NATIONAL TECHNICAL UNIVERSITY OF ATHENS, School of Chemical Engineering,
Dept. of Material Science & Engineering

THE ALEXANDRIA HANDS-ON WORKSHOP: CONNECTING THE NTUA HOLY AEDICULE EXPERIENCE WITH THE HRIAC EXCAVATIONS AT THE SHALLALAT GARDENS

Alexandria, 2 June 2022

HELLENIC RESEARCH INSTITUTE OF THE ALEXANDRIAN CIVILIZATION

PATRIARCHATE OF ALEXANDRIA AND ALL AFRICA

GREEK COMMUNITY OF ALEXANDRIA

Hands-on methodology of Non-Destructive Testing for the Protection of Monuments

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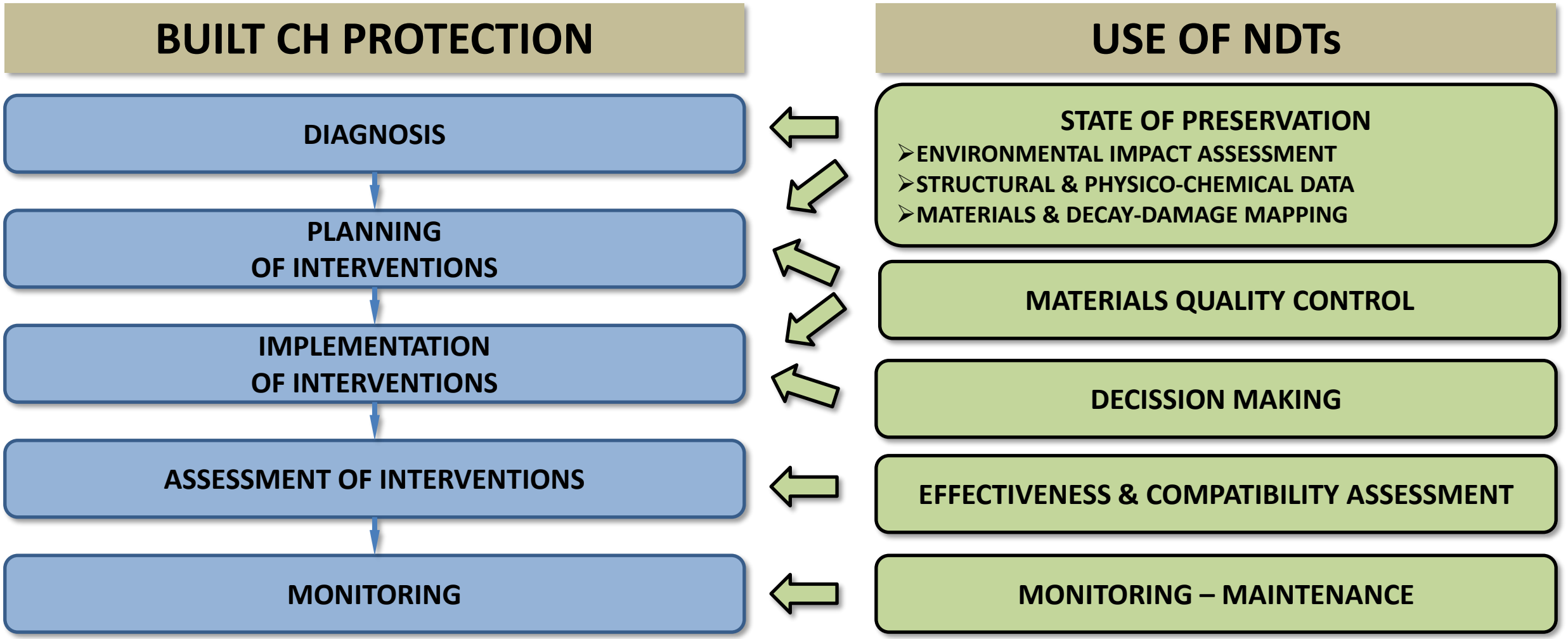
EDICULA: Educational Digital Innovative Cultural heritage related Learning Activities
Project Code: 2020-1-EL01-KA203-079108

Non-Destructive Techniques (NDT) are used in the Field of Protection of Cultural Heritage because:

- ✓ ***Destructive sampling is prohibited in the conservation of historic monuments***
- ✓ ***They offer certain unique capabilities in a variety of applications***



Validation by laboratory testing

NATIONAL TECHNICAL UNIVERSITY OF ATHENS
LABORATORY OF MATERIALS SCIENCE AND ENGINEERING

- Portable Digital Microscopy
- Digital Image Processing
- Colorimetry
- Ultrasonic Testing
- Schmidt hammer
- Endoscopy
- Infrared Thermography
- Ground Penetrating Radar

Advanced Spatial Data Management & Assessment Methods

MONUMENT SCALE

- Characterization of Materials
- Evaluation of Materials & Interventions Compatibility
- Environmental Impact Assessment

INTEGRATED PROJECTS

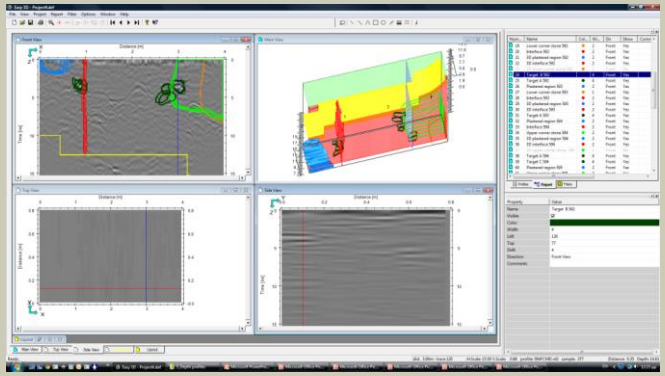
- Strategic Planning of Conservation Interventions on Historic Buildings
- Strategic Planning of Environmental Management as a Tool for a Sustainable Preservation of Historic Cities

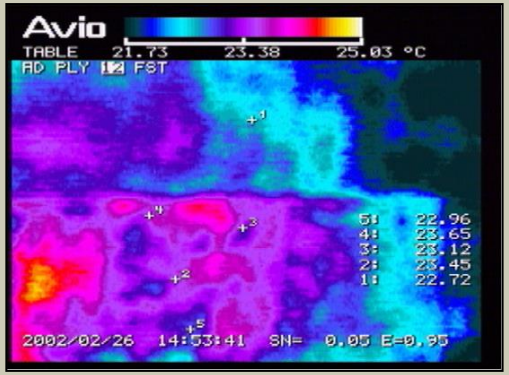
Short description of the theory of some Non-Destructive Techniques (NDT)

Digital Microscopy (DM): magnified visible spectrum images can be acquired, in situ or in lab, for the material under investigation. No treatment of the material is required.

Infra Red Thermography (IRT): Every material emits infrared radiation above absolute zero temperature. IRT measures the thermal variations of the material under investigation and produces an image. The IRT image presents temperature readings and their distribution on the examined surface by the rendering of different colors.

During Ground Penetrating Radar (GPR) measurements a short electromagnetic pulse (10MHz – 10GHz) is produced and propagated into the structure, part of the pulse energy is reflected (due to the presence of internal interfaces between materials of different dielectric constant), rendering a 2-D or 3-D image of the sub-surface. Results reveal internal structure of masonries, location of cavities, identification of detachments and internal cracks, assessment of decay depth.





Short description of the theory of some Non-Destructive Techniques (NDT)

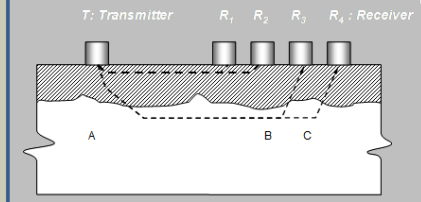
Portable spectrophotometer for measuring color variables (Colorimetry): It measures the reflected light of a material in the visible region. Spectra reflectance curve as a function of wavelength can be drawn, and then tristimulus chromatometric values are estimated. Following, these values can be converted to several color spaces to describe the color of the material under investigation. In conservation science the CIE Lab 1976 Color space is used more often .

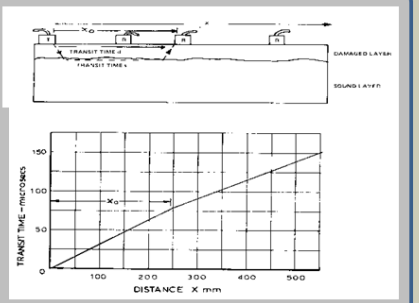
Raman spectroscopy is a technique, which is very sensitive to structural changes, used to understand molecular bonding in materials. It is a scattering technique, where photons from a laser source are used, typically in the infrared to UV wavelengths. Of the incident photons, a few undergo Raman scattering, losing energy through exciting vibrational modes of the sample. These scattered photons are detected to make a spectrum. Raman spectroscopy is commonly used to provide a structural fingerprint by which molecules can be identified.

Ultrasound pulse velocity measurements (UPV): Measures the velocity of ultrasounds traveling through a media, is recorded. The UPV depends on the media's density and the presence of voids and cracks. Thus, estimation of the depth of the decay patterns (crusts, cracks etc), evaluation of the effectiveness and the depth of penetration of restoration interventions.

Depth of Crust

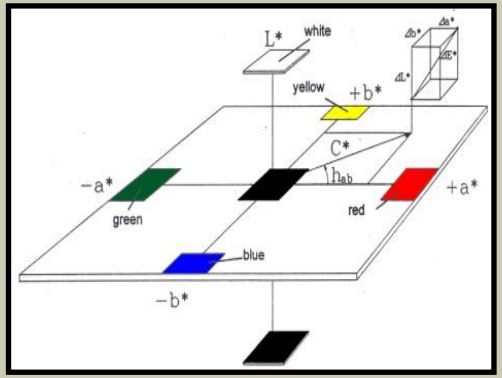
$$\alpha = \frac{l_o}{2}\left(\frac{V_S - V_D}{V_S + V_D}\right)^{1/2}$$





where V_S, V_D, are the ultrasonic velocities in the healthy and damaged part of the stone, respectively and l_0 the distance between the transducers where a change in slope of the distance-time curve is observed

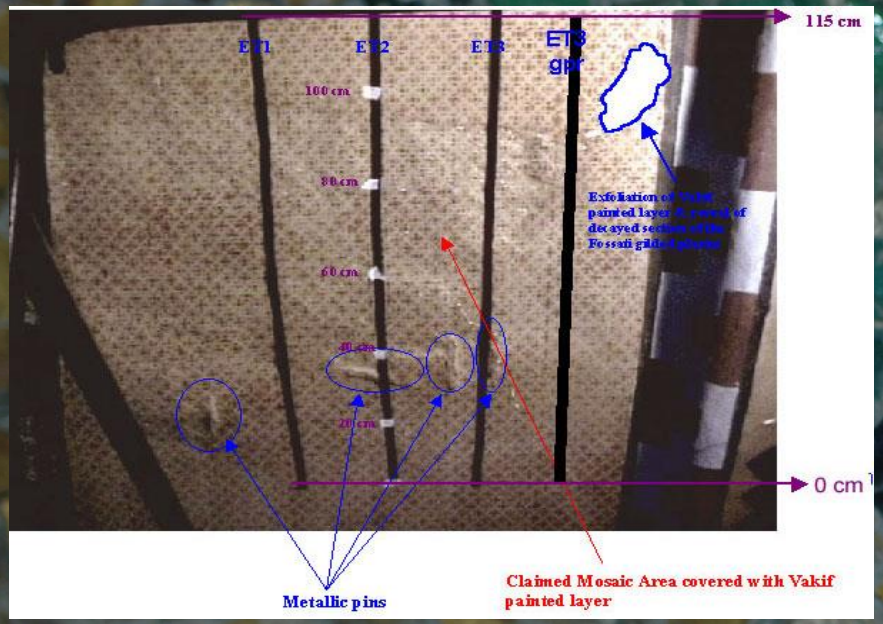
G. Batis, A. Moropoulou "Non-destructive testing of materials – Ultrasonics" in Laboratory notes of the Course 5202 "Building Materials" School of Chemical Engineering, National Technical University of Athens, pp. 69-77 (2011)

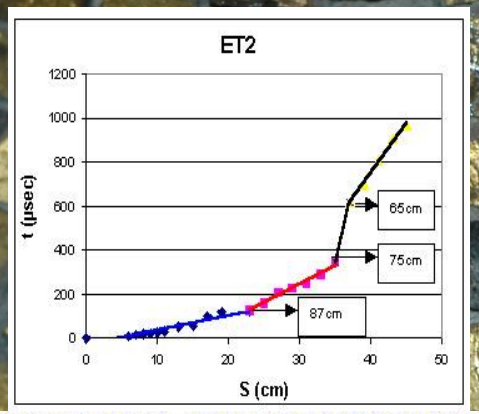


Hagia Sophia: GPR, UPV, IRT application

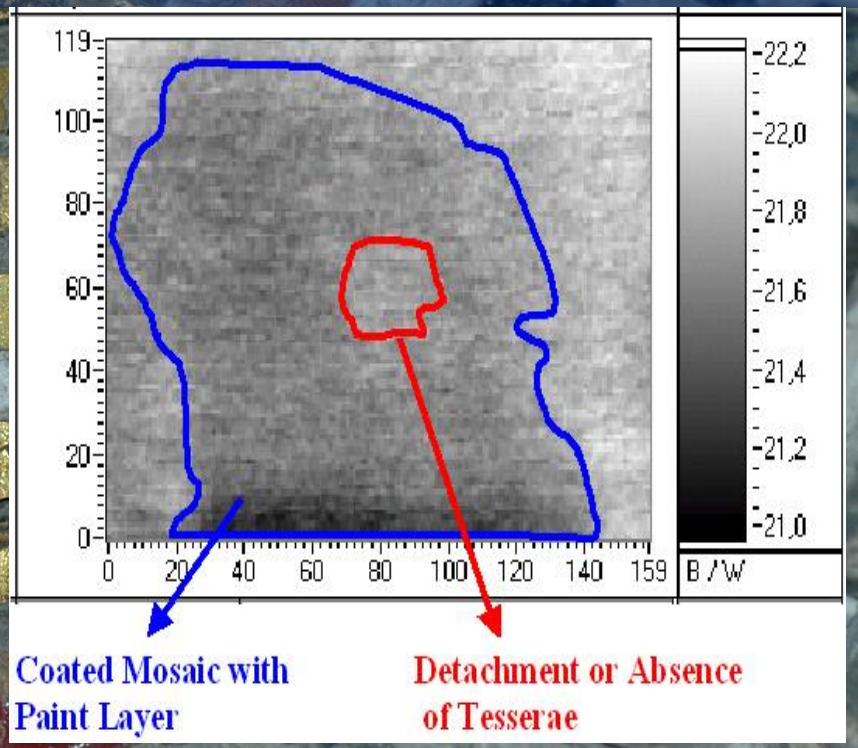
Compatibility assessment of previous conservation interventions

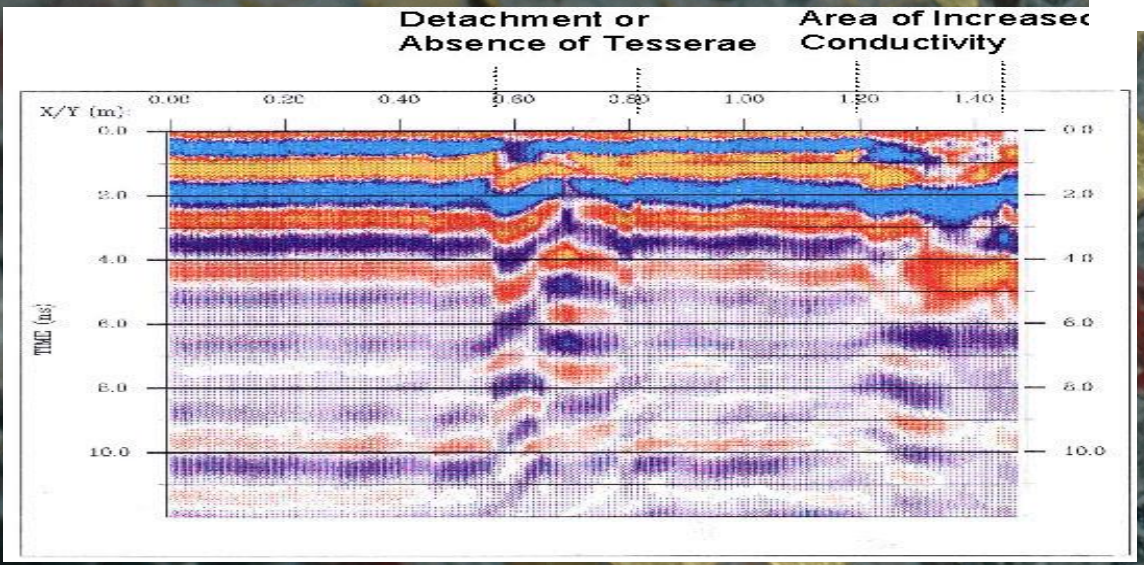
Examined surface: Vakif intervention at the dome of Hagia Sophia, between the 19th and the 20th rib





Area 1 (blue line): 112 – 87 cm ⇒ Area of Vakif painted plaster
Area 2 (red line): 87 – 75 cm ⇒ coated mosaic with paint layer
Area 3 (black line): 73 – 65cm ⇒ area with detachment or absence of tesserae



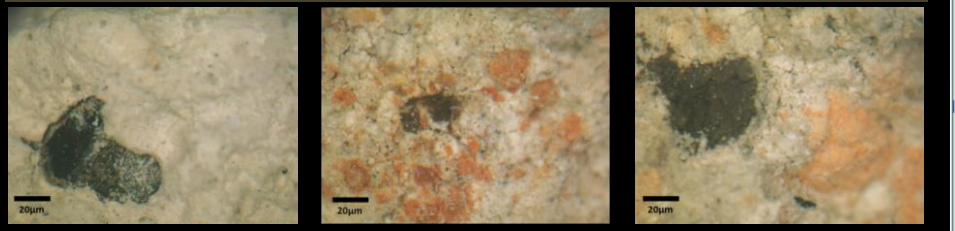


NDT reveals surfaces of plastered mosaics, wherein areas of detached tesserae, as well as areas with moisture problems and presence of salts are displayed.

The boundaries of problematic areas are detectable,

Holy Aedicule: application of DM, IRT, GPR

DM: Classification of historical mortars

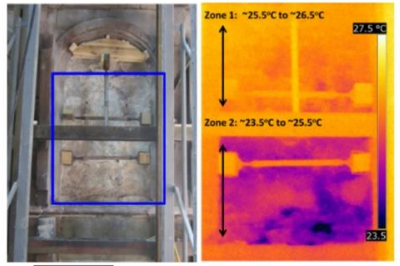
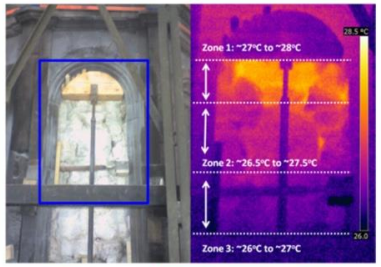
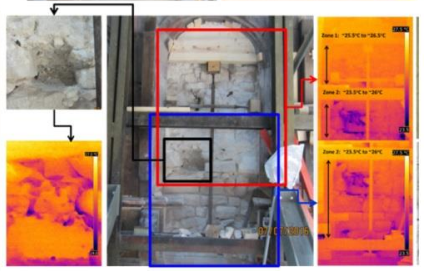
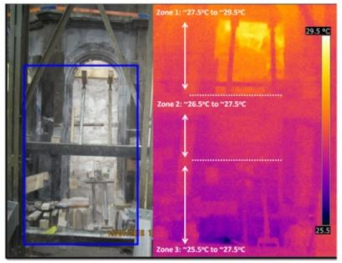
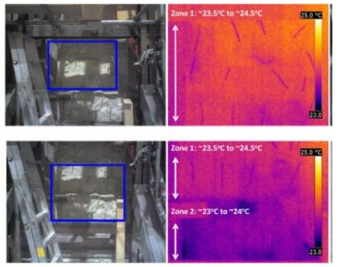
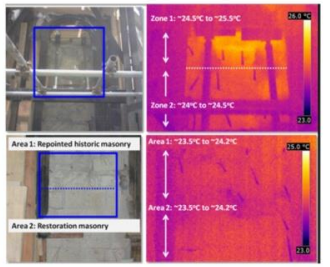


DM: Cracks investigation

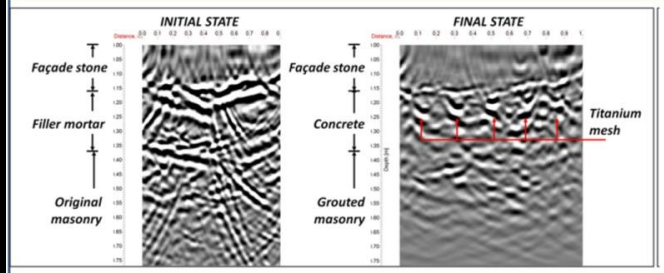
DM: Cracks sealing

Upper horizontal crack | Middle horizontal crack | Lower horizontal crack

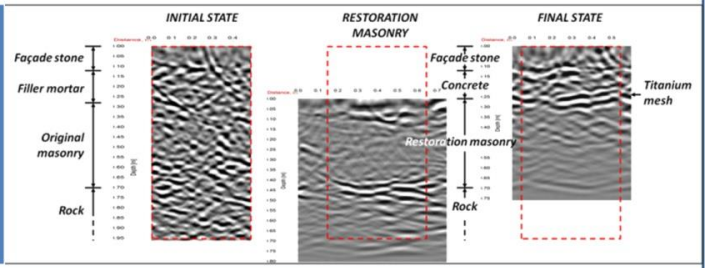
Monitoring of panel N2

		Project phases	Monitoring of panel N4
•Disintegrated state of the filling mortar layer •Intense rising damp from the underground •Anisotropy regarding moisture transfer phenomena		After façade stone slabs removal - filling mortar investigation	 •rising damp of the lower masonry parts •presence of voids and defect areas •transition temperature zone between zones, above and below middle masonry area
•Variety of different mortars detected •Continuous effect of rising damp •Thermohygric incompatibility between historical building materials (mortars & stones)		After filling mortar removal – Historical masonry	 •voids and defect areas still present •continuous affect of rising damp •anisotropic moisture transfer & thermo-hygric behavior of historical building materials
•Temperature distribution width became tighter •Compatibility among restoration mortar, building stones & historical mortar •Capillary rise continues to affect the restored masonry		Application of masonry restoration mortar – Restored masonry	 •More homogenous temperature distribution •Compatibility between restoration mortar and historical masonry •Compatibility between historical and restoration masonry

IRT revealed the presence of rising damp, leading to a survey of the Holy Aedicule's underground areas to identify moisture sources and propose appropriate measures; as well as it revealed the problem of voids and defect areas at the upper masonry part supporting the decision for the monument's upper zone grouting



Application of optimized restoration concrete & comparison of initial and final state

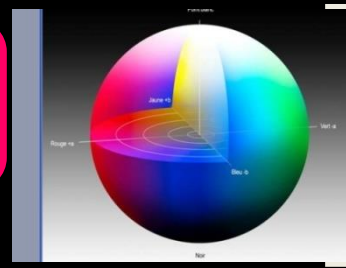


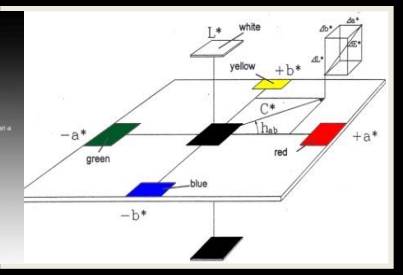
In both cases (N2 & N4 panels) the presence of the concrete layer and the titanium mesh, the repointing of the masonry and, where applicable, the restoration masonry, have improved structural homogeneity and cohesion between layers, as evidenced by the lack of voids and cracks

GPR data Dr K. Lampropoulos, 2017-2018

Aesthetical Evaluation of cleaning on pentelic marble architectural surfaces – Academy of Athens

Colorimetry
CIELab color space:
evaluation of color modifications





- **L, Lightness**
- **difference in red-green a***
- **difference in blue-yellow b***
- **total colour difference ΔE**

$$\Delta E^*ab=[(\Delta L^*)^2+ (\Delta a^*)^2+(\Delta b^*)^2]^{1/2}$$

Estimation of color parameters' modification of different decay patterns on exterior marble surfaces after cleaning

Aesthetic parameters:

ΔC*ab < 0 ⇒ less saturated areas after cleaning

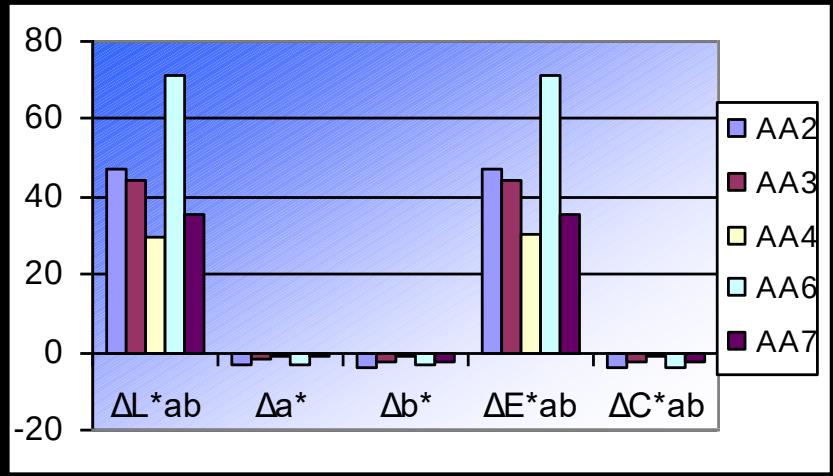
Δa* < 0 ⇒ greener (less red)

Δb*<0 ⇒ bluer (less yellow)

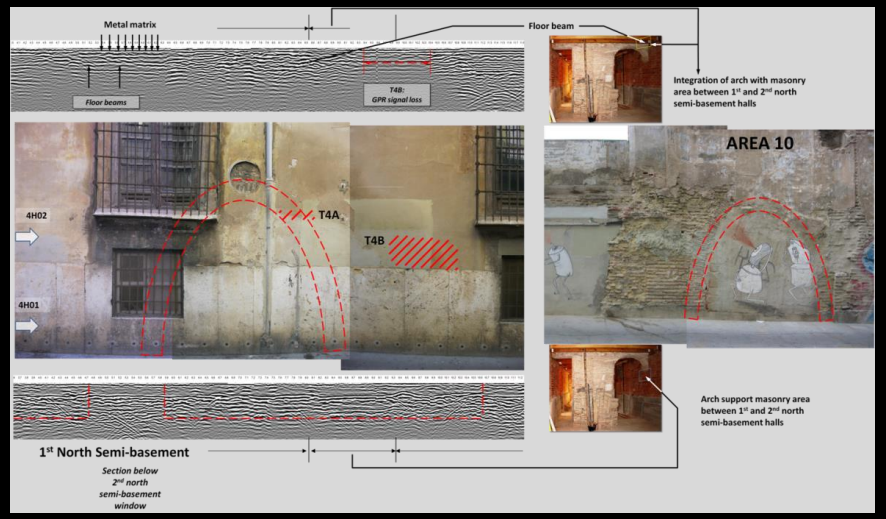
ΔL*ab > 0 higher lightness (more white) after cleaning

Validation according to EN15886:2010 Conservation of cultural property-Test methods-Colour measurement of surfaces,

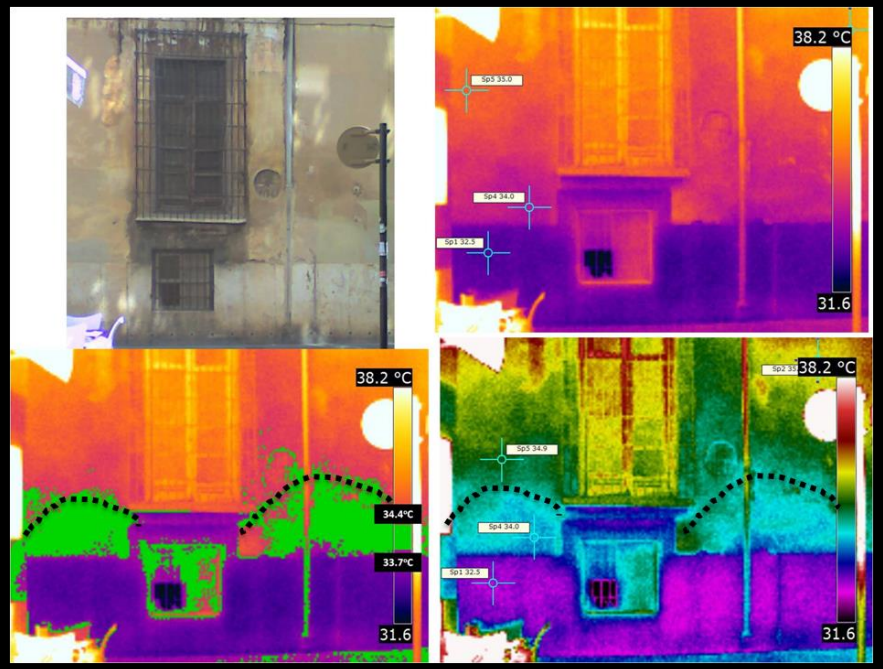
AA2: grey crust
AA3: dust fall
AA4: washed out surface
AA6: black-grey crust
AA7: area of grey veins



GPR, IRT application - Colegio del Arte Mayor de la Seda de Valencia



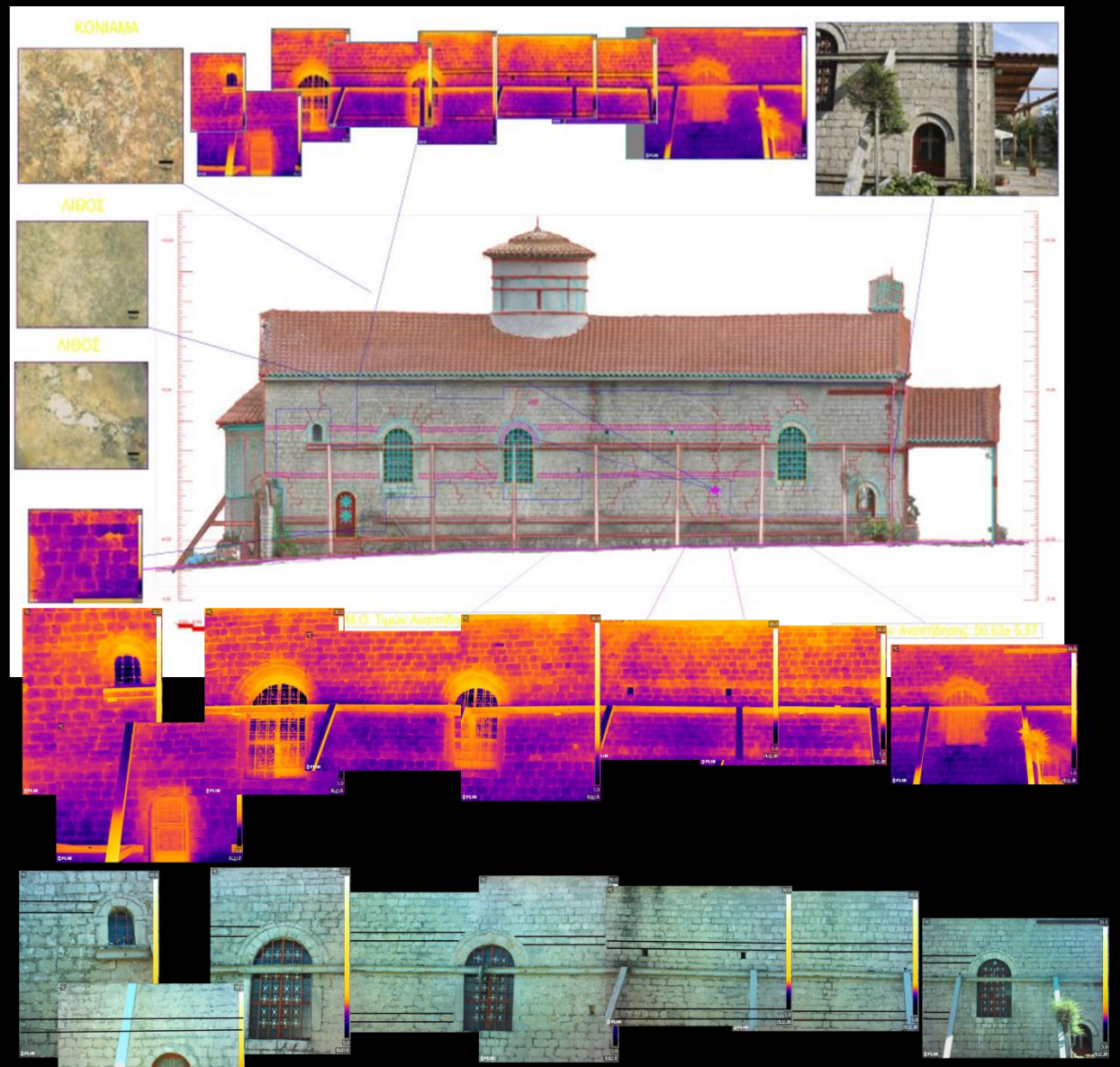
Assessment of preservation state of masonries
Identification of hidden features

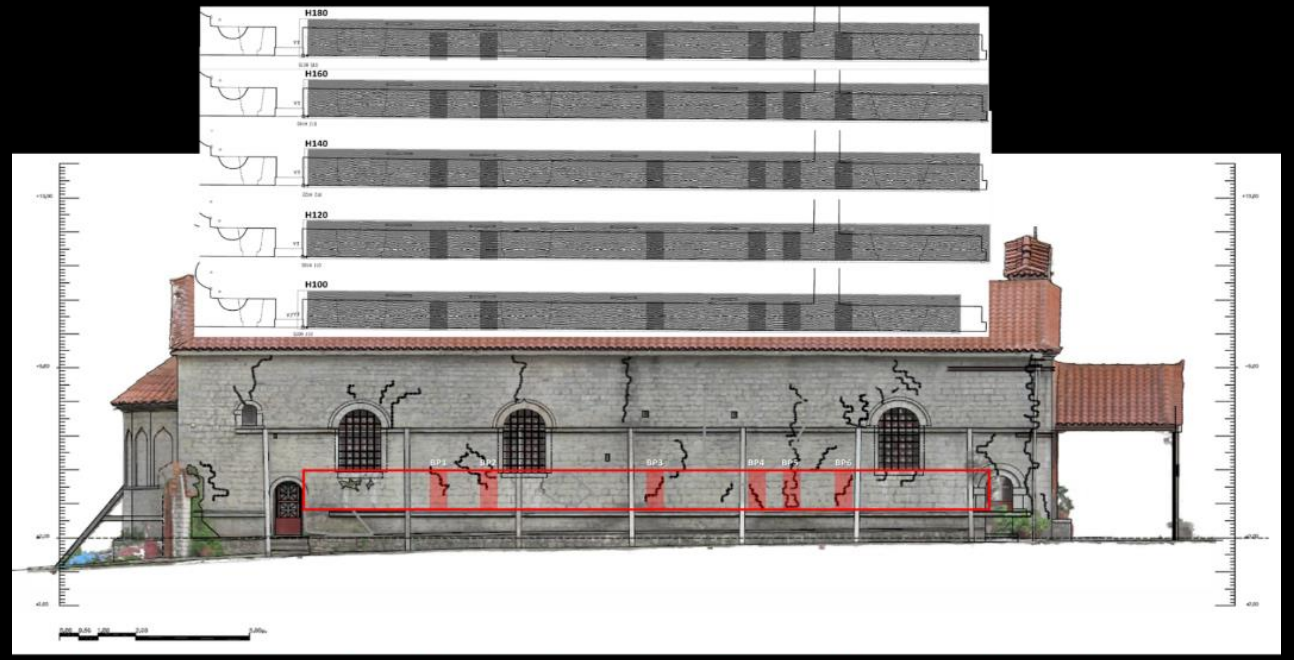


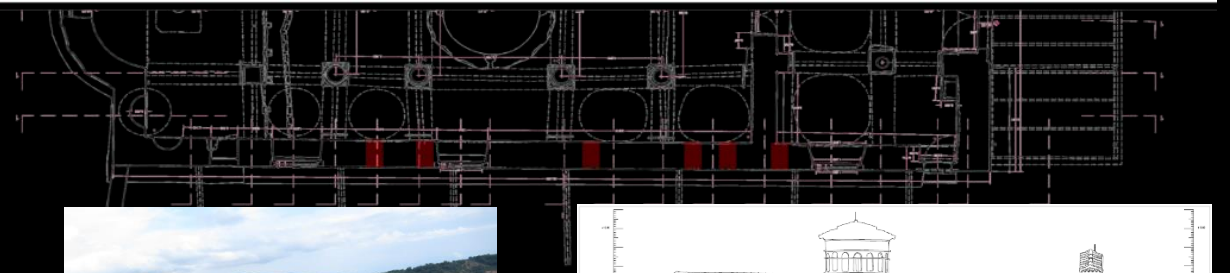
GPR data Dr K. Lampropoulos, 2014-2015

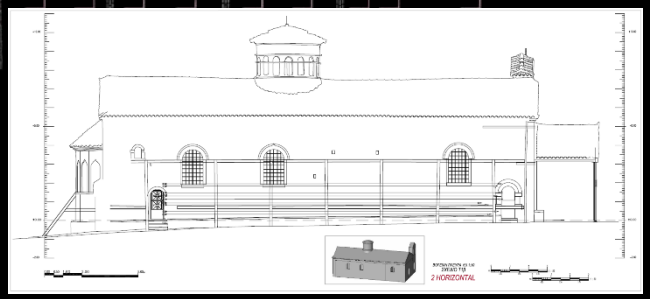
IRT & GPR: Identification of wooden structural elements within the masonry

Byzantine Monastery of Panagia Varnakova





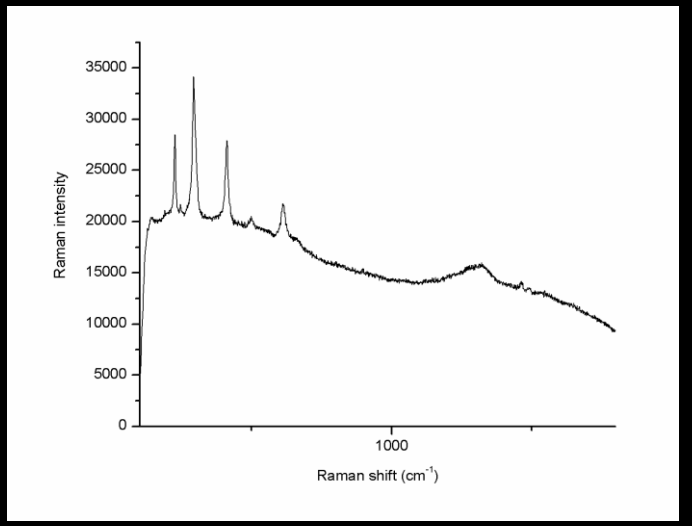




GPR data Dr K. Lampropoulos, 2019-2020

Raman Spectroscopy

Hephaisteion (Ancient Agora, Athens): Patina identification

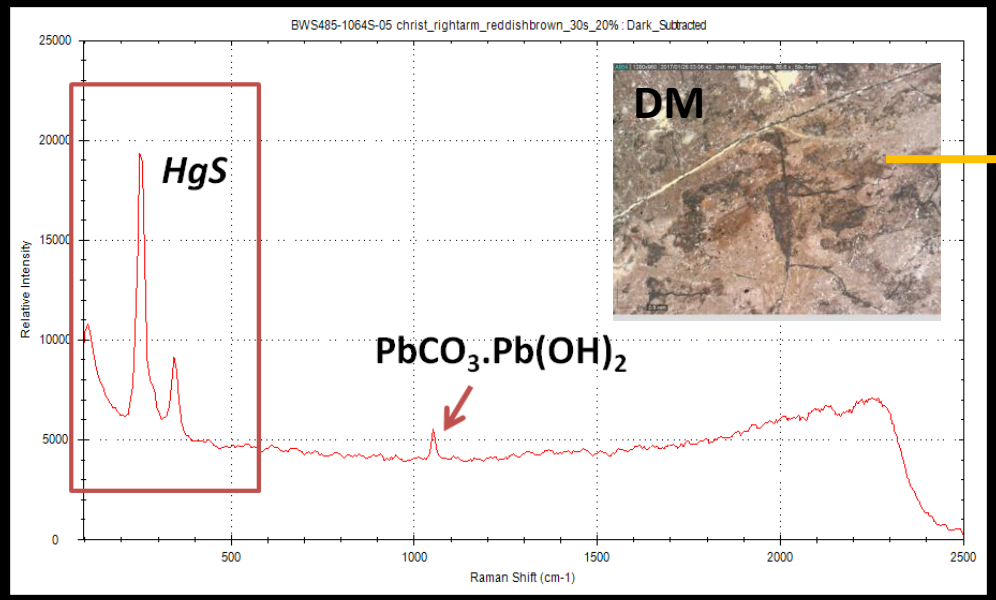


Characteristic bands of hematite: (α-Fe_2O_3): use of red ochre.

Ntoutsi, Delegou, Moropoulou, 2015

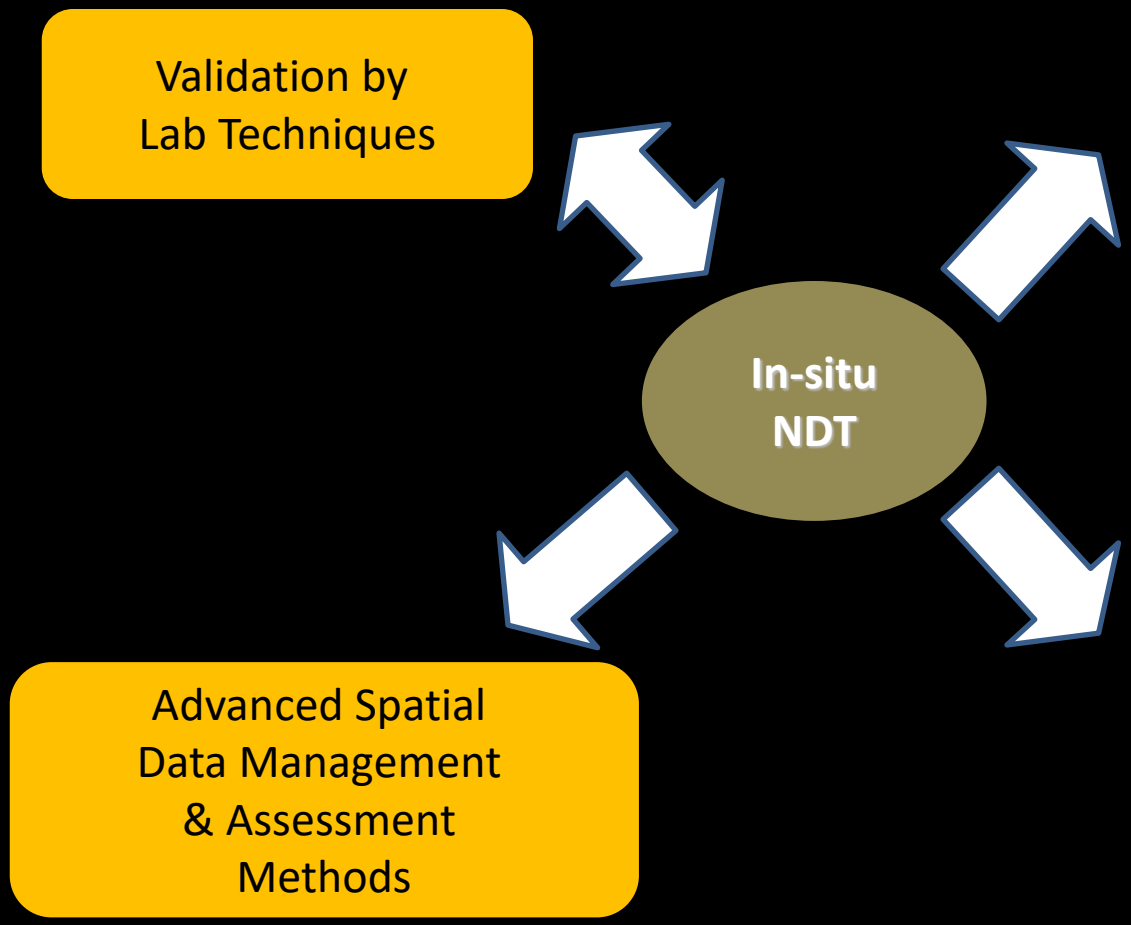
Raman bands: 291*vs*, 410*m* , 506*w*, 608*m*, 1300 *(br)*

The gilded marble relief of Christ Resurrection in the Holy Tomb Chamber



➢**Flesh tones were achieved by a mixture of cinnabar (characteristic bands at 252 (vs) & 345 (m) cm^{-1}) with lead white (characteristic band at 1052 cm^{-1}).**

Materials Science - Non Destructive Testing – Remote Sensing – Management Systems



Monument Scale

- Materials Characterization
- Evaluation of Materials Compatibility
- Environmental Impact Assessment
- Monitoring of Conservation works
- Sustainability assurance

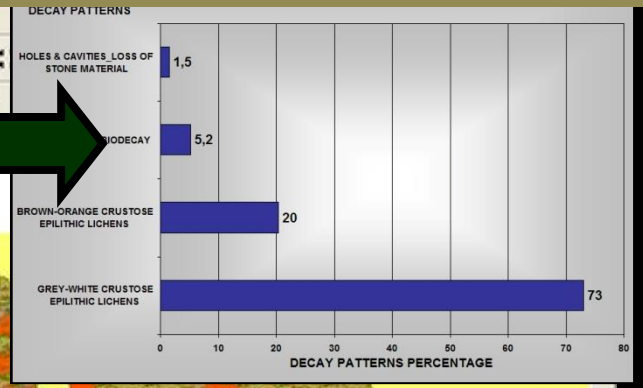
Integrated Projects

- Strategic Planning of Conservation Interventions on Historic Buildings
- Strategic Planning of Environmental Management as a Tool for a Sustainable Preservation of Historic Cities

Ascribing attributes (building materials data) to features (spatial data)

GIS thematic map of building materials and decay patterns – Acropolis of Sarantapichos, Rhodes Greece (geometric documentation – building materials documentation)

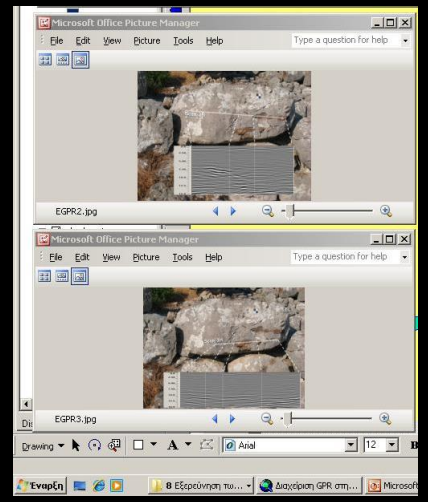
Stone is more susceptible to lichens biodecay than to fungus



Orange color – lichens
Black color – fungus

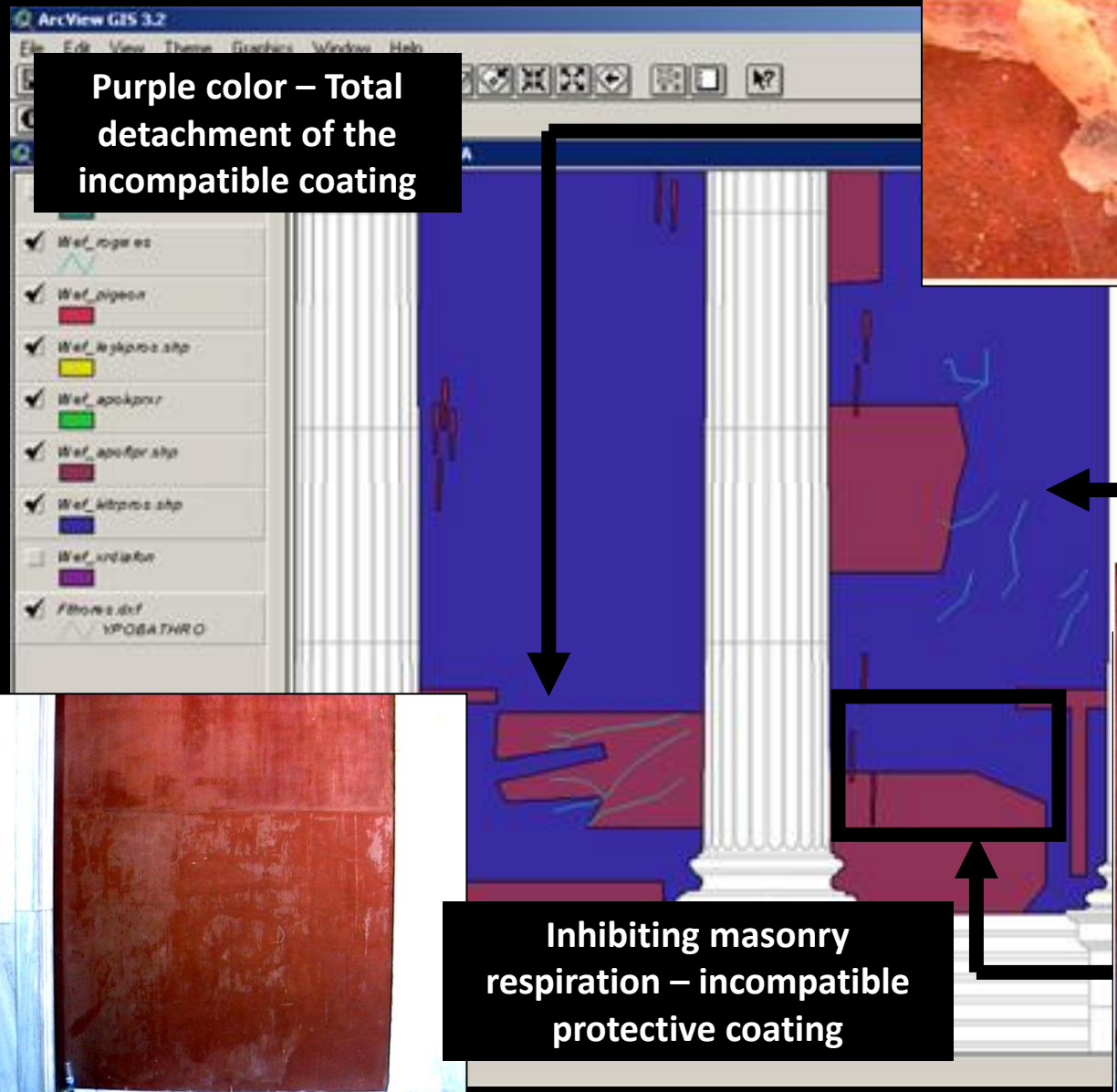
Interface stone - lichen

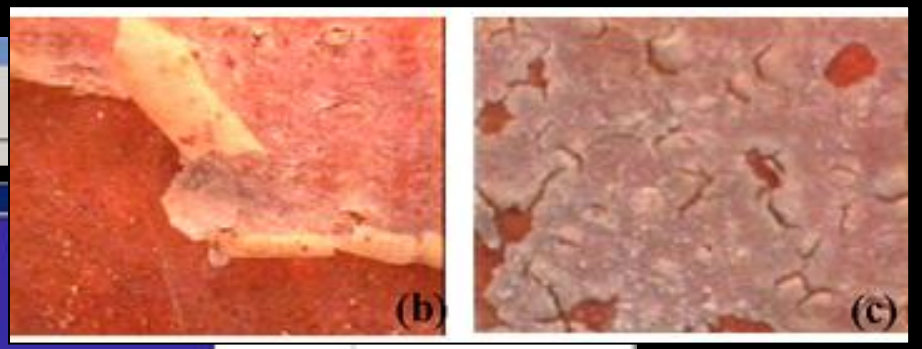
Brown color – grey compact fossiliferous limestone

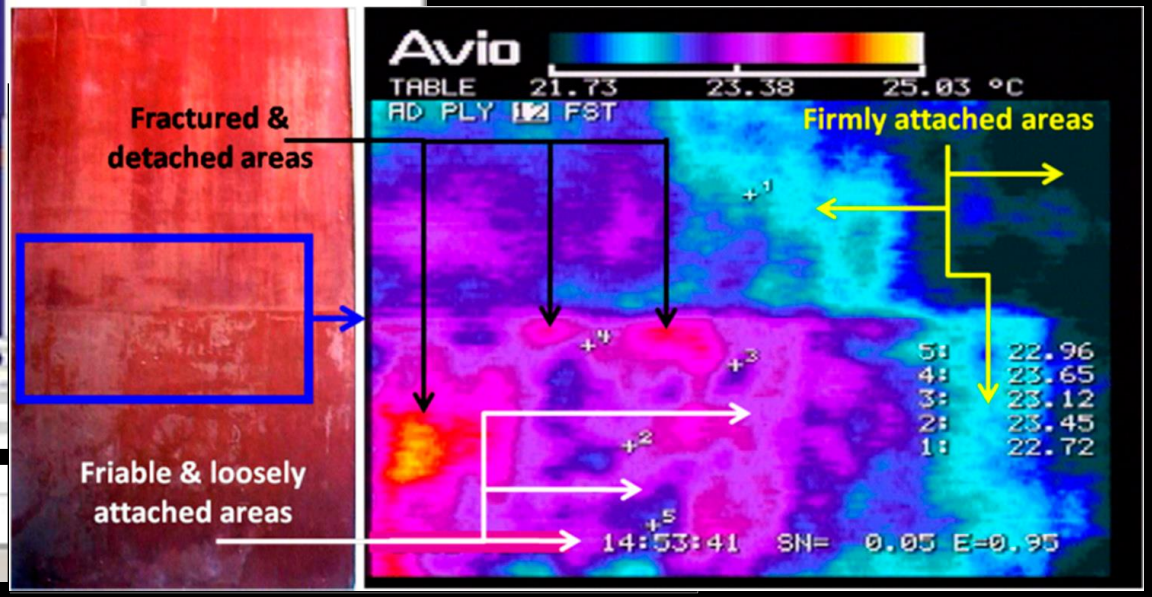


Delegou, Tsilimantou, Ioannidis, Moropoulou, 2007

GIS thematic map of decay – plastered architectural surfaces of National Archaeological Museum of Athens
Spatial classification of decay patterns







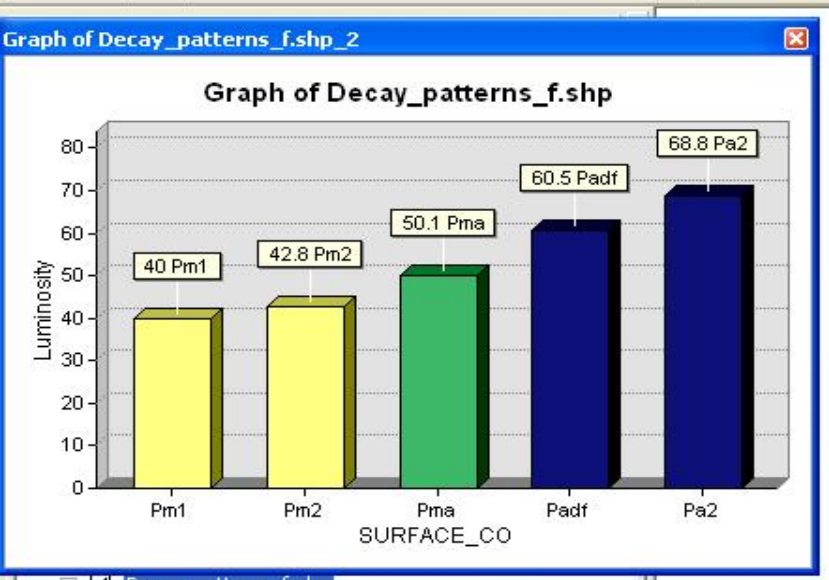
GIS thematic map of decay – attributing the physicochemical characteristic of color lightness L* on the spatial entities of the architectural surfaces of National Library of Greece

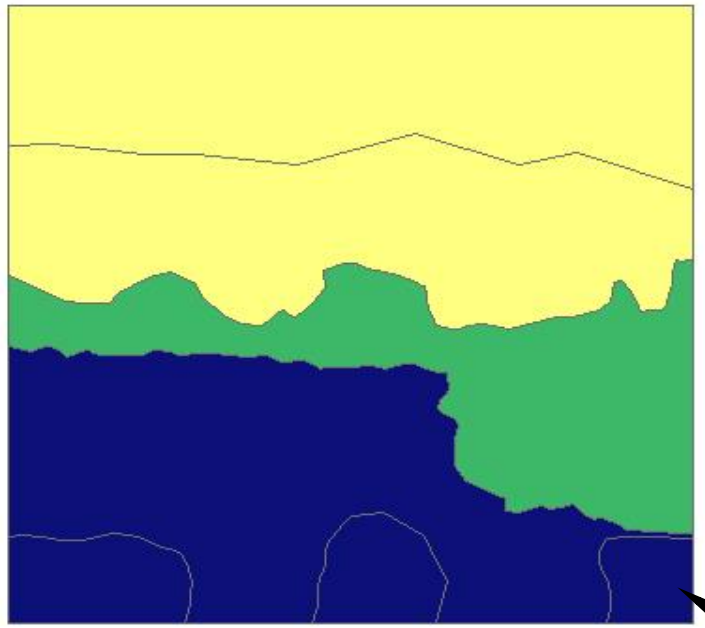
ebe_1 - ArcMap - ArcView

File Edit View Insert Selection Tools Window Help

Editor Task: Create New Feature Target:

Graph of Decay_patterns_f.shp_2





Decay_patterns_f.shp
B_L_
40.00 - 42.80
42.81 - 50.10

Comparative diagram – 3 classes based on Jenks method

RDB

Attribute

ID	SU	PATTERNS	AREA_METER	PERIMETER	B_WIDTH_OF_GYPSU	B_ROUGHNESS	B
1	Pm1		0.214	2.412	0	8	
2	Pm2	COHESIVE BLACK-GREY CRUST	0.206	2.522	80	10	
3	Pma	INTERCRYSTALLINE FRACTURES WITH HIGH AMOUNT OF BLACK DEPOSITIONS	0.162	2.948	30	7	
4	Padf	INTERCRYSTALLINE FRACTURES WITH LOWER AMOUNT OF BLACK DEPOSITIONS	0.229	2.934	0	29	
5	Pa2	WASHED OUT SURFACES	0.071	1.826	0	27	

Record: 0 Show: All Selected Records (0 out of 5 Selected) Options

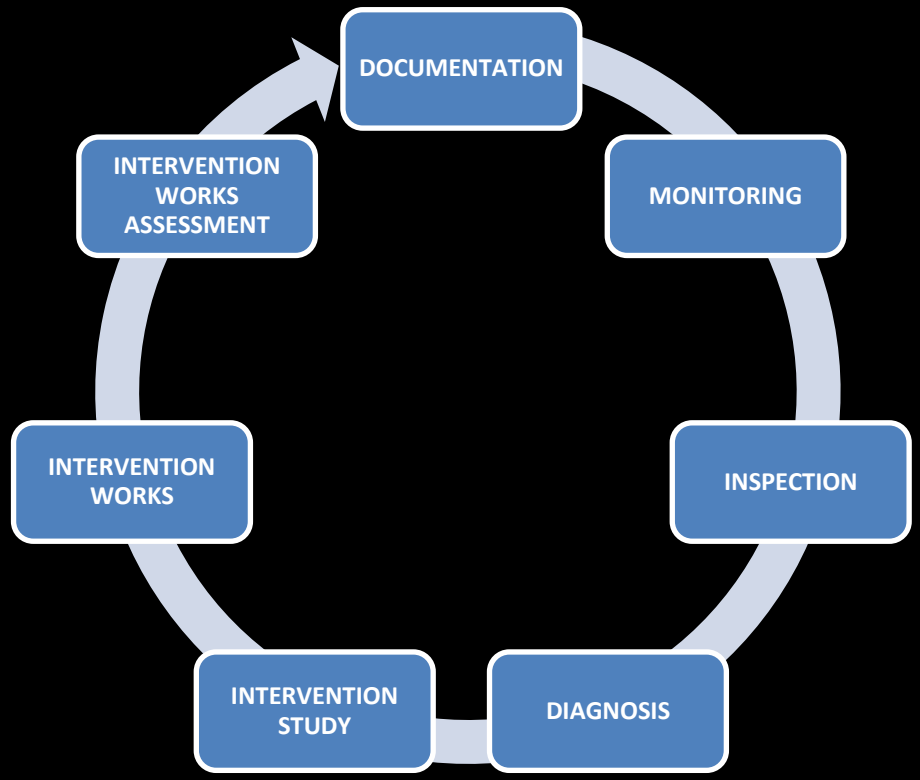
start MOROPOULOU_SPEECH ebe_1 ebe_1 - ArcMap - Arc... EN 4:51 μμ

Decision Making Procedures

NDTs are valuable tools

LEAD TO

ACCORDING TO THE NECESSITY OF PERFORMING:
INSPECTION - DIAGNOSIS - INTERVENTION WORKS




THANK YOU