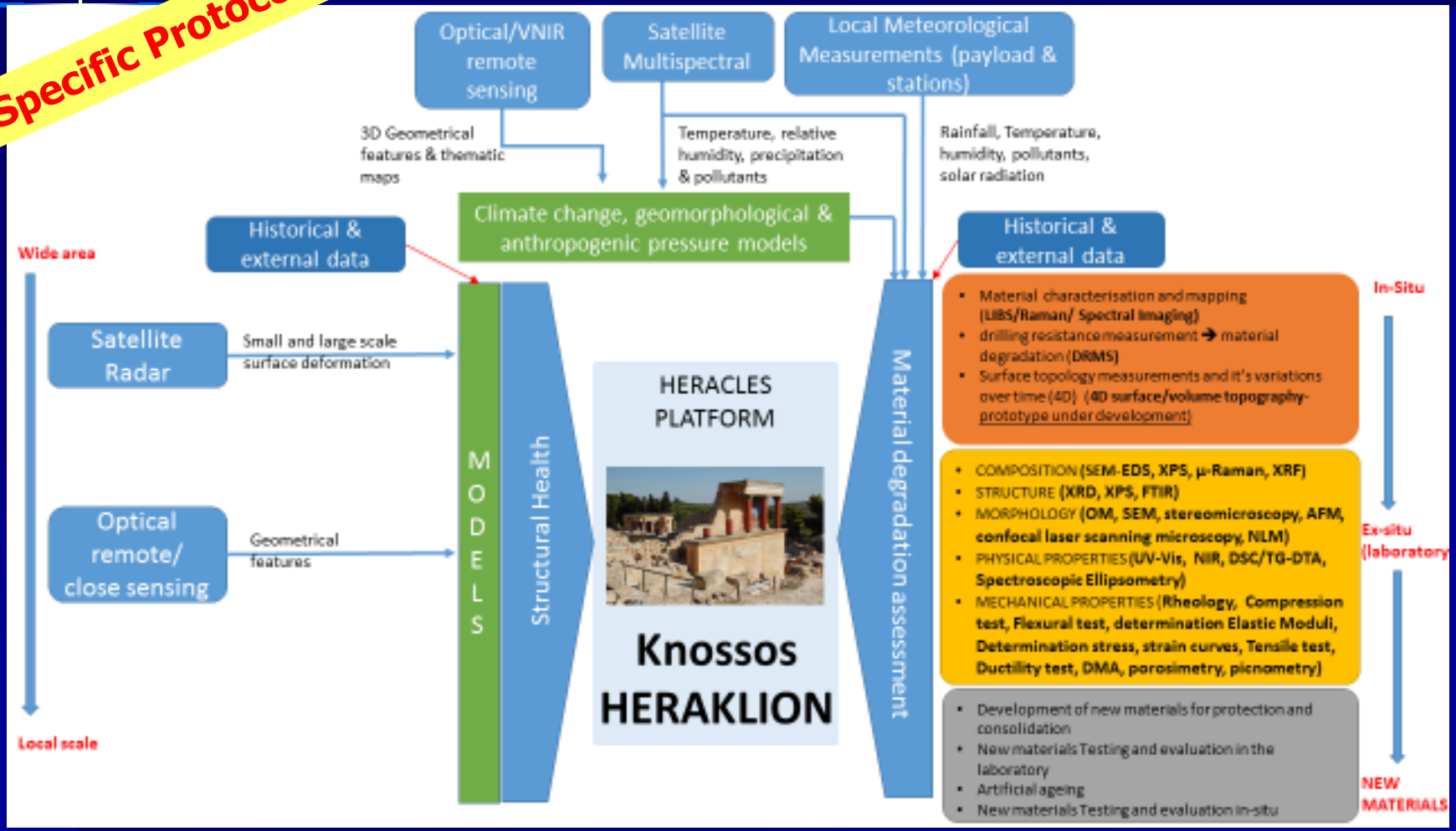
Systematic protocol
Koules Fortress

Specific Protocol



Systematic protocol
Knossos Palace

Specific Protocol



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FACING THE CHALLENGE

International Conference
June 21-22, 2019
Athens, Greece

Only in the HERACLES test beds, Italy and Greece, there are 69 UNESCO world heritage sites (tangibles) and in all Europe much more….!!!

….. a vulnerable European heritage at risk to preserve !

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Ευχαριστώ

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