NATIONAL TECHNICAL UNIVERSITY OF ATHENS [GREECE]

SAPIENZA UNIVERSITA DI ROMA [ITALY]

BEZALEL ACADEMY OF ARTS AND DESIGN [ISRAEL]

PerpetielSI SRL

PERPETIELSI SRL [ROMANIA]

ISRAEL ANTIQUITIES AUTHORITY [ISRAEL]

HELLENIC RESEARCH INSTITUTE OF THE ALEXANDRIAN CIVILIZATION [GREECE]

The EDICULA Project | MULTIPLIER 1 [E1]:
The Historic City of Jerusalem, The Holy Sepulchre: A Hands-on Experience

PUBLIC EVENT, Hansen House, 04.04.2022

The Holy Sepulchre rehabilitation project: An emblematic source of Innovation

National Technical University of Athens
Chief Scientific Supervisor, Prof. Antonia Moropoulou

NTUA Interdisciplinary Team:
Prof. E. Korres, Prof. A. Georgopoulos, Prof. A. Moropoulou, Prof. C. Spyrakos,
Assist. Prof. Ch. Mouzakis, Deputy Construction Site Manager

Co-funded by the Erasmus+ Programme of the European Union

ΙΔΡΥΜΑ ΚΡΑΤΙΚΩΝ ΥΠΟΤΡΟΦΙΩΝ IKY

EDICULA

Educational Digital Innovative Cultural heritage related Learning Activities

Project Code: 2020-1-EL01-KA203-079108

Historic initiative of the Greek-Orthodox Patriarch of Jerusalem to invite the NTUA

The project was initiated, became possible and is executed under the governance of His Beatitude, the Greek-Orthodox Patriarch of Jerusalem, Theophilos III.

His Beatitude, the Greek-Orthodox Patriarch of Jerusalem, Theophilos III invited Professor Antonia Moropoulou (March 2015) and signed a programme agreement with the National Technical University of Athens in order to conduct a study regarding *"Materials & Conservation, Reinforcement and Rehabilitation Interventions in the Holy Edicule of the Holy Sepulchre"* with the consensus of all three Christian Communities

NATIONAL TECHNICAL UNIVERSITY OF ATHENS
Interdisciplinary Research Group for the Monuments Protection

Materials & Conservation, Reinforcement and Rehabilitation Interventions in the Holy Edicule of the Holy Sepulchre

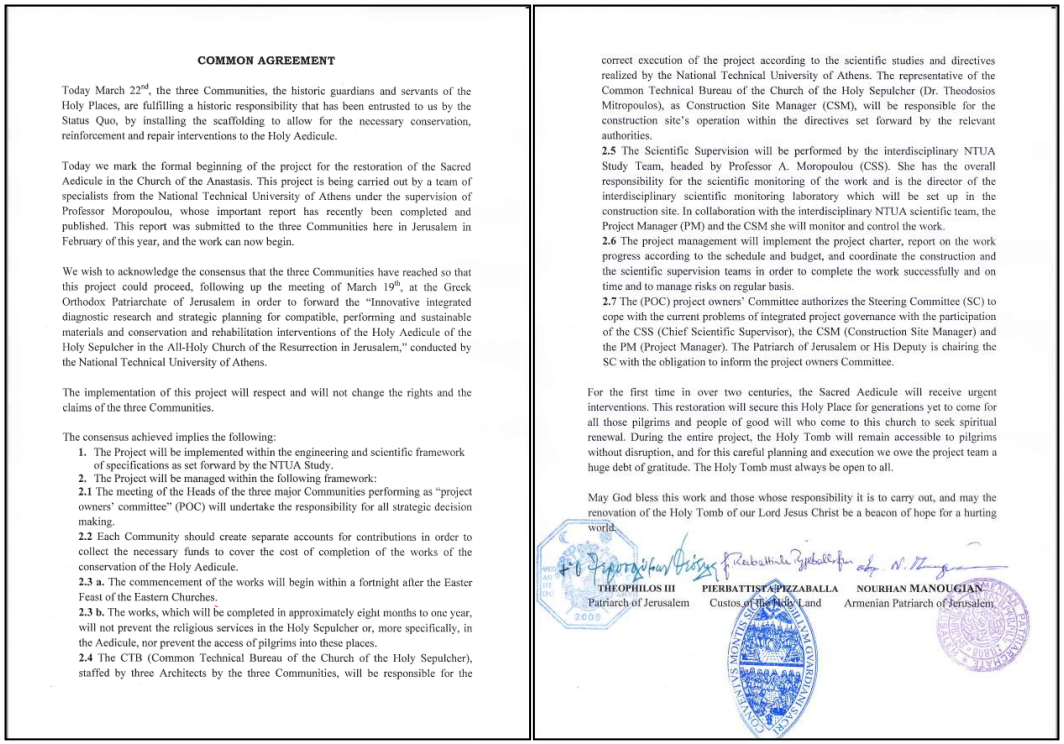
Final Report Presentation,
27 January 2016, Consulate General of Greece in Jerusalem
19 February 2016, Greek-Orthodox Patriarchate of Jerusalem
8 March 2016, Zappeion Hall, Athens

Scientific Coordinator:
Prof. A. Moropoulou

Interdisciplinary Research Group NTUA**:**
Prof. E. Korres, School of Architecture Engineering NTUA, Former Director of the Interdisciplinary Postgraduate Programme "*Protection of Monuments*"
Prof. A. Georgopoulos, School of Rural and Surveying Engineering NTUA, Laboratory of Photogrammetry
Prof. A. Moropoulou, Director of Studies in the NTUA Interdisciplinary Postgraduate Programme Direction «*Conservation Of Building Materials*», School of Chemical Engineering NTUA,
Laboratory of Materials Science and Engineering
Prof. C. Spyrakos, School of Civil Engineering NTUA, Laboratory for Earthquake Engineering

HISTORIC AGREEMENT BETWEEN THE THREE CHRISTIAN COMMUNITIES

The Common Agreement of the Status Quo provides him with the authority, in constant collaboration with the Leaders of the Christian Communities, the historic Guardians of the Holy Sepulchre, consisting of the Greek-Orthodox Patriarch of Jerusalem, Theophilos III, the Custos of the Holy Land of the Franciscan Order, Pierbattista Pizzaballa (until May 2016), today the Apostolic Administrator of the Latin Patriarchate of Jerusalem, and Francesco Patton (from June 2016), as well as the Armenian Patriarch in Jerusalem, Archbishop Nourhan Manougian, to **coordinate** all scientific, technical and administrative aspects of the project.



COMMON AGREEMENT

Today March 22nd, the three Communities, the historic guardians and servants of the Holy Places, are fulfilling a historic responsibility that has been entrusted to us by the Status Quo, by installing the scaffolding to allow for the necessary conservation, reinforcement and repair interventions to the Holy Aedicule.

Today we mark the formal beginning of the project for the restoration of the Sacred Aedicule in the Church of the Anastasis. This project is being carried out by a team of specialists from the National Technical University of Athens under the supervision of Professor Moropoulou, whose important report has recently been completed and published. This report was submitted to the three Communities here in Jerusalem in February of this year, and the work can now begin.

We wish to acknowledge the consensus that the three Communities have reached so that this project could proceed, following up the meeting of March 19th, at the Greek Orthodox Patriarchate of Jerusalem in order to forward the "Innovative integrated diagnostic research and strategic planning for compatible, performing and sustainable materials and conservation and rehabilitation interventions of the Holy Aedicule of the Holy Sepulcher in the All-Holy Church of the Resurrection in Jerusalem," conducted by the National Technical University of Athens.

The implementation of this project will respect and will not change the rights and the claims of the three Communities.

The consensus achieved implies the following:

1. The Project will be implemented within the engineering and scientific framework of specifications as set forward by the NTUA Study.
2. The Project will be managed within the following framework:

2.1 The meeting of the Heads of the three major Communities performing as "project owners' committee" (POC) will undertake the responsibility for all strategic decision making.

2.2 Each Community should create separate accounts for contributions in order to collect the necessary funds to cover the cost of completion of the works of the conservation of the Holy Aedicule.

2.3 a. The commencement of the works will begin within a fortnight after the Easter Feast of the Eastern Churches.

2.3 b. The works, which will be completed in approximately eight months to one year, will not prevent the religious services in the Holy Sepulcher or, more specifically, in the Aedicule, nor prevent the access of pilgrims into these places.

2.4 The CTB (Common Technical Bureau of the Church of the Holy Sepulcher), staffed by three Architects by the three Communities, will be responsible for the correct execution of the project according to the scientific studies and directives realized by the National Technical University of Athens. The representative of the Common Technical Bureau of the Church of the Holy Sepulcher (Dr. Theodosios Mitropoulos), as Construction Site Manager (CSM), will be responsible for the construction site's operation within the directives set forward by the relevant authorities.

2.5 The Scientific Supervision will be performed by the interdisciplinary NTUA Study Team, headed by Professor A. Moropoulou (CSS). She has the overall responsibility for the scientific monitoring of the work and is the director of the interdisciplinary scientific monitoring laboratory which will be set up in the construction site. In collaboration with the interdisciplinary NTUA scientific team, the Project Manager (PM) and the CSM she will monitor and control the work.

2.6 The project management will implement the project charter, report on the work progress according to the schedule and budget, and coordinate the construction and the scientific supervision teams in order to complete the work successfully and on time and to manage risks on regular basis.

2.7 The (POC) project owners' Committee authorizes the Steering Committee (SC) to cope with the current problems of integrated project governance with the participation of the CSS (Chief Scientific Supervisor), the CSM (Construction Site Manager) and the PM (Project Manager). The Patriarch of Jerusalem or His Deputy is chairing the SC with the obligation to inform the project owners Committee.

For the first time in over two centuries, the Sacred Aedicule will receive urgent interventions. This restoration will secure this Holy Place for generations yet to come for all those pilgrims and people of good will who come to this church to seek spiritual renewal. During the entire project, the Holy Tomb will remain accessible to pilgrims without disruption, and for this careful planning and execution we owe the project team a huge debt of gratitude. The Holy Tomb must always be open to all.

May God bless this work and those whose responsibility it is to carry out, and may the renovation of the Holy Tomb of our Lord Jesus Christ be a beacon of hope for a hurting world.

THEOPHILOS III Patriarch of Jerusalem

PIERBATTISTA PIZZABALLA Custos of the Holy Land

NOURHAN MANOUGIAN Armenian Patriarch of Jerusalem

NATIONAL TECHNICAL UNIVERSITY OF ATHENS

INTERDISCIPLINARY RESEARCH GROUP FOR THE MONUMENTS PROTECTION

SCIENTIFIC SUPERVISION, MONITORING AND DECISION MAKING

PROJECT FOR THE CONSERVATION, REINFORCEMENT AND REPAIR INTERVENTIONS FOR THE REHABILITATION OF THE HOLY AEDICULE OF THE HOLY SEPULCHRE IN THE ALL-HOLY CHURCH OF RESURRECTION IN JERUSALEM

National Technical University of Athens

Chief Scientific Supervisor:

Prof. Antonia Moropoulou

A Collective Work by

NTUA Interdisciplinary Team

Prof. E. Korres, Prof. A. Georgopoulos, Prof. A. Moropoulou, Prof. C. Spyrakos,

Assist. Prof. Ch. Mouzakis, *Deputy Construction Site Manager*

An exemplary project highlighting Greek and European Innovation and Expertise in the field of Cultural Heritage protection

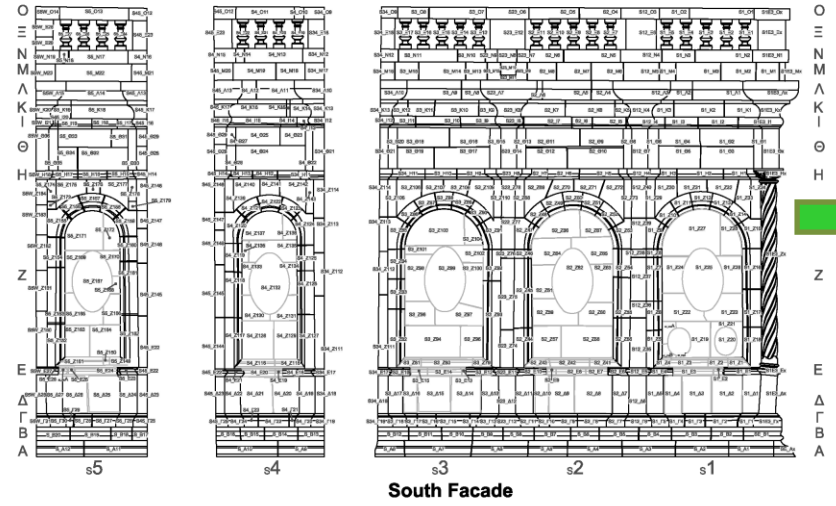
Exploiting a multilevel integrated interdisciplinary approach

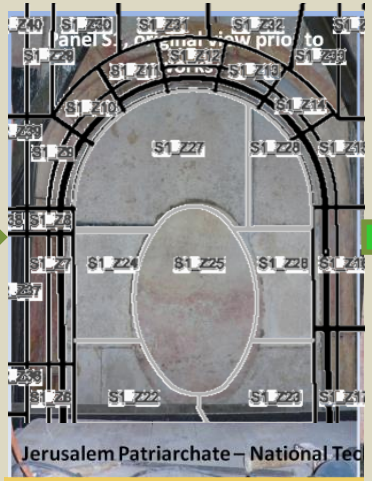
Implementation of an integrated methodology

DISMANTLING AND REMOVAL OF THE STONE PANELS

☑ 20.07.2016

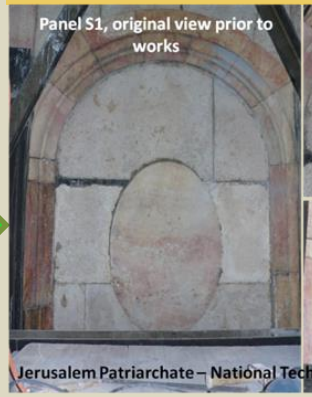
Architectural design from 3d geometric representation



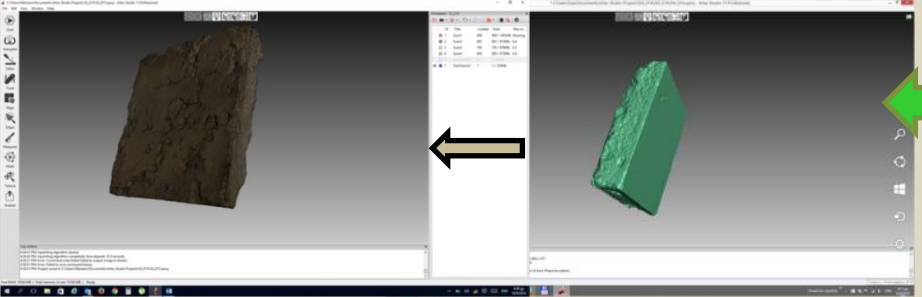


Codes are assigned to each stone

Dismantling process



3d Documentation of each stone slab

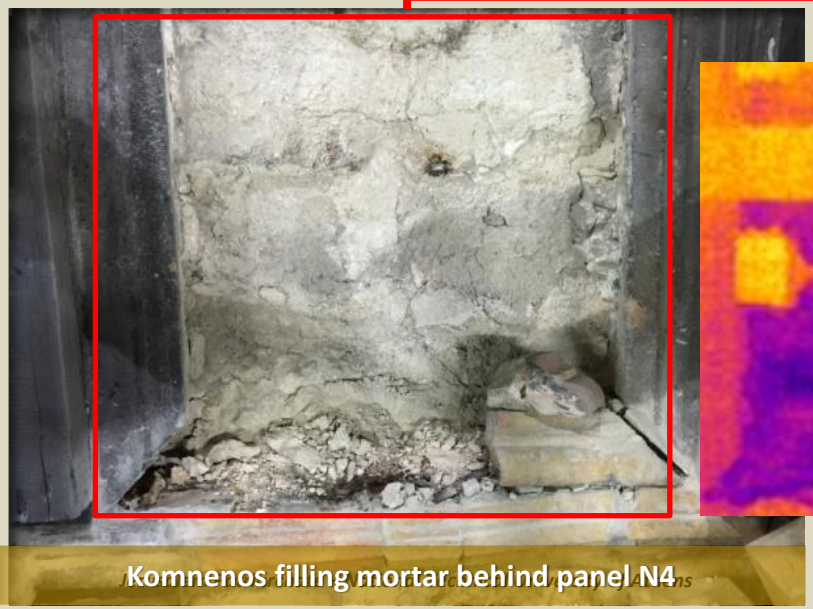


Data was used for the assessment of interventions

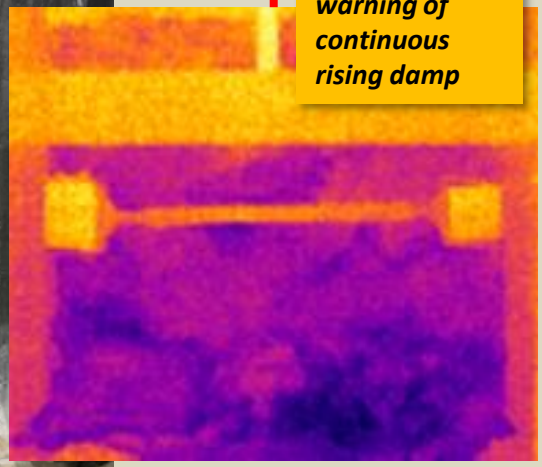
Removal of stone slab, transportation to conservation lab

REMOVAL OF DISINTEGRATED AND INCOMPATIBLE MORTARS

☑ 30.07.2016



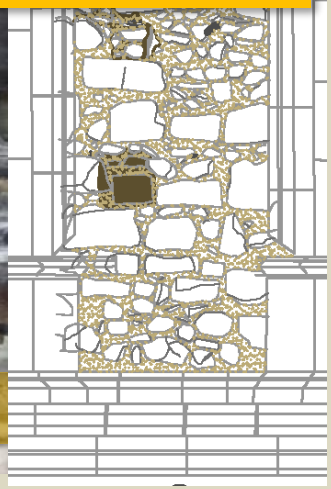
Komnenos filling mortar behind panel N4



Monitoring of thermohygric performance – warning of continuous rising damp

Cleaned masonry

Architectural and geometric documentation of historic masonry



REPOINTING OF MASONRY WITH RESTORATION MORTARS

☑ 7.10.2016

STUDY PROPOSAL

Compatible to the original mortars: Lime-pozzolan mortar (High reactivity metakaolin), with river quartz origin aggregates of 2 mm maximum gradation&inorganic mineral fibers. **Performing to the structural integrity of the original structure, according to FEM results: compressive strength >15 MPa**

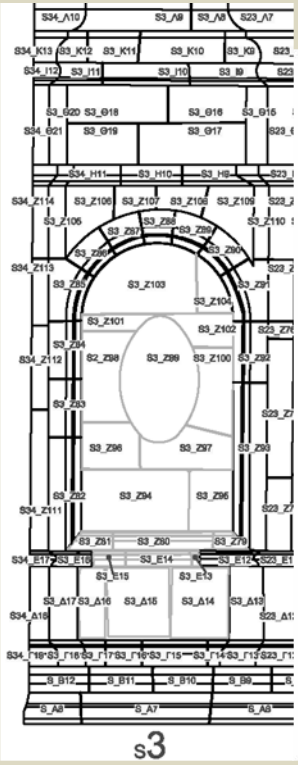
IMPLEMENTATION STUDY

MasterEmaco S 285 TIX
Lime-metakaolin mortar (with high reactivity metakaolin), without the presence of cement, with river quartz origin aggregates of a maximum gradation of 2mm and with the addition of mineral inorganic fibers. It guarantees compressive strength >15 MPa

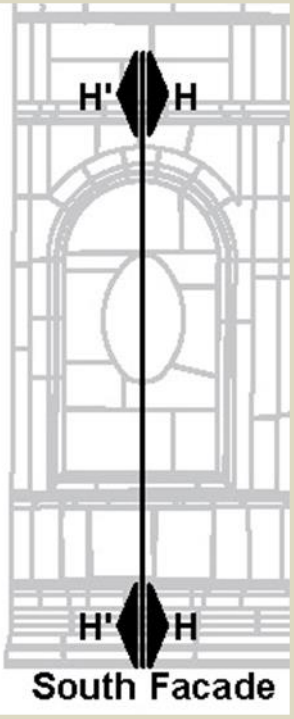
PARTIAL RECONSTRUCTION OF MASONRY AREAS TO ADDRESS SWELLING, STRUCTURAL INEFFICIENCY AND DAMAGE OF THE MASONRY

☑ 24.08.2016

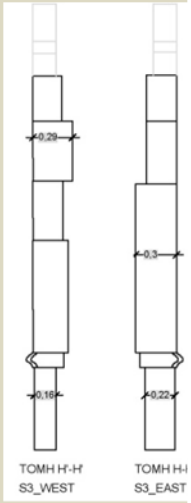
Geometric and architectural documentation



Exterior stone panels prior to disassembly



Exterior stone panels after removal of slabs



Interior historical masonry after removal of slabs

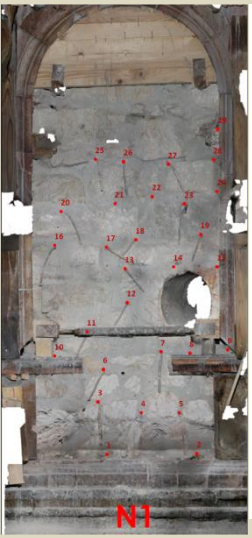
*The new masonry was **constructed using orthogonal stone blocks** with largely standardized dimensions, to ensure compatibility and to enhance mechanical performance and homogeneity. Jammain stone, a beige limestone from Palestine, is a type of Mizzy and was selected as the most compatible and performing stone (F_c 70MPa)*

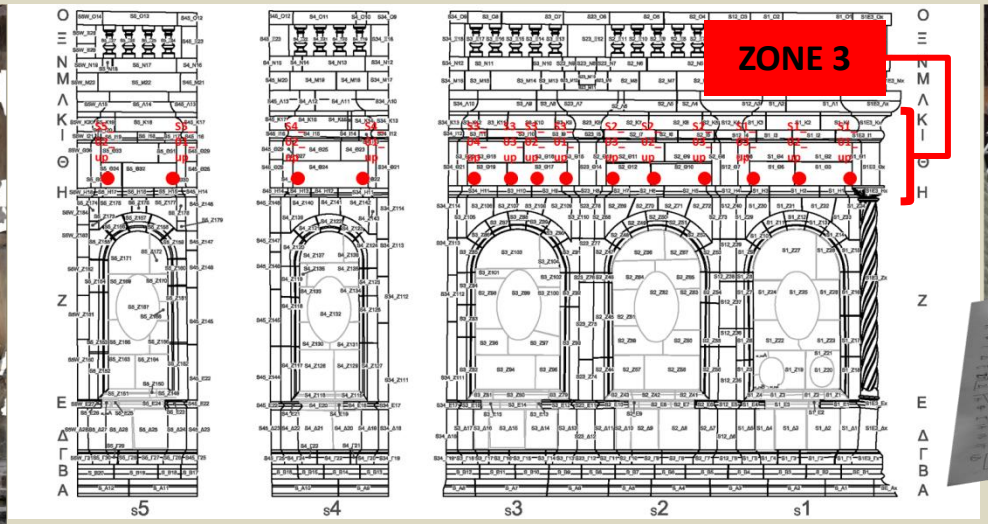
Basic requirements fulfilled:

- *Safety - structural integrity of the aedicule.*
- *New building stones compatible with the historic materials*
- *Preservation of the Holy Rock*

*The design of the repair masonry was based on data from geometric and architectural documentation **to ensure that the repair masonry conforms to the shape of the Holy Rock** and **does not protrude** such that it hinders the final reassembly of the exterior panels*

HOMOGENIZATION OF STRUCTURAL LAYERS AND CONSOLIDATION OF THE HOLY ROCK BY THE INJECTION OF COMPATIBLE GROUTS

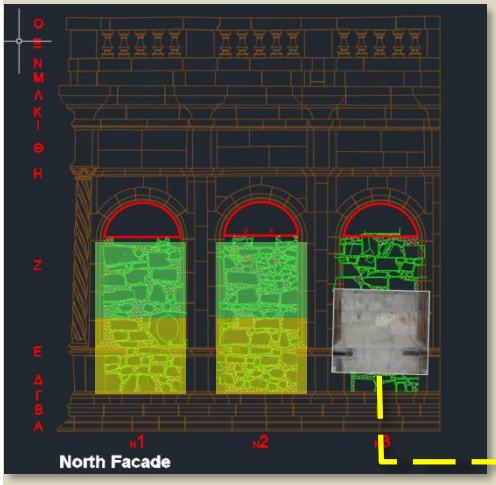




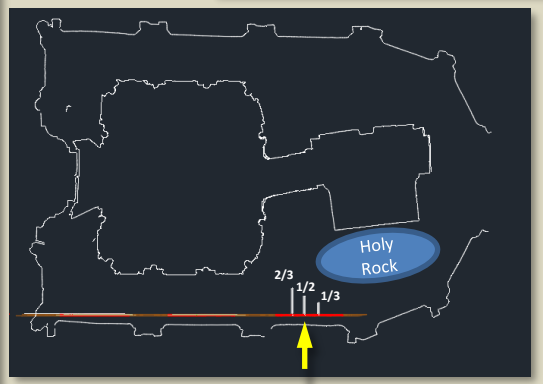
☑ 06.02.2017

Geometric and architectural documentation data facilitated grout injection tube design and documentation

Installation of injections pipes, creating a matrix at different depths, based on sections of the geometric model



☑ 28.10.2017



RESETTING OF EXTERIOR COLUMNS

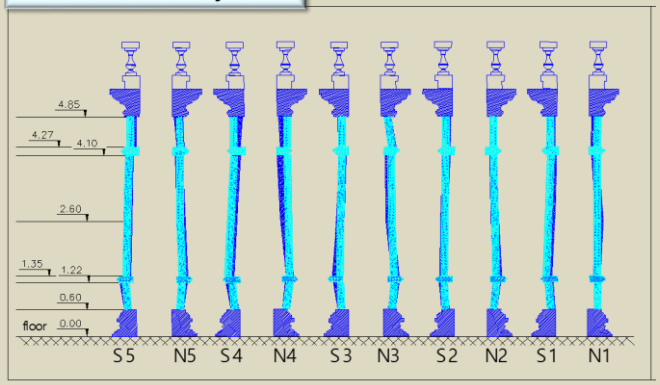
☑ 11.11.2016

Process of a column repositioning

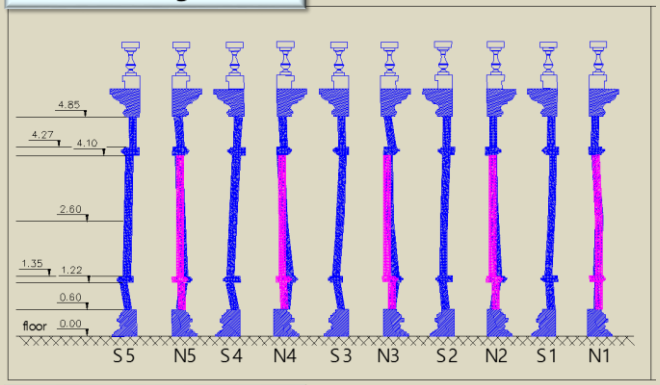
One of the basic requirements, **prior to the reassembly of the panel slabs and the addition of the filling mortar**, between the masonry and the stone panels, is the **resetting of the dislocated columns**.

Assessment of reduction of deviations from verticality during the works

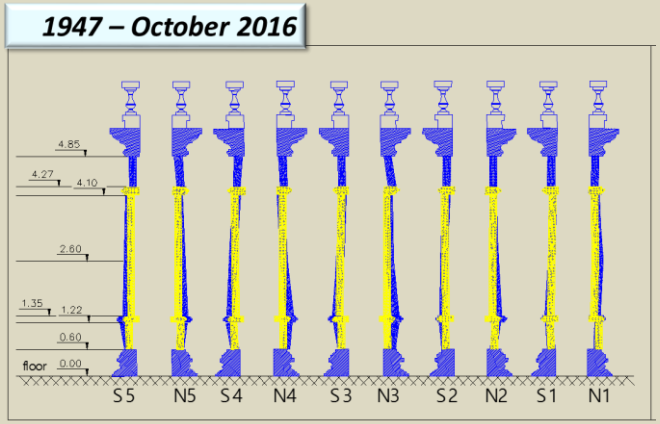
1947 – January 2016



1947 – August 2016



1947 – October 2016



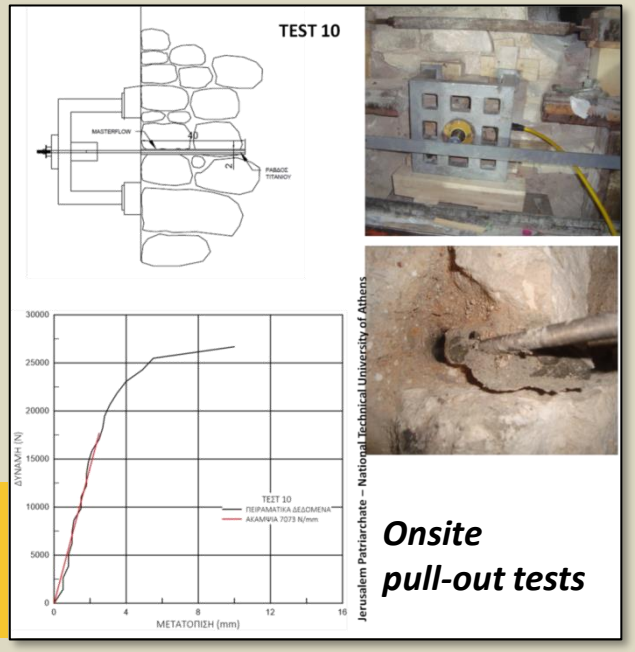
REINFORCEMENT BY TITANIUM

☑ 28.01.2017

The finding of corroded iron support bars necessitates the use of titanium, as proposed by the NTUA interdisciplinary team, in order to avoid such phenomena and ensure the longevity of the structure

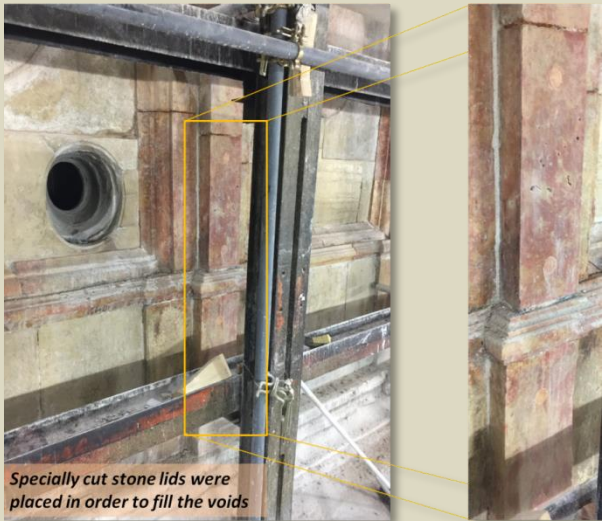
Examples of fully corroded iron support bars in area N1

Holes were drilled at the columns for the installation of titanium anchors



Onsite pull-out tests

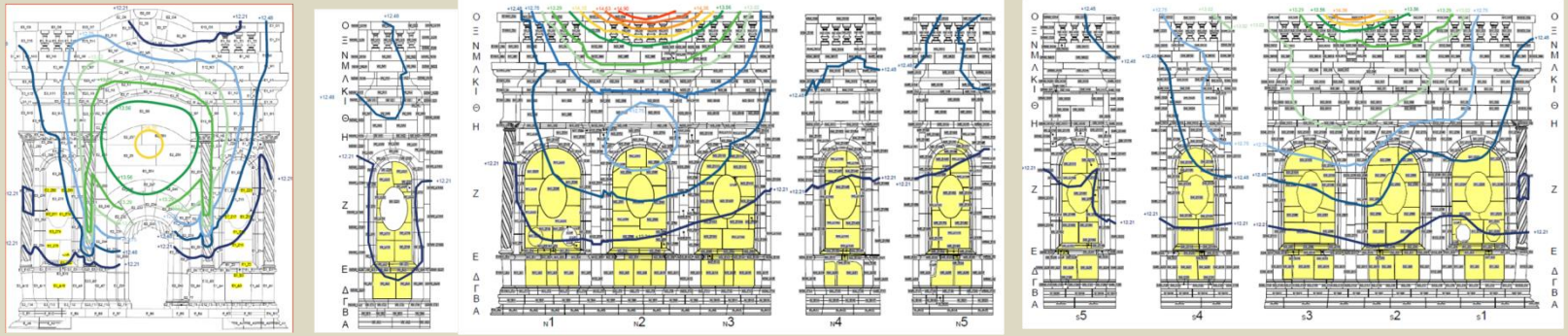
In-situ validation of titanium anchors and bolts design and implementation study



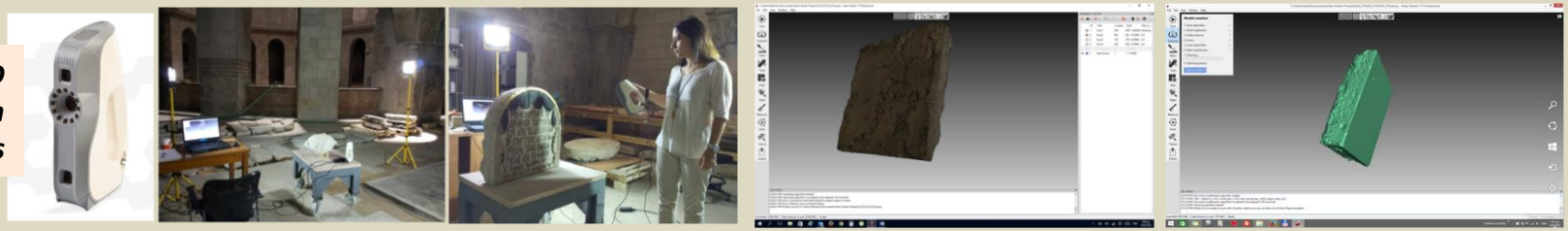
Specially cut stone lids were placed in order to fill the voids

DIGITAL DOCUMENTATION IN COOPERATION WITH THE RESULTS OF EXPERIMENTAL TESTS AND FEM PERMITS THE DESIGN OF SLABS ANCHORING

Calculation of seismic loads for the design of marble slab attachments by Finite Element Modeling analysis

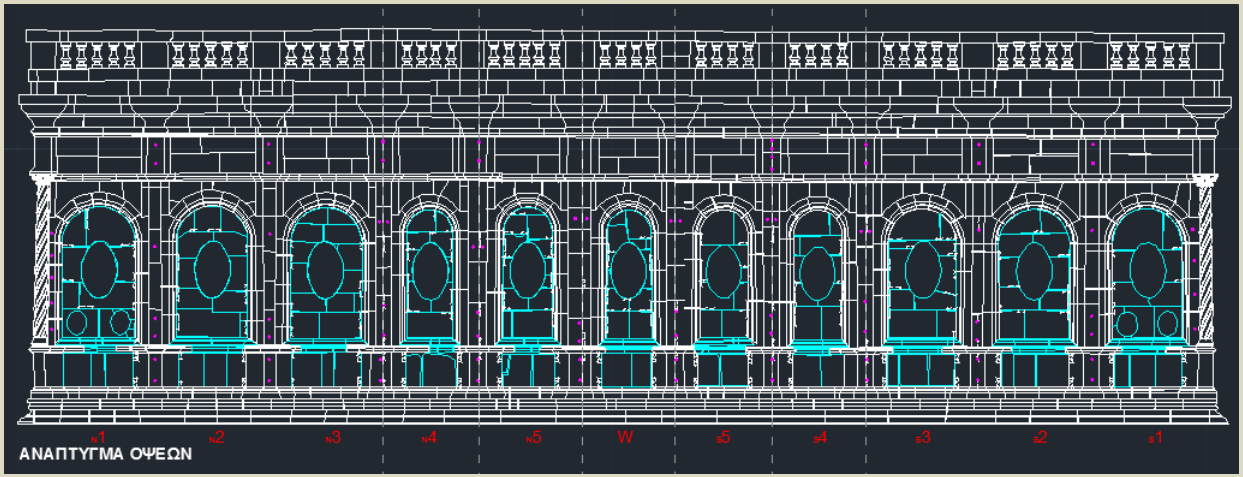


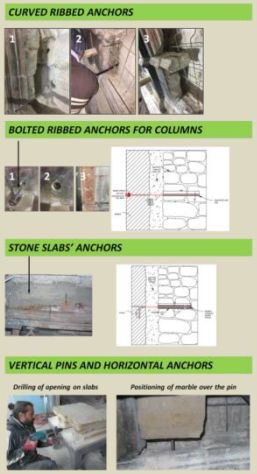
3D documentation of stone slabs



DESIGN OF REINFORCEMENT POSITIONS

Architectural and geometric documentation allows for the design of the anchors and bolts positions





RESETTING AND ANCHORING OF INTERIOR MARBLES

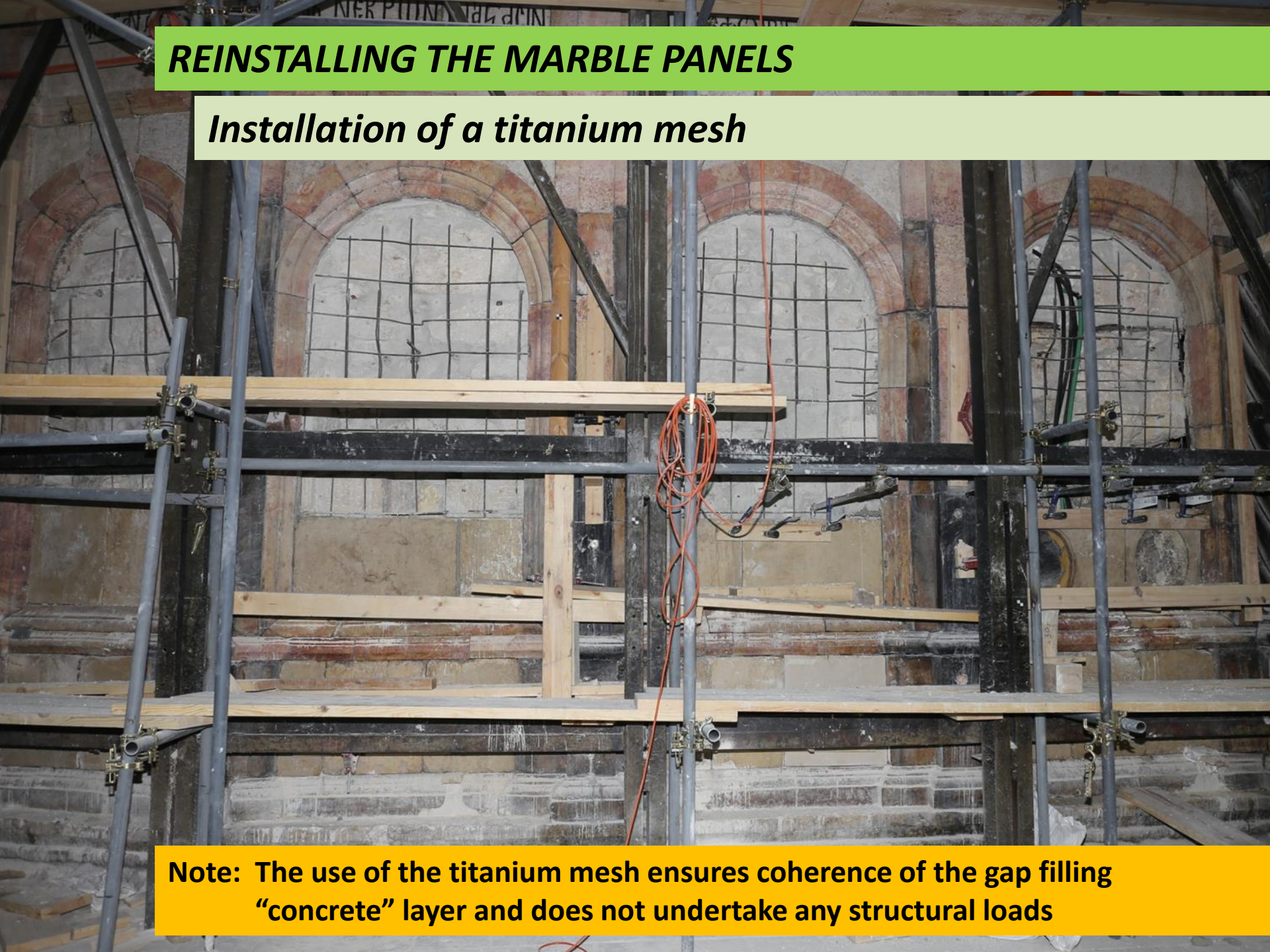
☑ 06.02.2017

Plan for anchoring of columns in the interior of the Chapel of the Angel (by Assist.Prof. Ch.Mouzakis)

3D reconstruction of the interior of the Chapel of the Angel

REINSTALLING THE MARBLE PANELS

Installation of a titanium mesh



Note: The use of the titanium mesh ensures coherence of the gap filling "concrete" layer and does not undertake any structural loads

REINSTALLING THE MARBLE PANELS

Reassembly of the stone slabs

Process of stone slabs reassembly

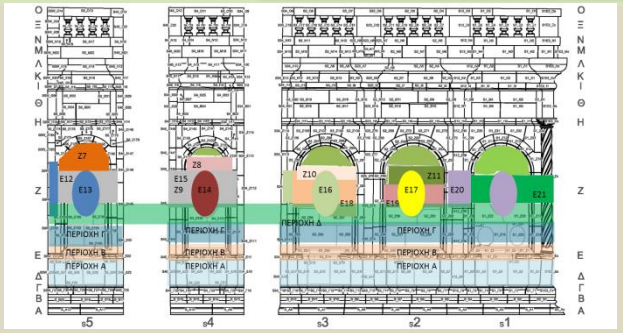
REINSTALLING THE MARBLE PANELS

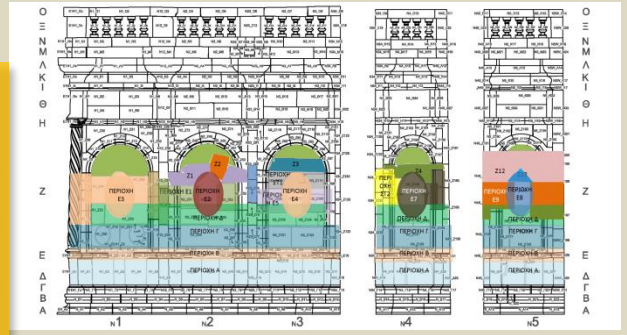
Application of the optimized filling mortar

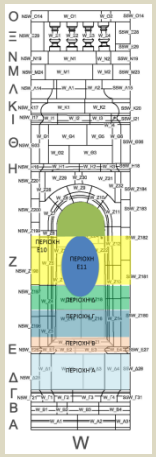
☑ 19.01.2017

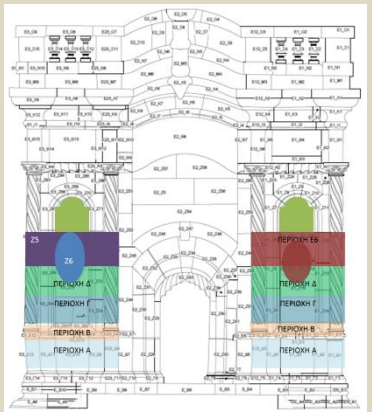
Use of compatible and performing "concrete" in order to fill the gap between the masonry and the reassembled stone slabs. Where the gap was less than 12 mm, the restoration mortar was applied

*All data was **digitally documented** and **validated by NDTs** in order to act as input data for the FEM analysis*





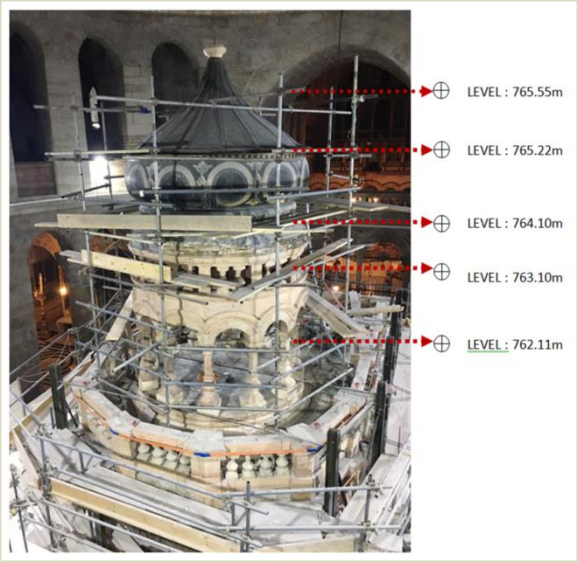


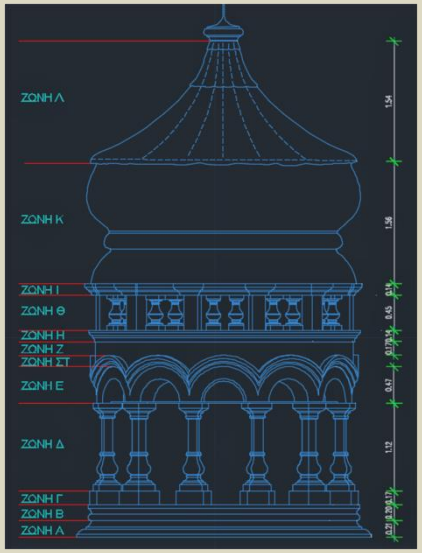


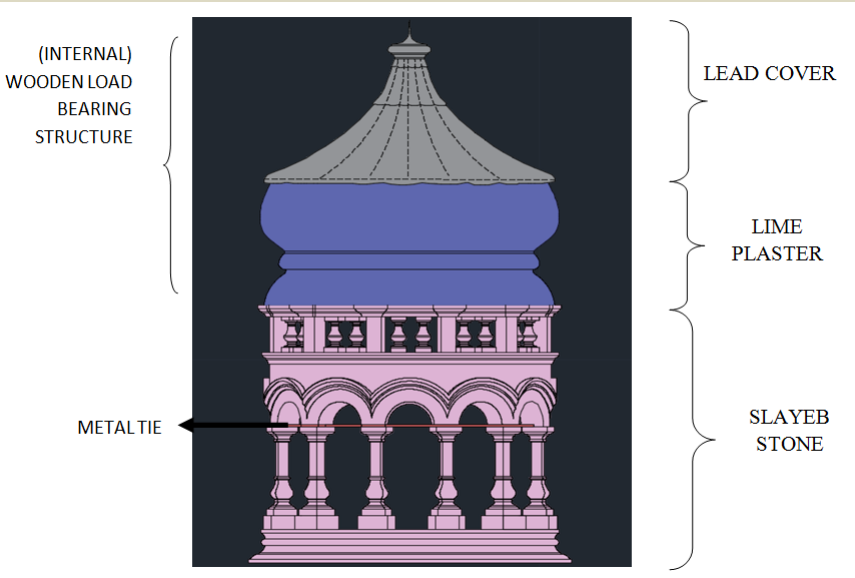
Ημερομηνία	Περιοχή	Κονίαμα/Σκυρόδεμα	Ποσότητα νωπού υλικού (kg)
	A	Σκυρόδεμα	1950,00
	B	Κονίαμα	187,20
	Γ	Σκυρόδεμα	1706,25
	Δ	Σκυρόδεμα	1687,50
13/1/2017	E5	Σκυρόδεμα	150,00
17/1/2017	Z5	Σκυρόδεμα	75,00
17/1/2017	Z6	Κονίαμα	28,80
17/1/2017	EN TOP	Κονίαμα	58,97
17/1/2017	ES TOP	Κονίαμα	0,00

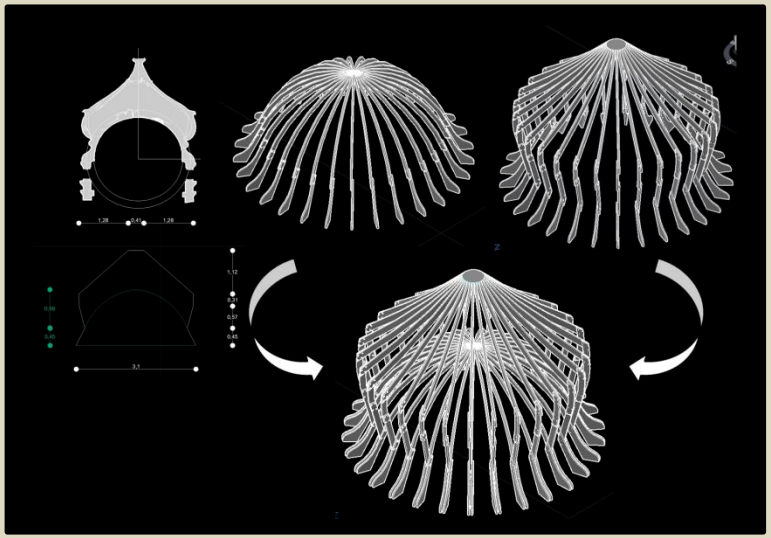
DESIGN OF CONSERVATION, REINFORCEMENT AND RESTORATION INTERVENTIONS

3D REPRESENTATION AND STRUCTURAL ANALYSIS





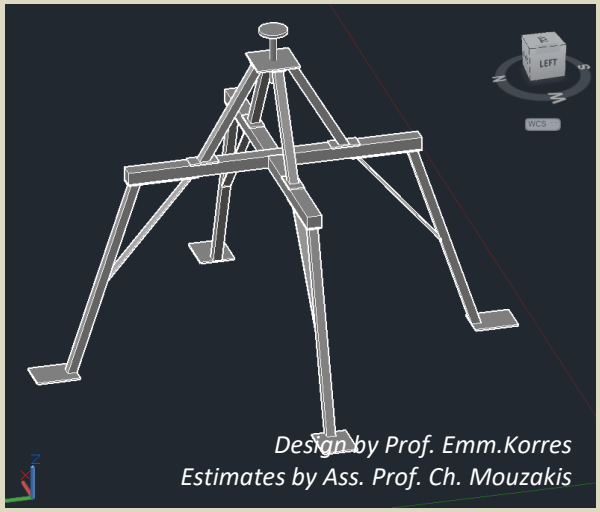




Georeferenced architectural analysis coupled with geometric and materials characterization data

3d Representation of the Onion Dome internal wooden structure

ONION DOME OUTER CUPOLA METAL SUPPORT



DISINFECTATION OF THE HOLY AEDICULE'S ONION DOME WOODEN ELEMENTS OF WOOD-BORING INSECTS AND FUNGHI


Disinfectation process


Ventilation system in the dome

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Infested Wooden Pieces

CLEANING

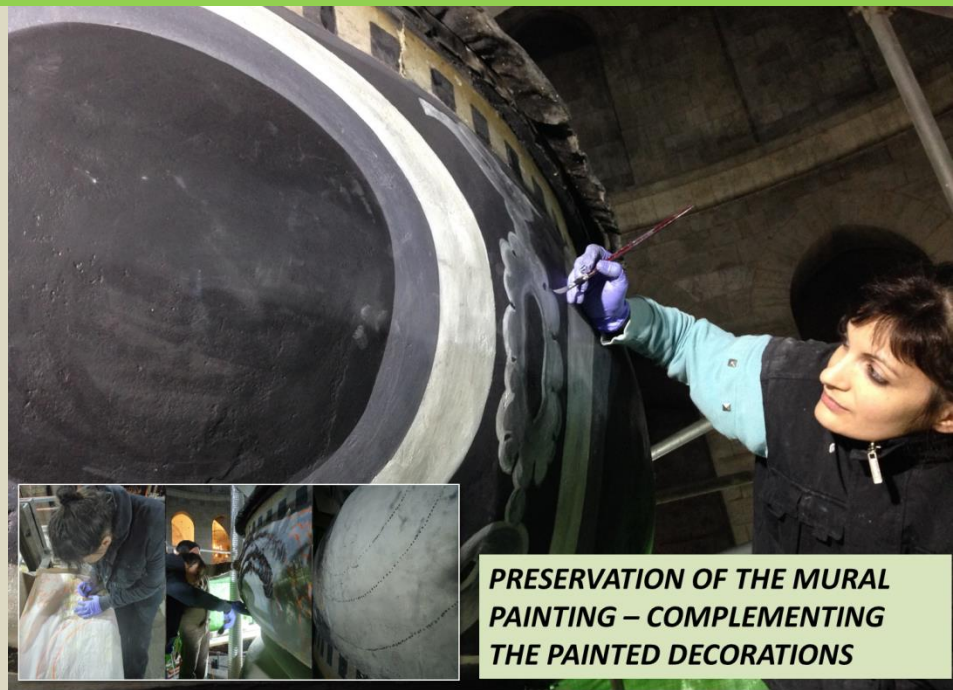
REINFORCEMENT AND CONSOLIDATION OF CRACKS

- Primal 3% acrylic emulsion

CONSERVATION INTERVENTIONS AT THE ONION DOME

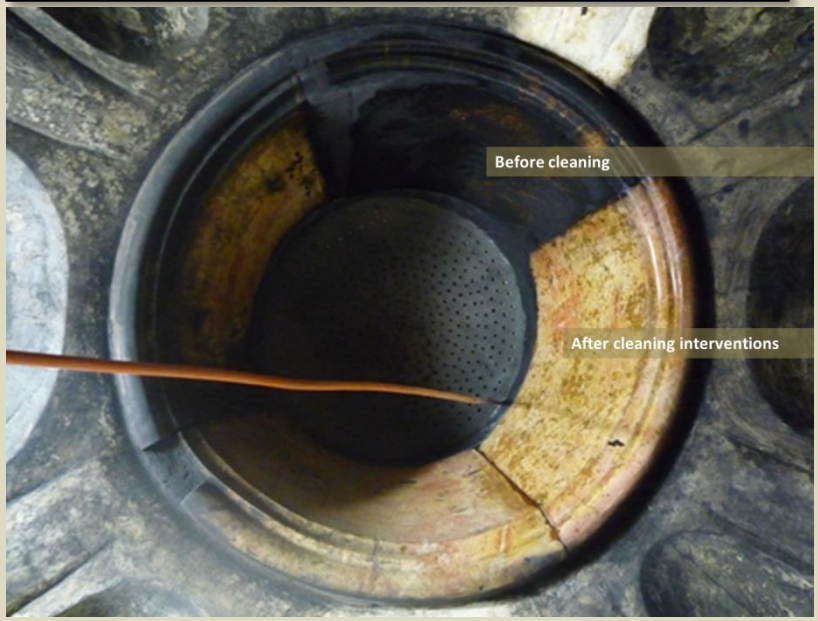
APPLICATION OF PLASTERS (TWO LAYERS)

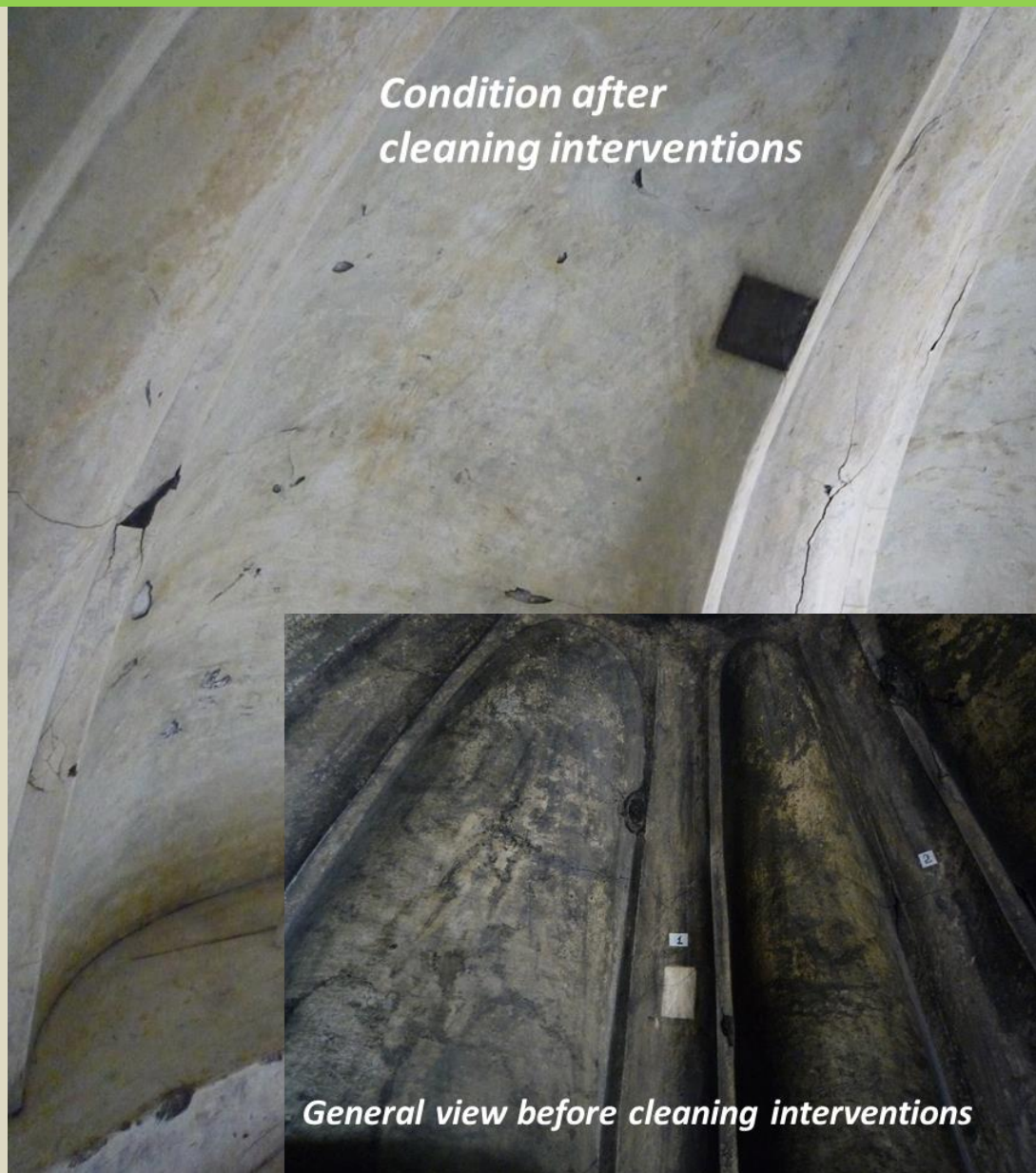
1st layer: MasterEmaco S TIX 285
2nd (top) layer: MasterEmaco S TIX 285 sieved at 1mm

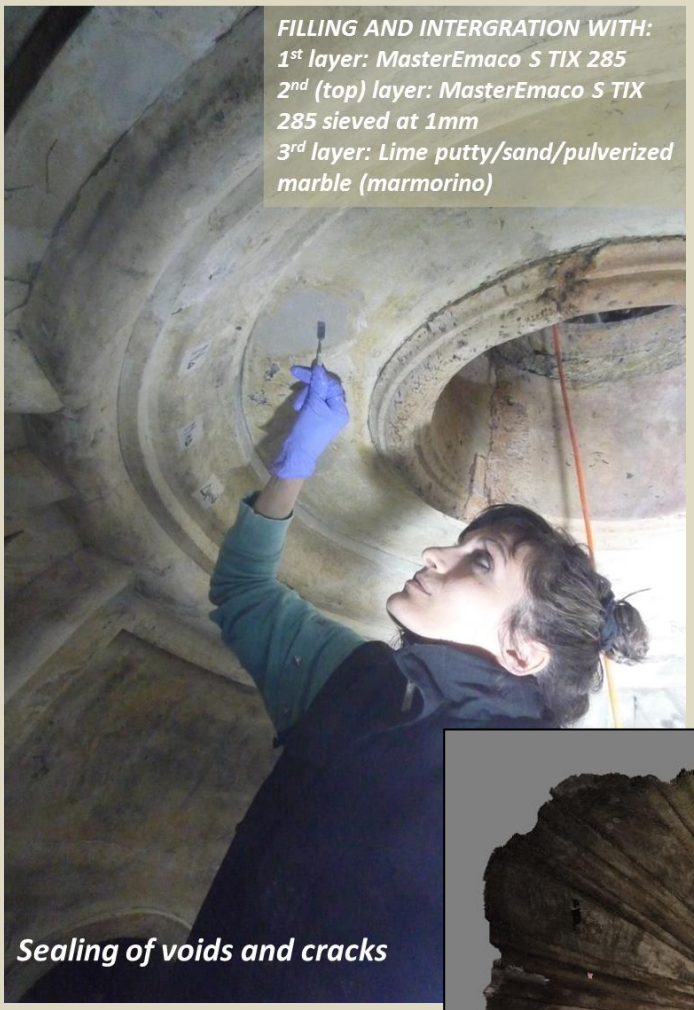


PRESERVATION OF THE MURAL PAINTING – COMPLEMENTING THE PAINTED DECORATIONS

CONSERVATION INTERVENTIONS AT THE DOME OF THE TOMB CHAMBER

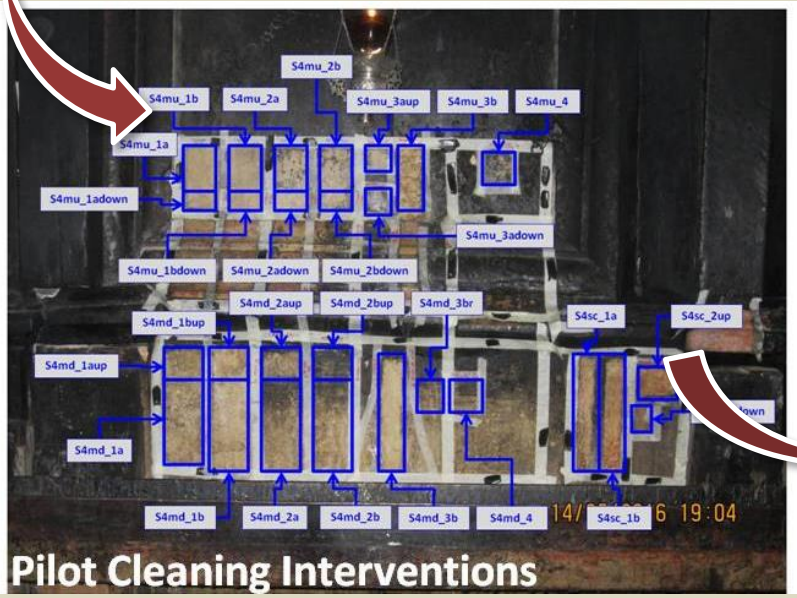






CONSERVATION INTERVENTIONS AT THE DOME OF THE CHAPEL OF THE ANGEL

CLEANING INTERVENTIONS

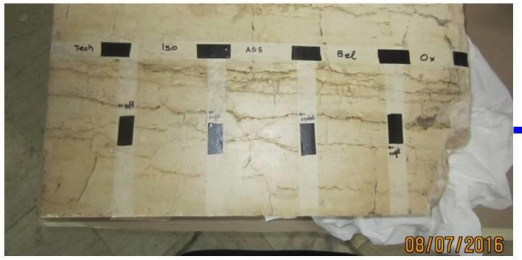


PROTECTION INTERVENTIONS

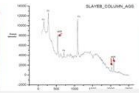
FROM PILOT APPLICATION

TO FINAL APPLICATION

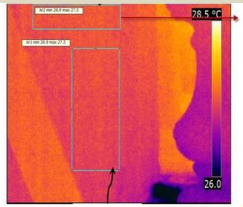
Pilot Protection Interventions



Assessment

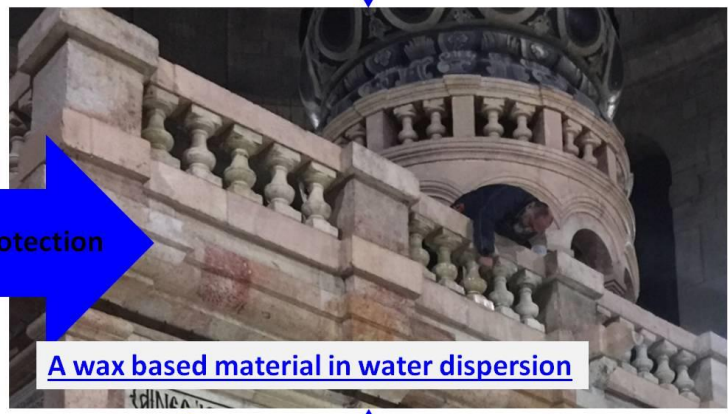


FOM Raman Karsten Tubes



IRT

Final Protection

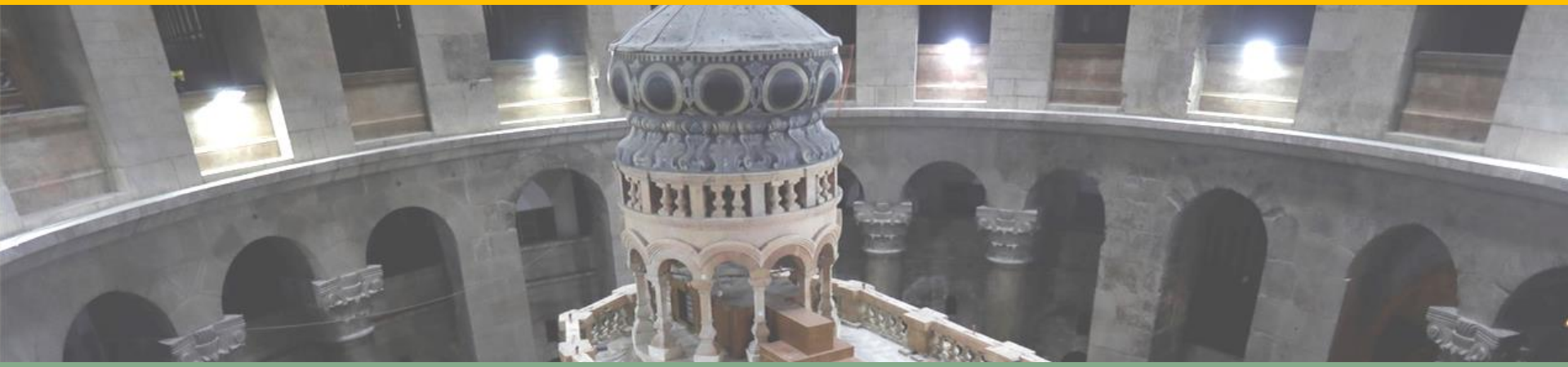


A wax based material in water dispersion

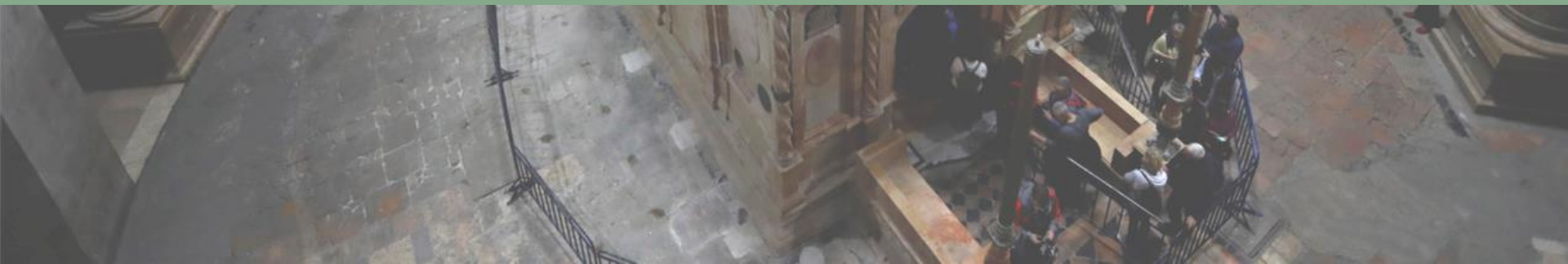
Decision making

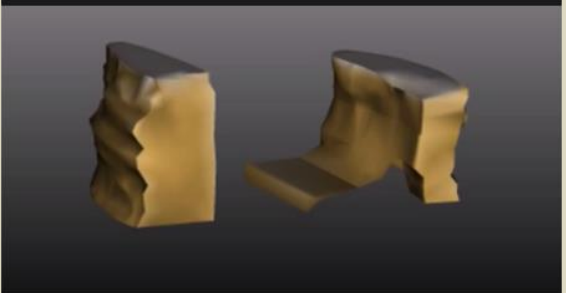
In order to ensure sustainability, a cultural rehabilitation of the pilgrims' attitude is required. The extinguishing of the candles onto the Aedicule's exterior facades, must stop

Innovative methodology to ensure the project's goals



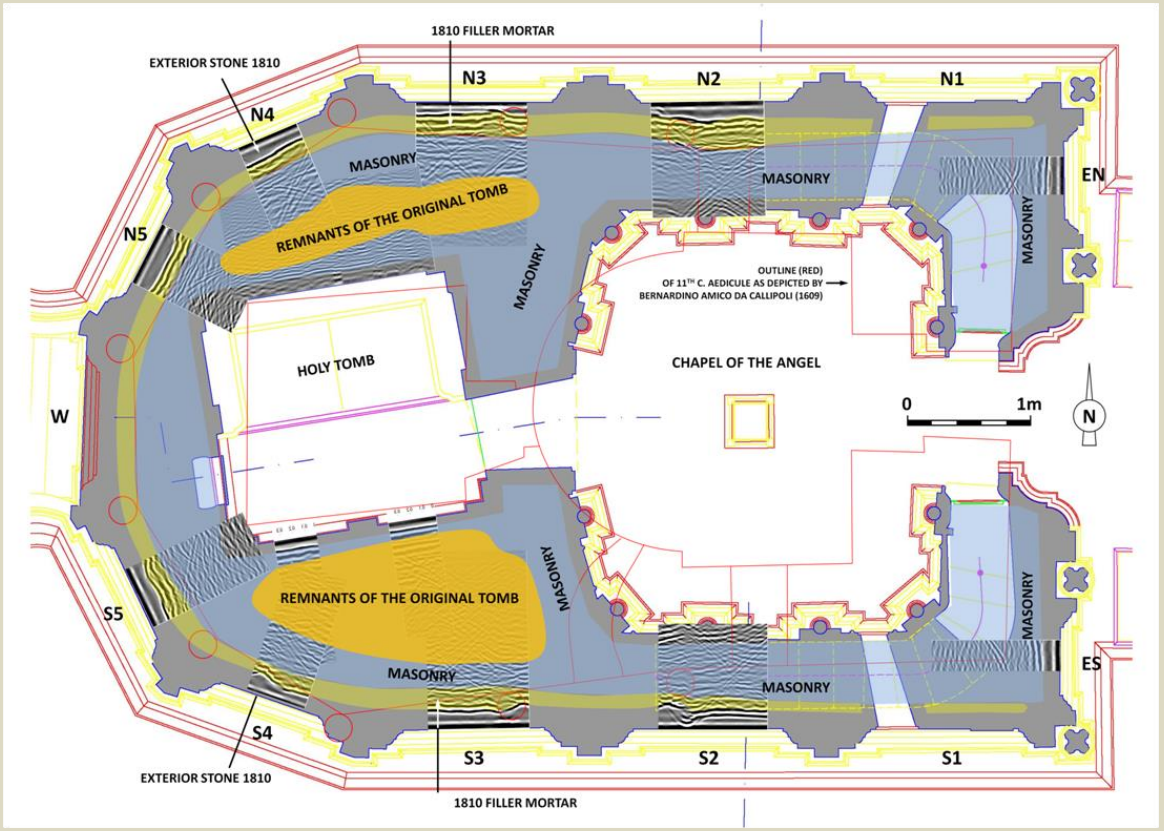
1. Ensure structural integrity, compatibility, performance of materials & interventions
2. Preserve and highlight the values
3. Ensure sustainability





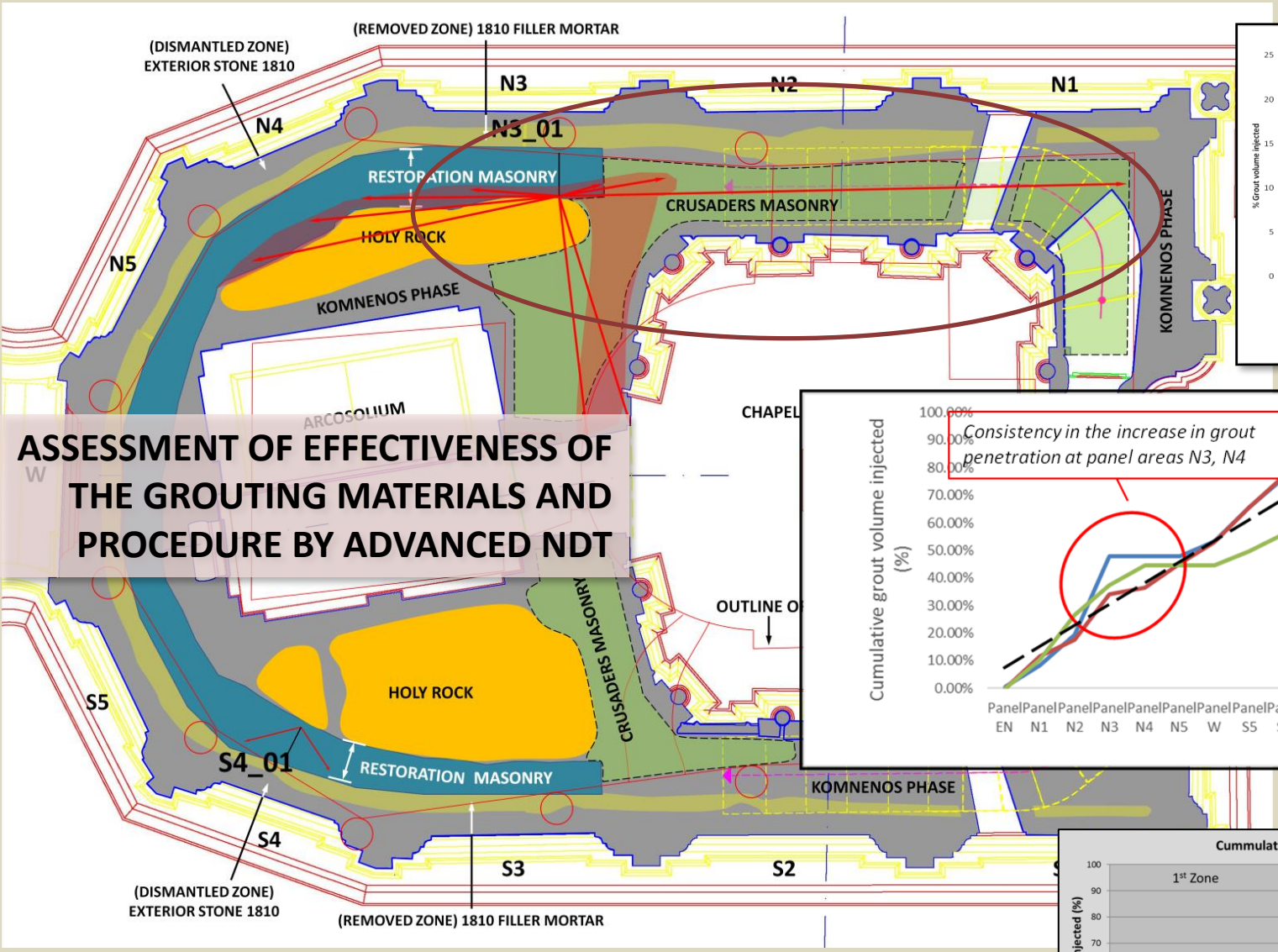
INNOVATIVE PROSPECTION OF THE NON-VISIBLE LAYERS OF THE AEDICULE AS A MAJOR TOOL FOR ITS REHABILITATION

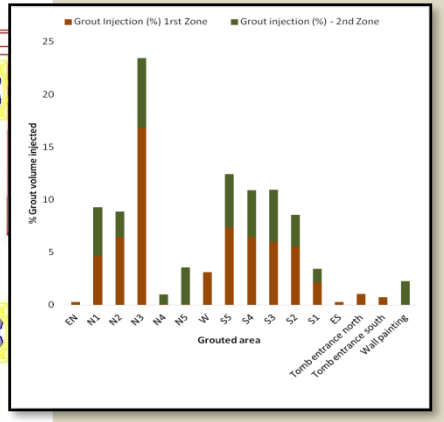
Integrated Non-destructive Prospection, Architectural and Geometric Documentation Digitally Render the Internal Structure of the Holy Aedicule and Reveal its Construction Phases

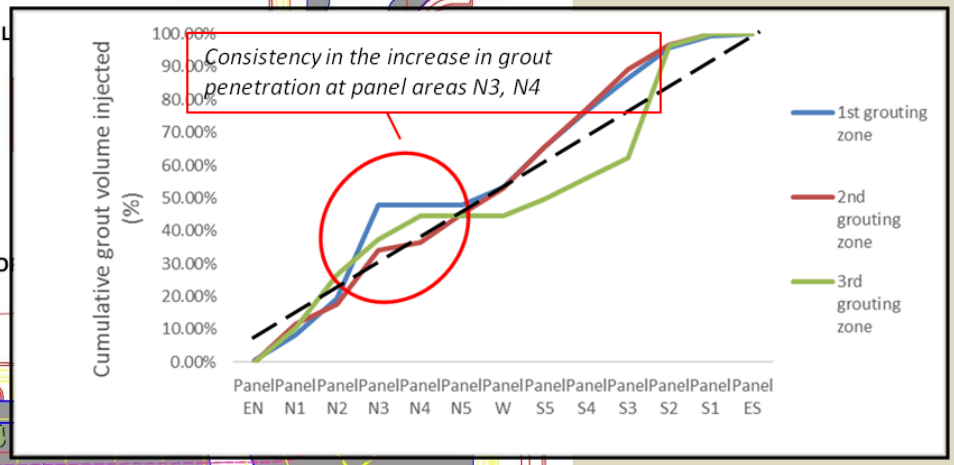


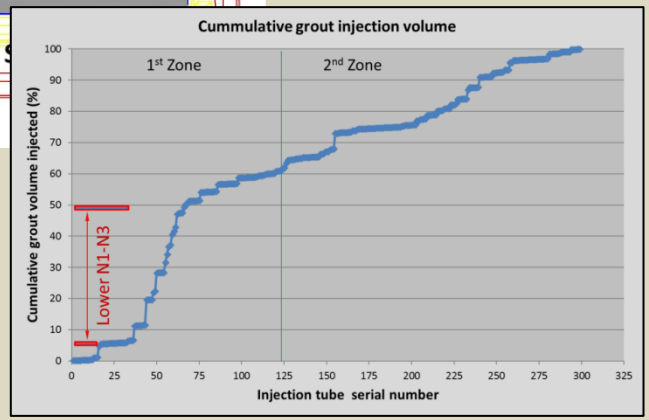
GEOMETRIC AND DIGITAL DOCUMENTATION

ASSESSMENT OF EFFECTIVENESS OF THE GROUTING MATERIALS AND PROCEDURE BY ADVANCED NDT

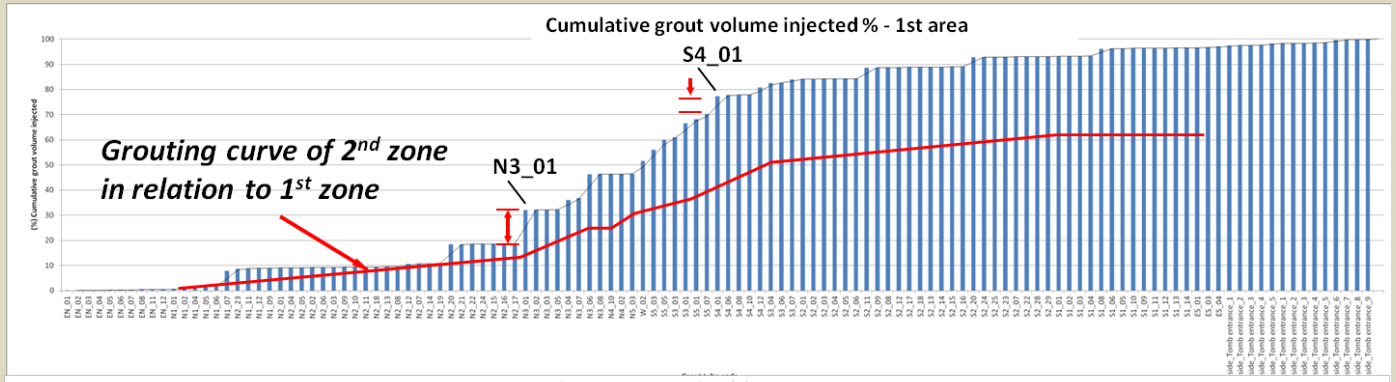


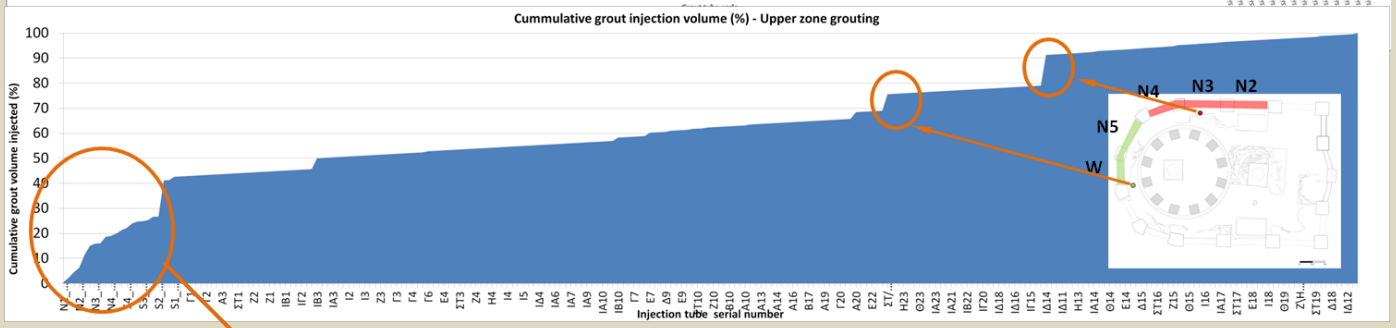


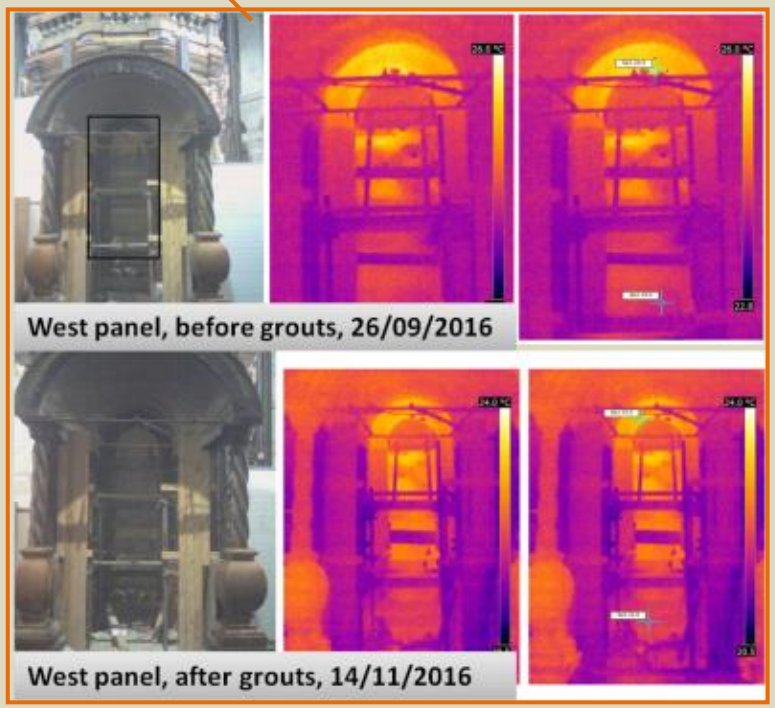




Analysis of the relative location of the exit tubes in the case of insertion tube N3_01, based on the internal structure of the Aedicule as revealed by GPR analysis, shows that ***grouting was successful in homogenizing the interface between the restoration masonry and the north block of Holy Rock as well as the other construction phases***





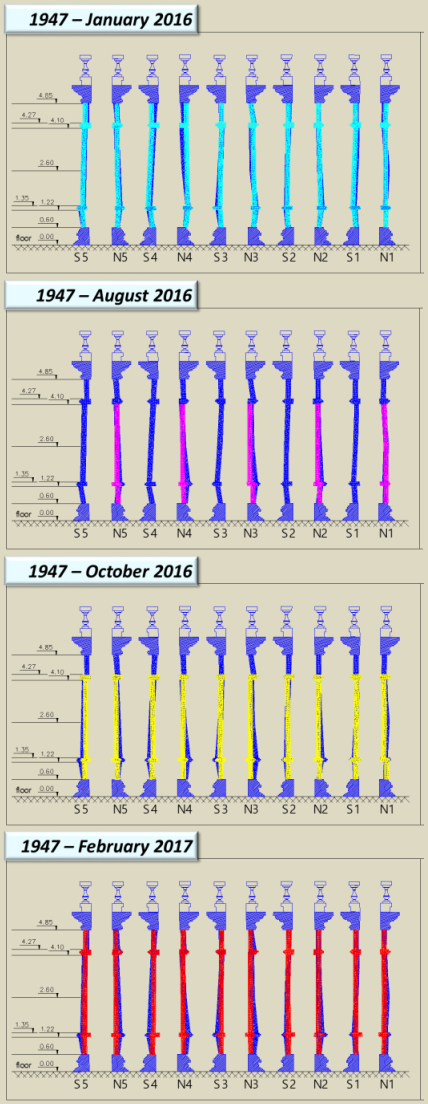


NDTs FACILITATE DECISION MAKING

The higher areas of the panels consumed a significant volume of grout ~40%; this is in accordance with IRTh results conducted after the lower part grouting, which ***showed the presence of voids at the higher panel levels and indicated the necessity of the upper zone grouting***

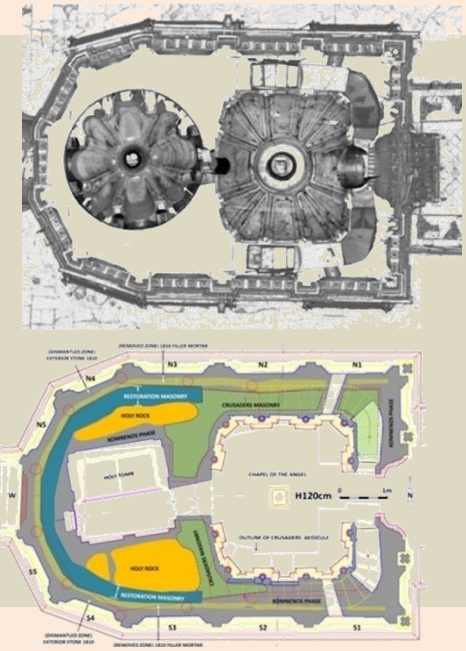
INNOVATIVE METHODOLOGY TO ENSURE STRUCTURAL INTEGRITY

Time Evolution of the columns' Deviations from verticality



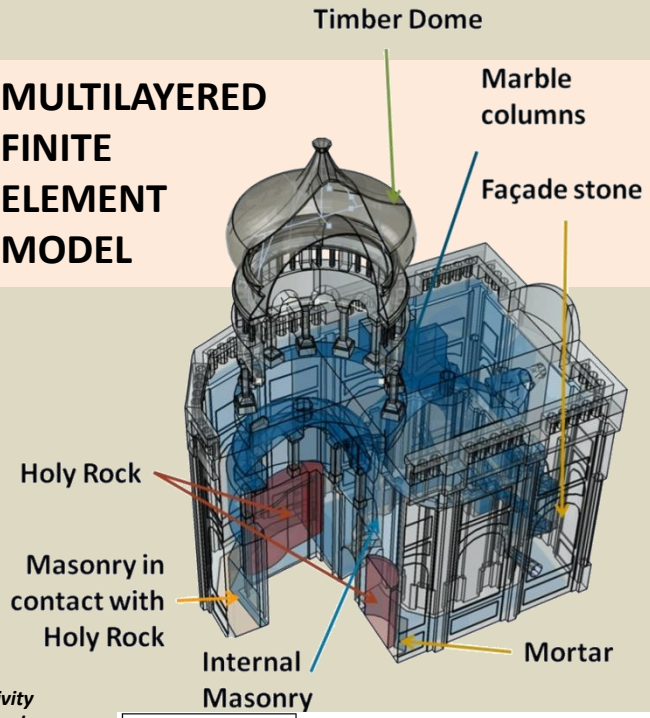
Diminution of the deformations

DIGITAL GEOMETRIC DATA

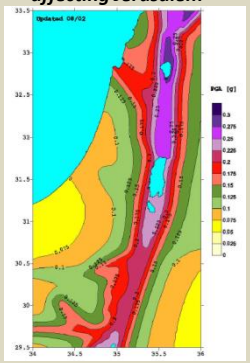


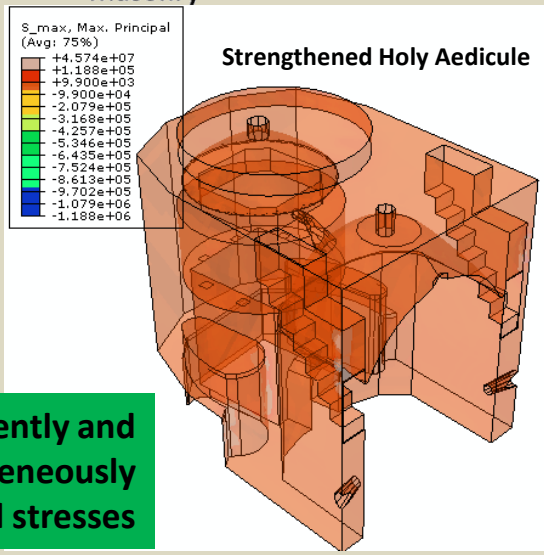
DIGITALIZED MATERIAL DATA

MULTILAYERED FINITE ELEMENT MODEL



Seismic activity affecting Jerusalem





Bearing efficiently and homogeneously max principal stresses

THE RESPONSE OF THE RETROFITTED STRUCTURE IS VALIDATED

*The **retrofitted structure** fulfills the **damage limitation performance level** for the design seismic action.*

INNOVATIVE METHODOLOGY TO REVEAL AND INTERPRET FINDINGS TO PRESERVE AND HIGHLIGHT THE VALUES OF THE MONUMENT

Lifting of the stone of the Tomb revealing the burial monument

3D Reconstruction of the Burial Surface

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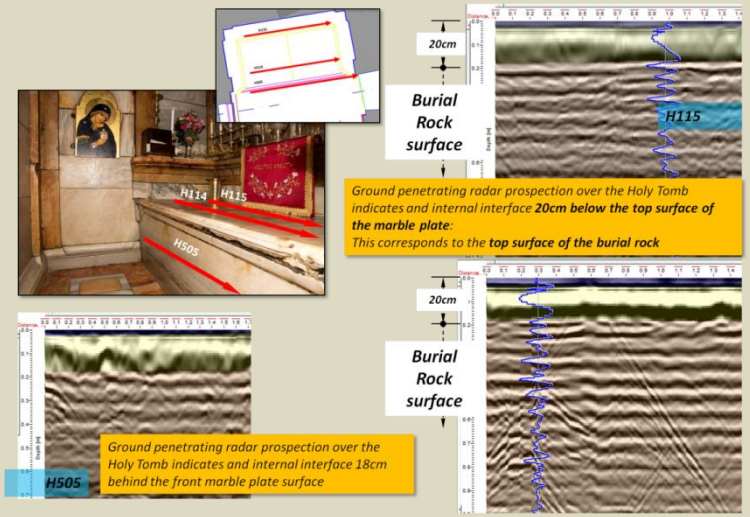
INNOVATIVE METHODOLOGY TO REVEAL AND INTERPRET FINDINGS TO PRESERVE AND HIGHLIGHT THE VALUES OF THE MONUMENT

INNOVATIVE NON-DESTRUCTIVE INSPECTION BY NTUA TO REVEAL THE BURIAL MONUMENT'S MORPHOLOGY

Georadar prospection over the closed tomb

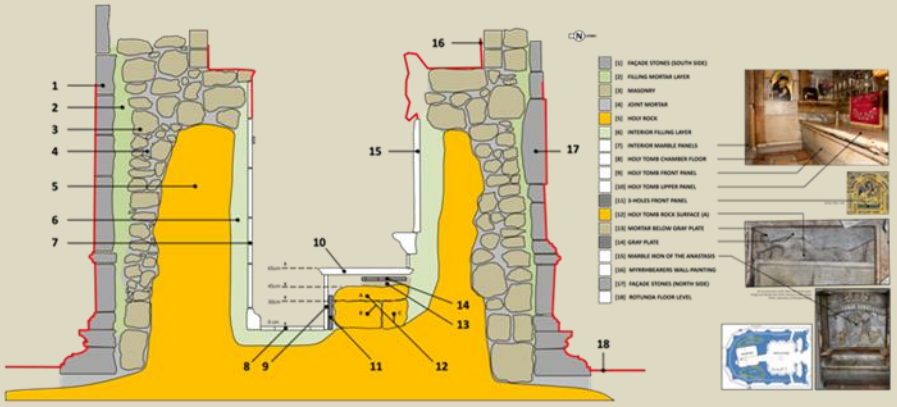


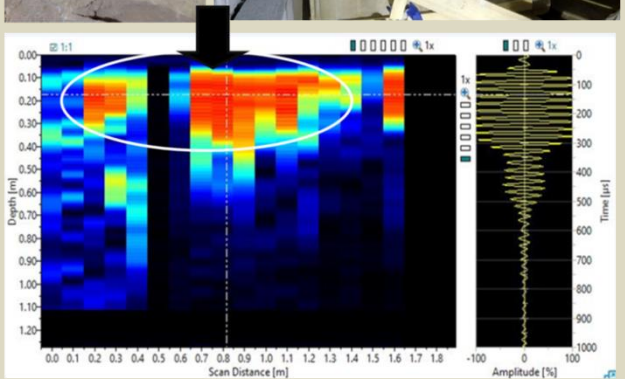
*Ground penetrating radar prospection over the Holy Tomb indicates and internal interface **20cm below the top surface of the marble plate**:*
*This corresponds to the **top surface of the burial rock***

Ground penetrating radar prospection over the Holy Tomb indicates and internal interface 18cm behind the front marble plate surface

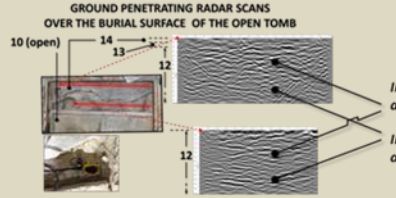
Digital portable microscopy over the burial surface

CONCEPTUAL DESCRIPTION OF HOLY TOMB BASED ON GEORADAR FINDINGS





GROUND PENETRATING RADAR SCANS OVER THE BURIAL SURFACE OF THE OPEN TOMB

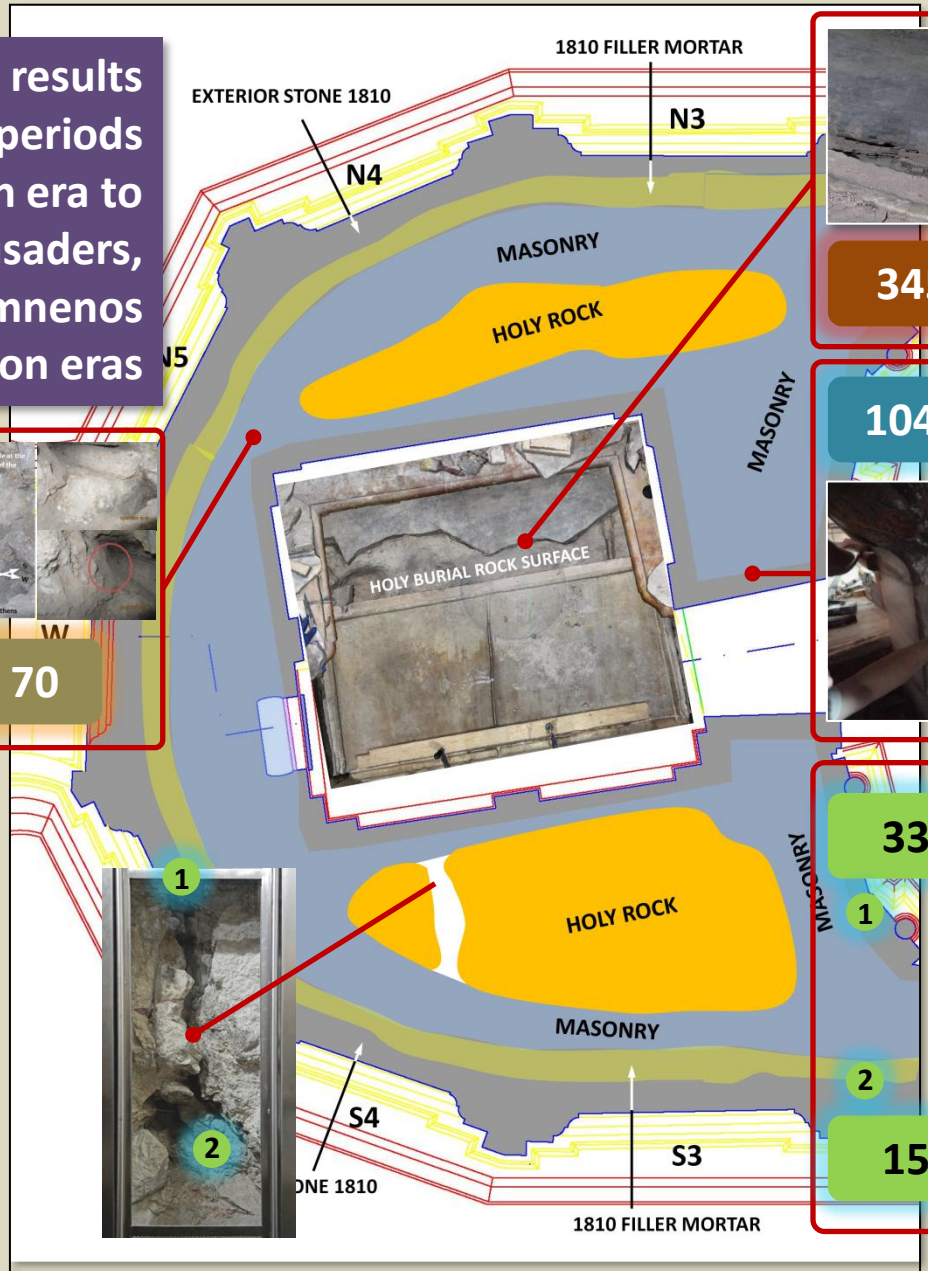


Indications of Internal Rock Feature or Planar Interface approximately 20cm Below The Burial Rock Surface

Indications of Internal Rock Feature or Planar Interface approximately 50cm Below The Burial Rock Surface

INNOVATIVE METHODOLOGY TO REVEAL AND INTERPRET FINDINGS TO PRESERVE AND HIGHLIGHT THE VALUES OF THE MONUMENT

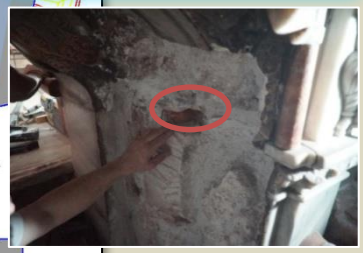
Archaeometric results stemming all historic periods from the Constantinean era to Byzantine, Crusaders, Renaissance and Komnenos restoration eras

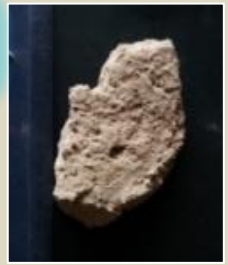


1560AD ± 70

345AD ± 230

1040AD ± 150



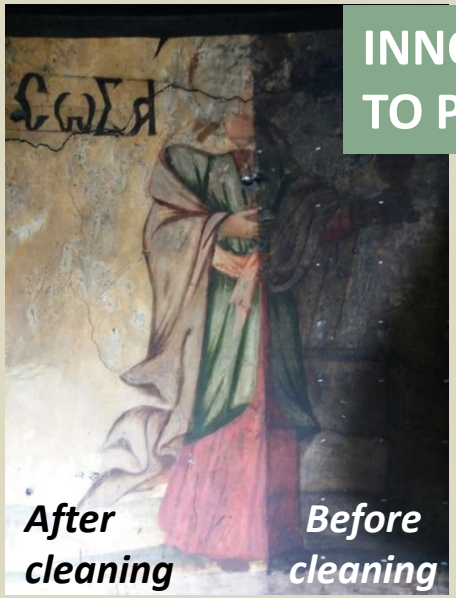


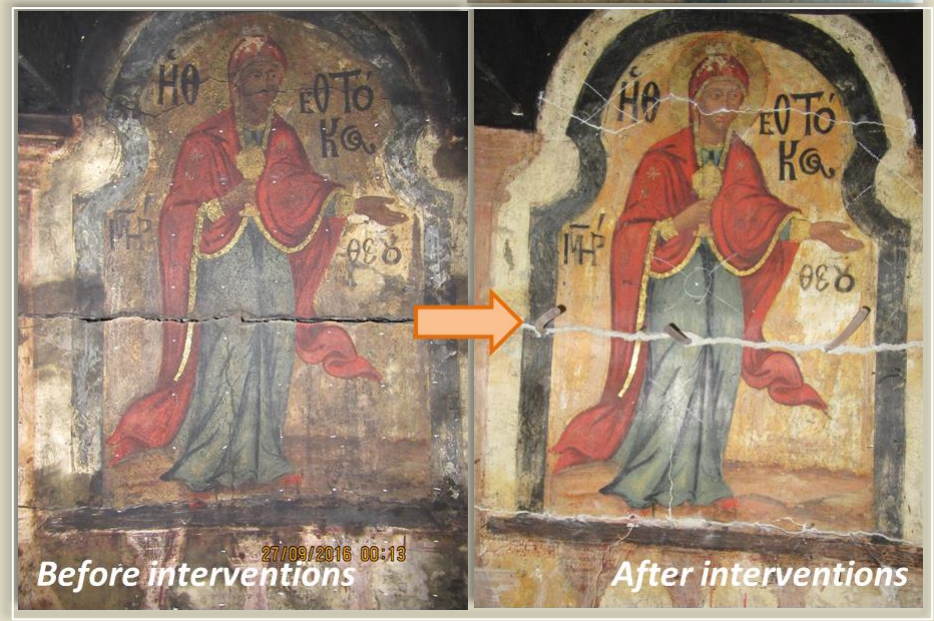
335AD± 235

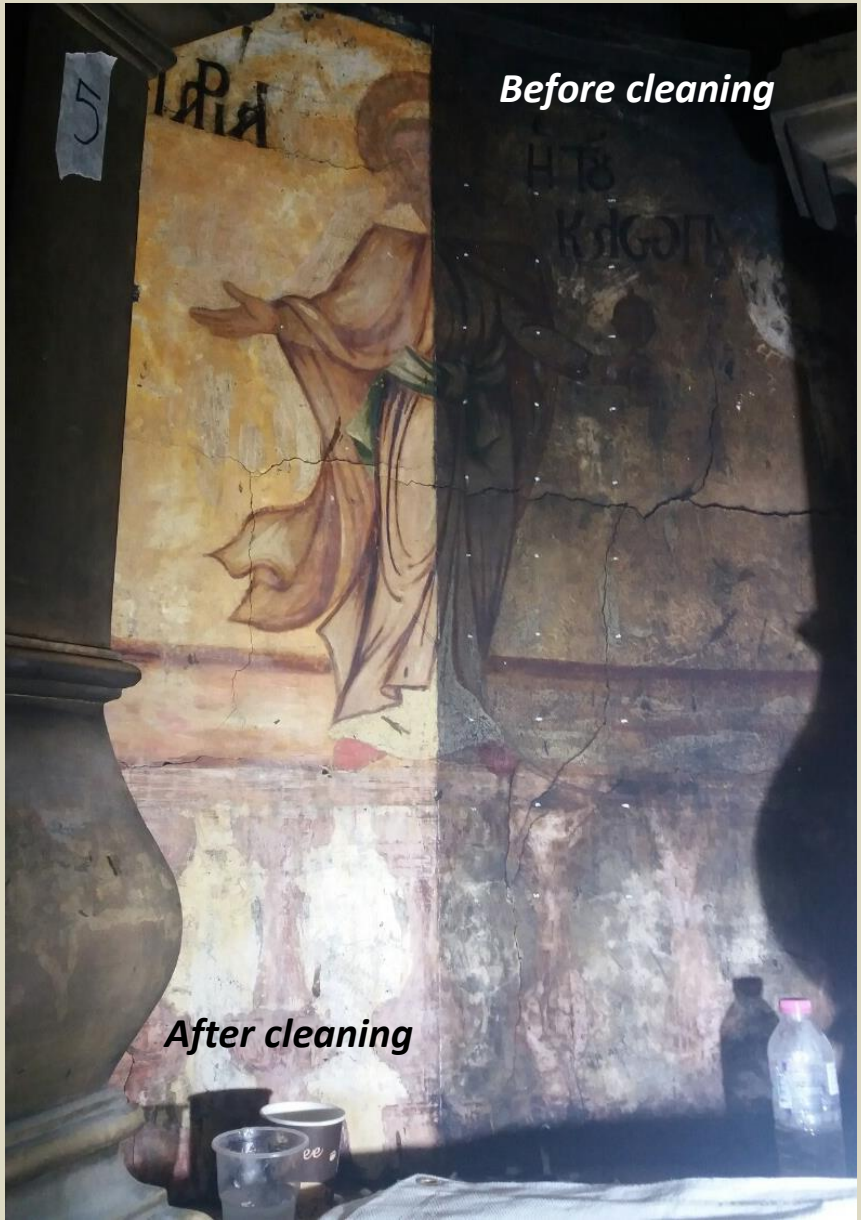
1570AD± 68

Moropoulou, A., Zacharias, N., Delegou, E. T., Apostolopoulou, M., Palamara, E., & Kolaiti, A. (2018). OSL mortar dating to elucidate the construction history of the Tomb Chamber of the Holy Aedicule of the Holy Sepulchre in Jerusalem. *Journal of Archaeological Science: Reports*, *19*, 80-91.

INNOVATIVE METHODOLOGY TO REVEAL AND INTERPRET FINDINGS TO PRESERVE AND HIGHLIGHT THE VALUES OF THE MONUMENT







REVEALING & CONSERVATION OF THE FRESCOES: CHAMBER OF THE TOMB

INNOVATIVE METHODOLOGY TO REVEAL AND INTERPRET FINDINGS TO PRESERVE AND HIGHLIGHT THE VALUES OF THE MONUMENT

Northwest façade

- *Before: left* (May 2015)
- *After: right* (March 2017)

South façade

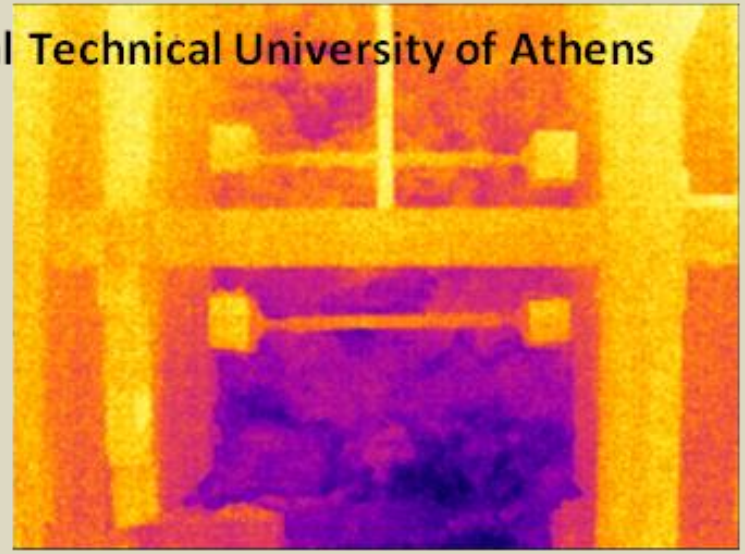
- *Before: upper* (May 2015)
- *After: lower* (March 2017)

REVEALING, CLEANING AND PROTECTION OF EXTERIOR FAÇADE INSCRIPTIONS

INNOVATIVE METHODOLOGY OF RISK ASSESSMENT: SUSTAINABILITY AT RISK

RISK ASSESSMENT:
INTENSE RISING DAMP FROM THE UNDERGROUND

Immediately after the removal of the external stone slabs intense rising damp phenomena were observed



The temperature difference between the lower and the upper part of the masonry is suggested from the thermograph (July 2016)

The revealed masonry behind panel N2

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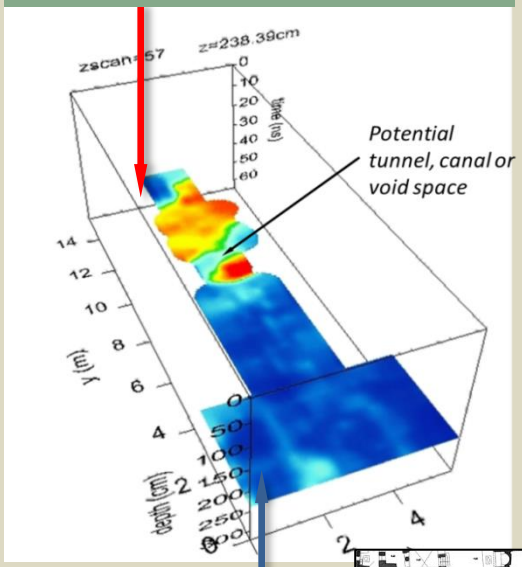
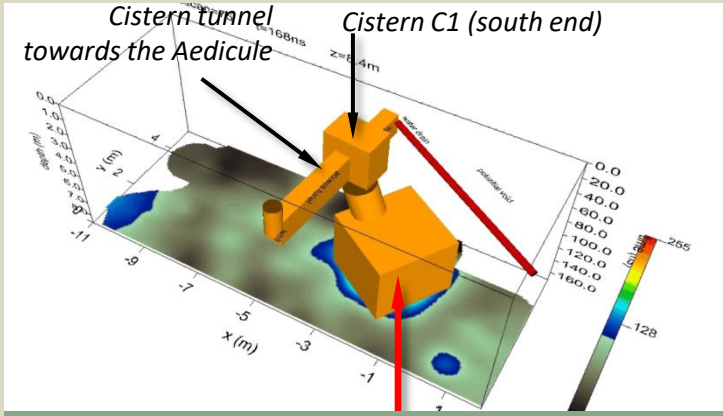
RISK ASSESSMENT: 3D DIGITAL NDT PROSPECTION OF UNDERGROUNDS RISKS

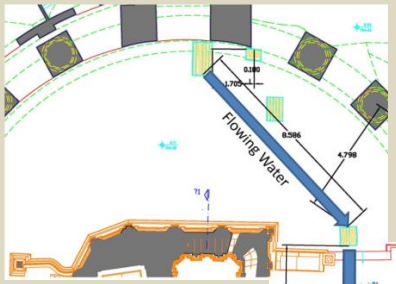
Ground penetrating radar, ***Electrical Resistivity Survey***, ***Electromagnetic Probe Systems***, and ***Robotic Cameras*** identified and documented the nature and state of all underground features related to water and humidity transport phenomena below and around the Holy Aedicule and neighboring areas

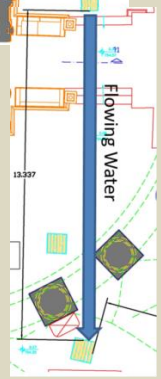
Presence of a potential void space under the Chapel of the Angel



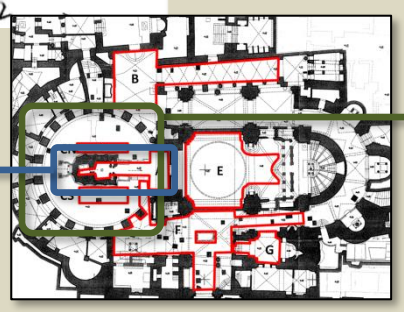


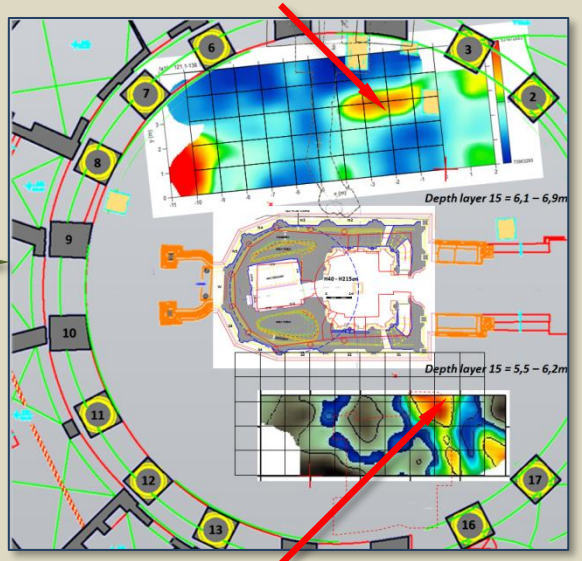
Large underground void *below cistern C1*





The underground canal that runs at the north east and east sides of the Rotunda floor, is active, full of water, and passes in front of the Aedicule



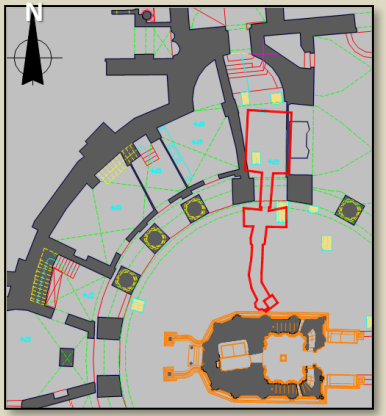


Underground feature in correlation with *the north* ***void space***

Underground water and drainage channels in *need* ***proper design, reconstruction*** *and* ***maintenance***

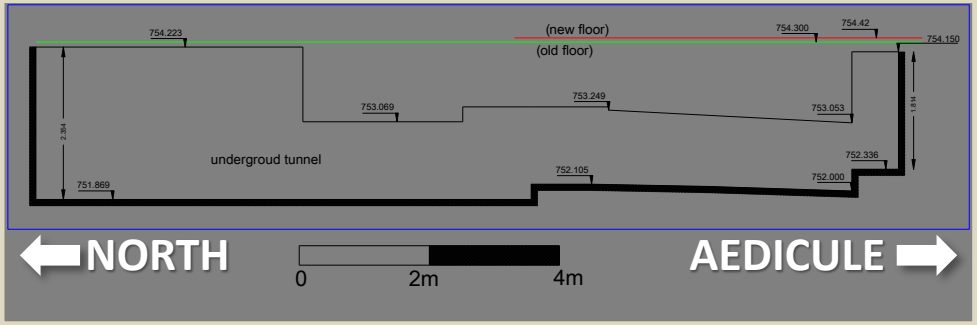
RISK ASSESSMENT: 3D GEOMETRIC DOCUMENTATION OF UNDERGROUND ENVIRONMENT

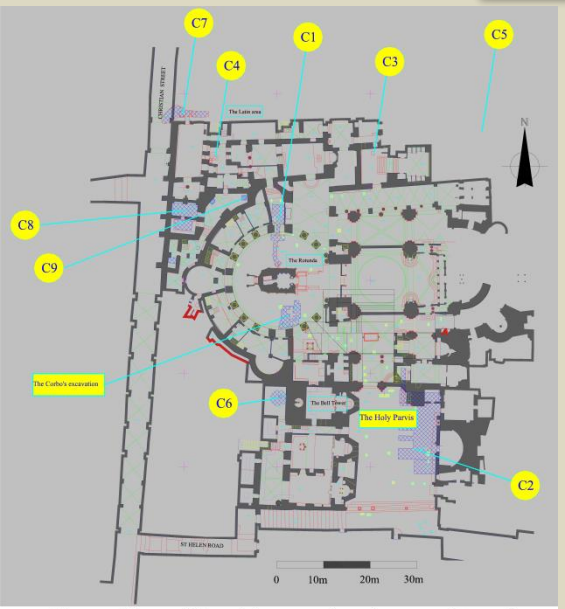
Geometric documentation *determined the* ***depth of each cistern*** *determined its* ***positional relation to the Holy Aedicule*** *in order to assess its eventual impact and* ***documented in detail*** *the most important cisterns*



The position of the cisterns &underground tunnels on the ground plan of the Holy Sepulchre Complex.

C1 ***Geometric documentation (vertical section) of cistern C1***





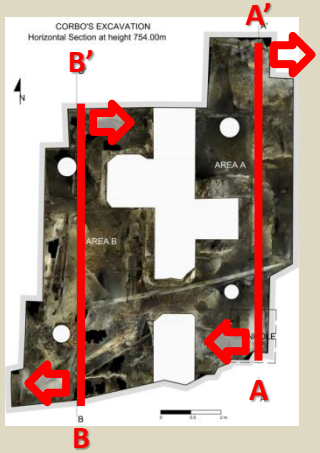
The positions of the cisterns and underground tunnels are presented on the ground plan of the Holy Sepulchre Complex

Cistern	Depth (m)	Situation	Minimum distance from the center of the Holy Aedicule (m)
C1	2.43	without water	3.40
C2	7.30	without water	32.45
C3	-	-	34.00
C4	-	-	29.85
C5	-	-	
C6	11.40	water (0.90m)	23.07
C7	4.79	without water	38.38
C8	0.50	without water	21.38
C9	1.75	without water	18.76
Corbo's excavation	1.00 - 2.65	without water	5.31

1 ***Detailed documentation of underground cisterns***

Section B'B looking east

Orthophoto Horizontal Section at -1m

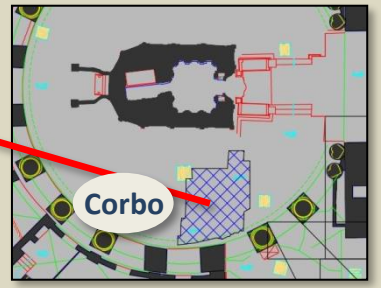


Section A 'A looking east

Section BB' looking west

Section AA' looking west

2 ***Depth, state and relative position of cisterns and underground tunnels in relation to the Holy Aedicule***

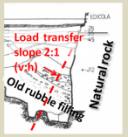


INNOVATIVE METHODOLOGY TO ENSURE SUSTAINABILITY:
UNDERGROUND INTERVENTIONS TO REVERSE THE RISK TO SUSTAINABILITY

FOUNDATION INTERVENTIONS FOR THE UNDERPINNING, REINFORCEMENT, WATER AND HUMIDITY CONTROL

***PROBLEM 1: FOUNDATION ON RUBBLE OF OLDER STRUCTURES AND/OR QUARRY STONES**, providing heterogeneous foundation with voids and weak spots. This condition appears to occur at the north and part of the south sides of the ante-chamber.*

INTERVENTION: **Grouting of the foundation**, using ALBARIA-based grout, with the objective to fill and/or consolidate voids in the rubble.



***PROBLEM 2: FOUNDATION ON NATURAL ROCK** (usually via a thin layer of bedding mortar), **BUT VERY CLOSE TO A STEEP SLOPE**. Condition appears to occur at the south side of the ante-chamber.*

INTERVENTION: A *slope inclination 2:1 is considered as minimum for the stability of the foundation*. If the slope of the natural rock is steeper than 2:1, the **rubble between the rock and the red dashed line will be grouted or removed and replaced** by ALBARIA-based mortar and/or stonework (using local Jerusalem red Slayeb limestone).

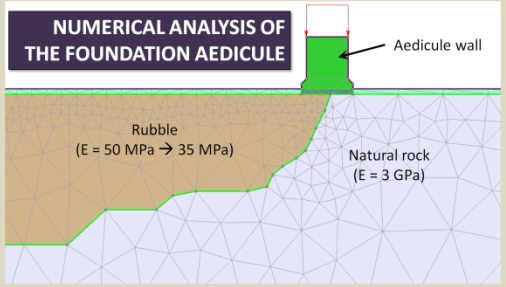
***PROBLEM 3: FOUNDATION ON NATURAL ROCK VIA A THIN (20-30CM) BEDDING LAYER OF LOW SILICATE MORTAR** which has degraded, mainly due to the long-term effects of moisture.*

INTERVENTION: : Corbo's south excavation will be **drained**, **ventilated** and the present reinforced **concrete slab** covering the excavation will be **replaced by a 15cm thick Glass Fibre Reinforced concrete slab**, supported on the perimeter and on the Constantinian stylobate crossing the excavation in the N-S direction (via special bedding to prevent damage to the stylobate). **A glass opening may be left, for antiquities inspection**

***PROBLEM 4: RISING WATER AND MOISTURE**, as leakages from cisterns and water conduits seep through cracks of the natural rock towards the foundation of the Aedicule.*

INTERVENTION: : Corbo's south excavation will be **drained**, **ventilated** and the present reinforced **concrete slab** covering the excavation will be **replaced by a 15cm thick Glass Fibre Reinforced concrete slab**, supported on the perimeter and on the Constantinian stylobate crossing the excavation in the N-S direction (via special bedding to prevent damage to the stylobate). **A glass opening may be left, for antiquities inspection**

NUMERICAL ANALYSIS OF THE FOUNDATION AEDICULE



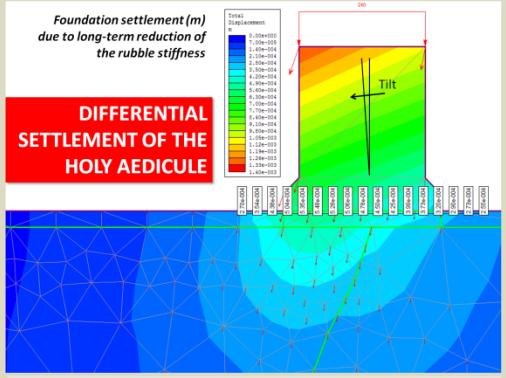
NUMERICAL ANALYSIS OF THE EFFECTS OF LONG-TERM DETERIORATION OF THE RUBBLE

(30% reduction of stiffness) on ground settlement and tilt of the aedicule walls.

- Analysis with finite element computer program PLAXIS.
- Modelling stages : Initial (ground and church loads) & deterioration of rubble under load (30% reduction of rubble stiffness)

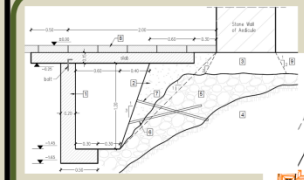
DIFFERENTIAL SETTLEMENT OF THE HOLY AEDICULE

Foundation settlement (m) due to long-term reduction of the rubble stiffness

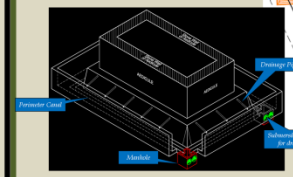


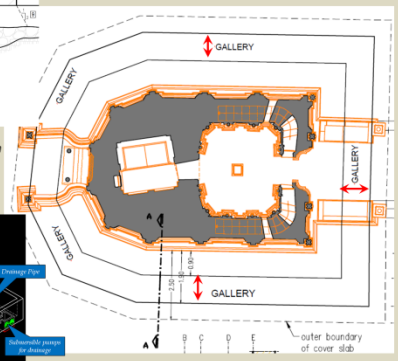
SETTLEMENT at left edge** of footing : 0.5 mm , Settlement **at right** edge of footing : 0.3mm, Tilt : $\theta = (0.5 - 0.3) / 800mm = 2.5 \times 10^{-4}$, Rotation of the top of the Aedicule wall (H=10m) : $\Delta y = H\,\theta = 10000 \times (2.5 \times 10^{-4}) =$ **2.5mm

DRAINAGE/VENTILATION GALLERY



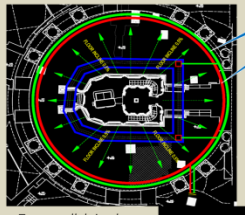
Section AA - Case 5 : Gallery excavated in rubble overlying the natural rock. The rubble is partly excavated and removed, away from the 1:1 stability line





PLAN OF THE PERIPHERAL DRAINAGE AND VENTILATION GALLERY

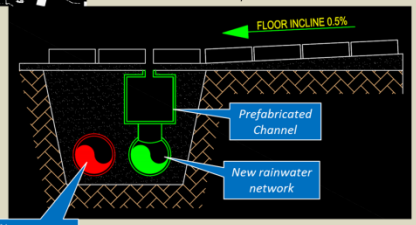
PERIPHERAL PIPING NETWORK



A new functional sewage and rainwater network will be constructed within the perimeter of Rotunda to replace the complex existing network

Inclinations for the best drainage of the surface water towards the new perimeter rainwater network.

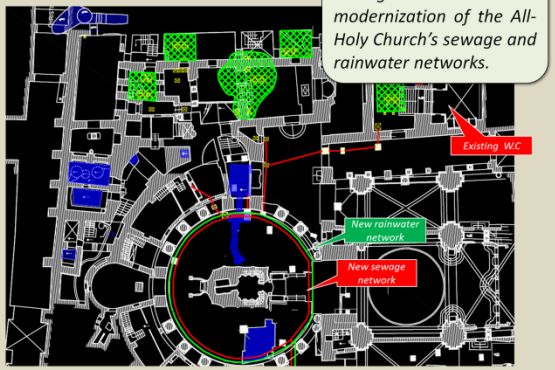
- *Two parallel circular networks in the proximity of Piers' foundation*
- *Connection of the underground gallery's manholes with the circular rainwater network*



Section of the new perimeter rainwater and sewage network.

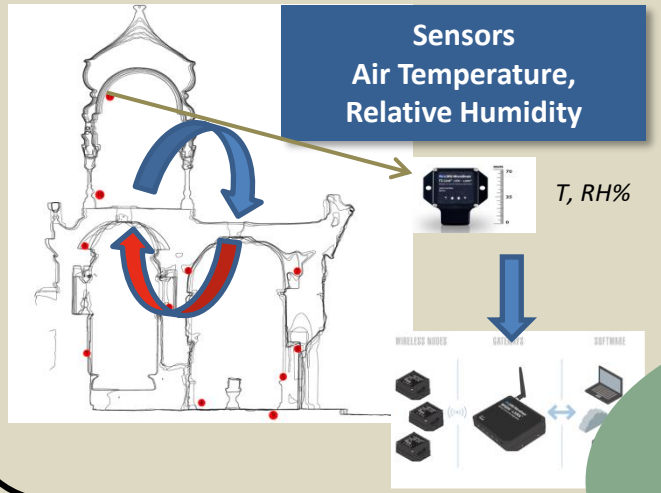
SEWAGE/RAINWATER NETWORK

Interventions for the arrangement and modernization of the All-Holy Church's sewage and rainwater networks.

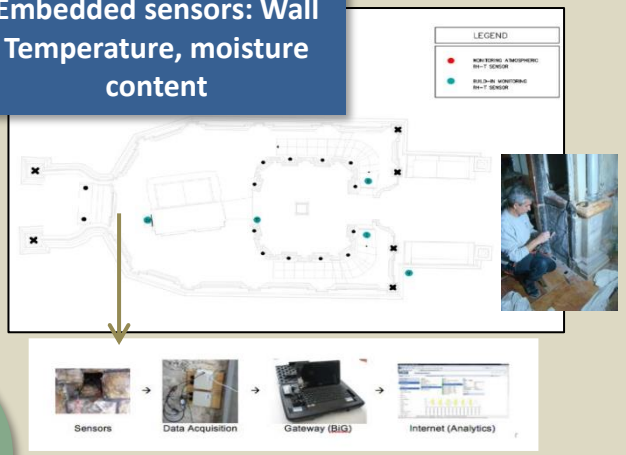


INNOVATIVE METHODOLOGY TO ENSURE SUSTAINABILITY:
MONITORING THE RESPONSE OF THE AEDICULE - MULTISENSORS

HYGROTHERMIC RESPONSE MONITORING

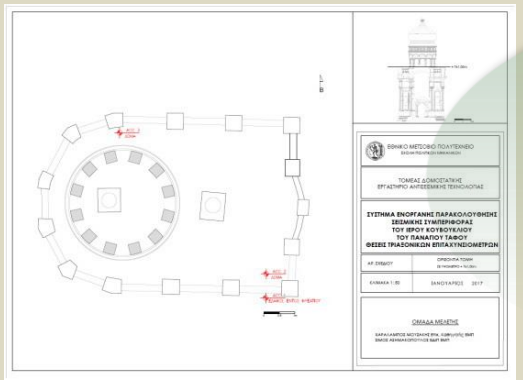


REMOTE DATA ACQUISITION

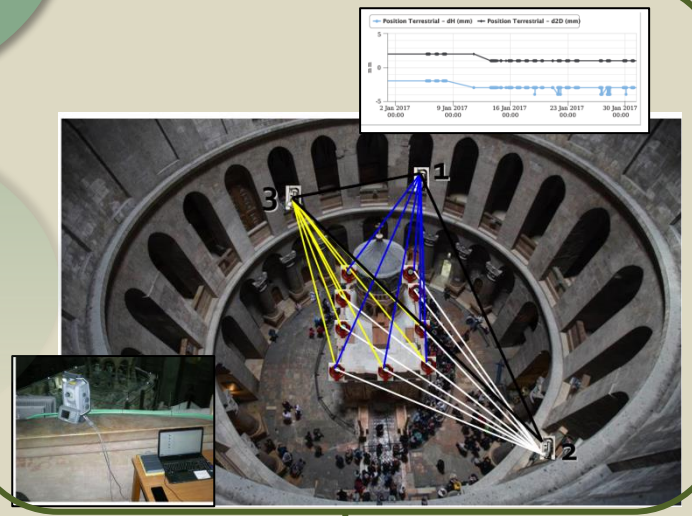


MULTIMODAL PERFORMANCE HEALTH MONITORING

Accelerometer



STRUCTURAL HEALTH MONITORING



3D PRECISE GEODETIC NETWORK

Innovations of the Holy Aedicule rehabilitation

Dynamic digital documentation as a core space of integration

This interdisciplinary project, within a holistic approach, merges capabilities and know-how from the scientific fields of architecture, civil engineering, surveying engineering, materials science and engineering, information technology, archaeometry and archaeology.

Throughout the project, innovative and high-measuring technologies were applied - with emphasis on non-destructive techniques - to fully document the Holy Aedicule, assess its state of preservation, identify the causes of the observed damages, and monitor all rehabilitation interventions

Innovations of the Holy Aedicule rehabilitation

Dynamic digital documentation as a core space of integration

The three-dimensional reconstruction of the monument provides an integrated core space, enables and optimizes:

- ✓ Accurate and detailed (3D) design of rehabilitation interventions
- ✓ Estimation of required quantities of restoration materials
- ✓ Dynamic environment for the optimization and redesign processes throughout all stages of the rehabilitation project
- ✓ Assessment of the rehabilitation, with reference to the main goals

Merging of all necessary information through the 3D data is achieved, by a **fragmented approach**

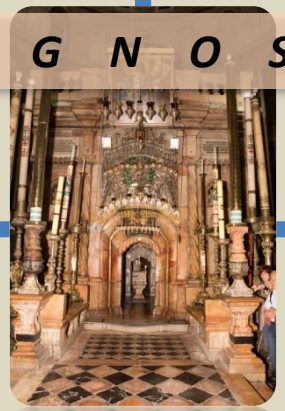
This provides the basis for TRANSDISCIPLINARITY

Aim and interdisciplinary methodology of Research

D O C U M E N T A T I O N

- Integrated documentation of the problem
- Geometric, Structural, Architectural documentation
- Documentation and characterization of building materials

D I A G N O S I S



- Prospection of building phases and decay diagnosis and pathology
- Assessment of current state against static and seismic loads

P R O P O S A L

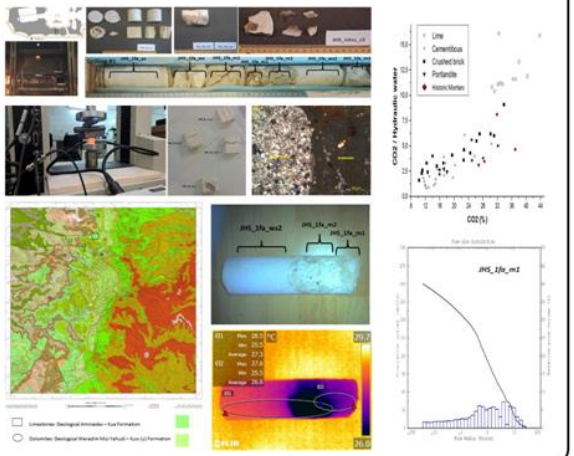
- Principles, ethics, requirements and instructions for conservation reinforcement and rehabilitation materials and interventions
- Continual update of the three religious communities of the Holy Church of the Resurrection in Jerusalem and organization of scientific and institutional debate for decision making regarding the most appropriate solution.

INTERRELATED GEOMETRIC, ARCHITECTURAL, MATERIALS AND STRUCTURAL DOCUMENTATION

How **architectural, historical and materials** characterization **geometrical** documentation and **structural** assessment act as **knowledge based digital infrastructure to support the design of the rehabilitation**

GEOMETRIC DOCUMENTATION

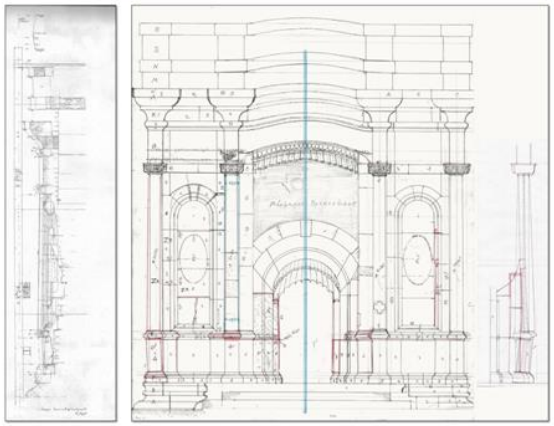
MATERIALS DOCUMENTATION



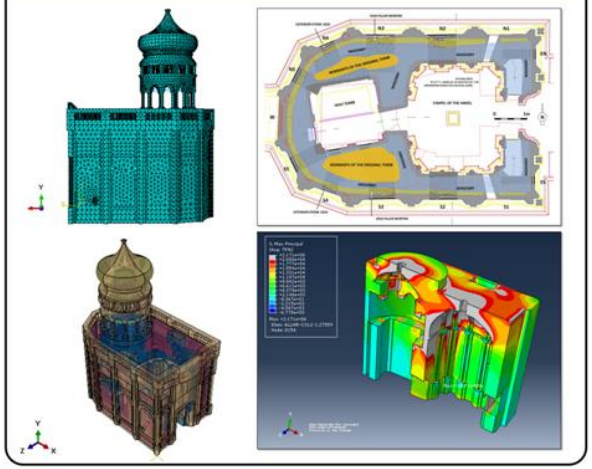
NATIONAL TECHNICAL UNIVERSITY OF ATHENS

DIAGNOSTIC INTERDISCIPLINARY STUDY

ARCHITECTURAL DOCUMENTATION



STRUCTURAL DOCUMENTATION



Knowledge based digital infrastructure to support the design of the rehabilitation

Minimum invasive
Maximum compatibility & performance with historical materials and structures

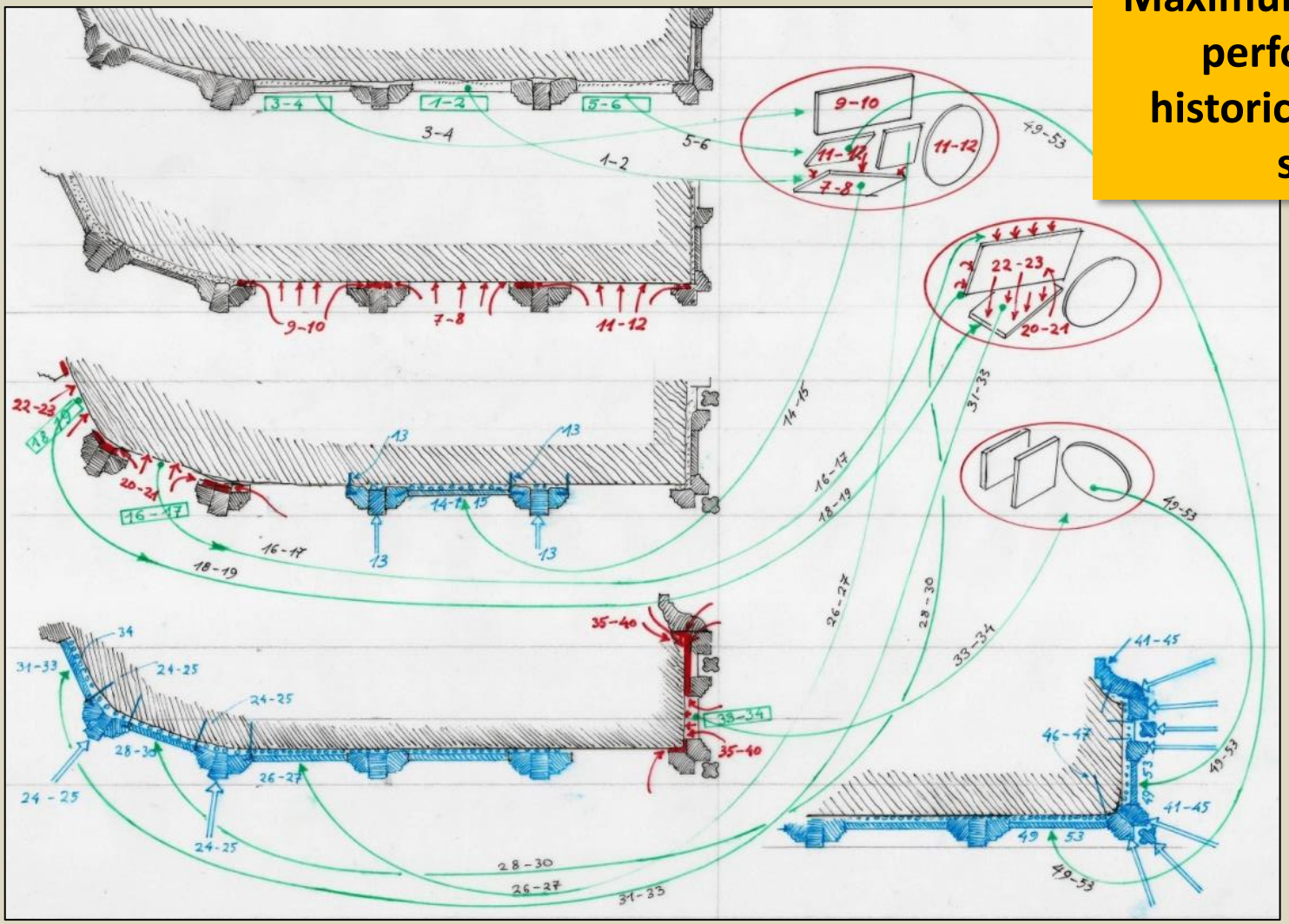


Diagram of the work's progress
(design by Prof. Em. Korres)

INNOVATIVE METHODOLOGY TO REVEAL AND INTERPRET FINDINGS TO PRESERVE AND HIGHLIGHT THE VALUES OF THE MONUMENT

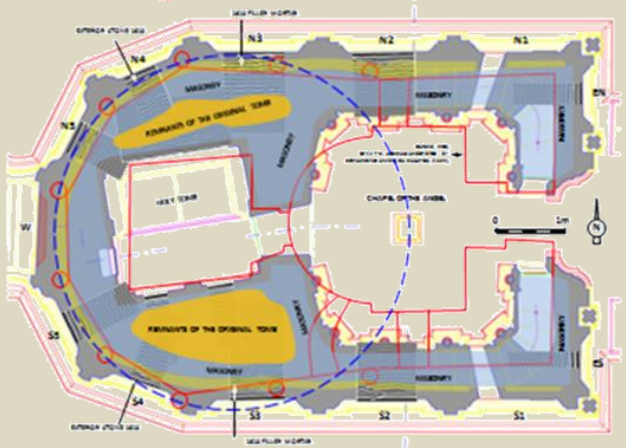
HISTORIC REPRESENTATION OF THE HOLY AEDICULE EVOLUTION BY DIGITAL CORRELATIONS: LATE 16th & EARLY 19th CENT. AEDICULE

Late 16th cent. Aedicule

Early 19th cent. Aedicule

The digital correlation, (NDT prospection, and architectural, geometric and historic documentations) of the late 16th and the early 19th c. Aedicule indicates the probability of embedded parts of the earlier structure:

- *At the western part, up to the Myrrhbearers area*
- *At the eastern part, up to 1.5m of the northern masonry of the Chapel of the Angel*

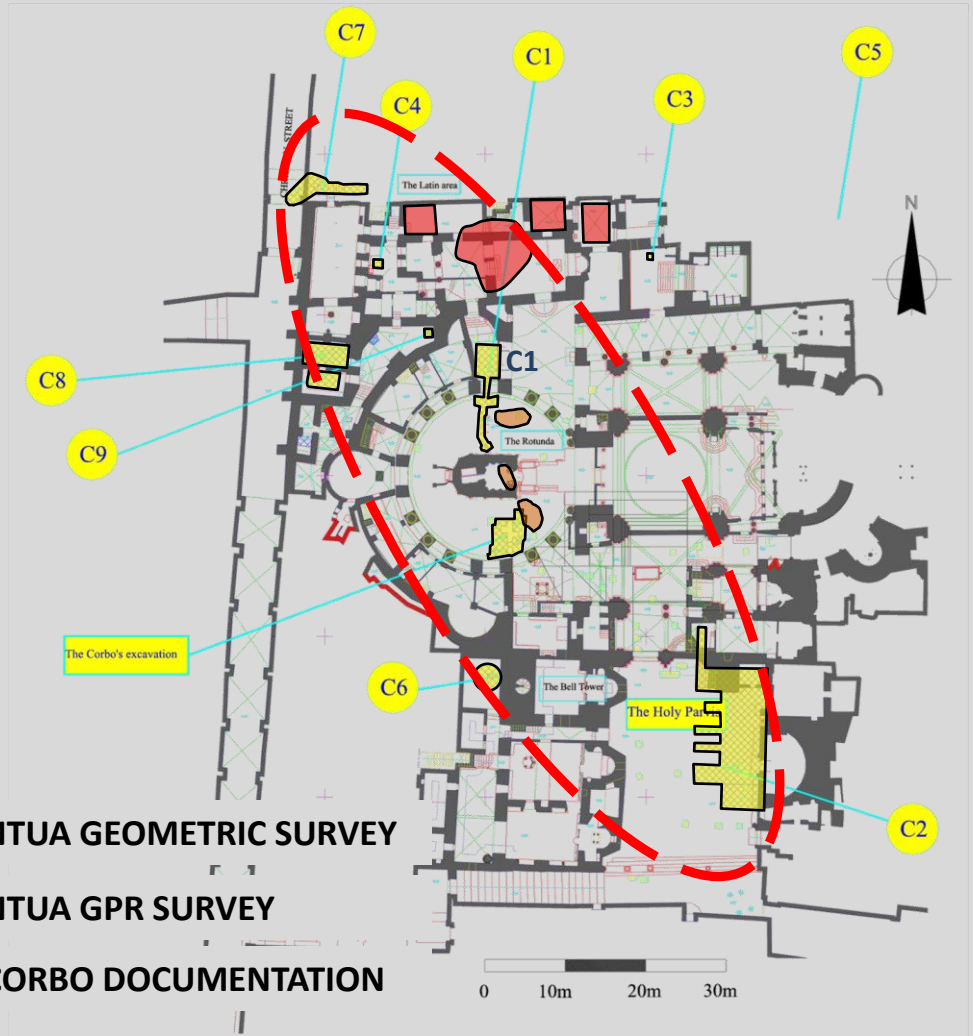


ACHIEVING THE PROJECT'S GOALS:
2. REVEALING AND PRESERVING VALUES

ARCHAEOLOGICAL SEMANTICS OF THE UNDERGROUND AREA OF THE CHURCH OF THE HOLY SEPULCHRE

NATIONAL TECHNICAL UNIVERSITY OF ATHENS
INTERDISCIPLINARY RESEARCH GROUP FOR THE MONUMENTS PROTECTION

The Holy Aedicule is located at the center and above a **cluster of underground cisterns**, and natural and manmade **underground voids** and spaces

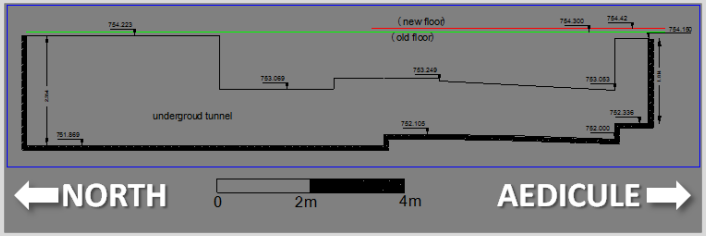


NTUA GEOMETRIC SURVEY

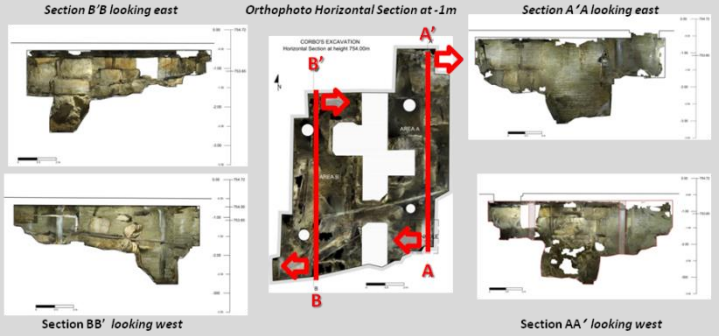
NTUA GPR SURVEY

CORBO DOCUMENTATION

Geometric documentation (vertical section) of cistern C1



Geometric documentation of Corbo's Excavation



Scientific Support to the Integrated Governance of the Project

*The **integrated scientific management of the project** is recognized as the only prerequisite that can successfully face the risks and uncertainties that arise during the progress of the Works.*

*Continuous scientific documentation, monitoring and assessment of all acquired data, in real scale and real time comprises the **scientific support to decision making**. Hence, the **integrated governance** of the project is achieved on the **basis of the NTUA study**, as well as the **NTUA scientific reports** throughout the implementation of the study*

SCIENTIFIC SUPPORT TO INTEGRATED GOVERNANCE

INTEGRATED GOVERNANCE OF THE PROJECT

Project Owners' Committee

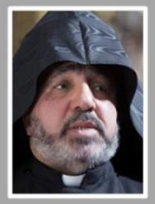
Custos of Franciscan Order

Pierbattista Pizzaballa (until May 2016)

Apostolic Administrator of Jerusalem

Francesco Patton (Since June 2016)

Patriarch Theophilos III (Chairman)



Armenian Patriarch Nourhan Manougian

Common Technical Bureau (Dr. Theodosios Mitropoulos, Osama Hamdan, Carla Benelli, Irene Badalian)

Project Steering Committee (5-7 members)

WMF/Mica Ertegun Fund/ Greek Orthodox Archdiocese of America (oversight)

Patriarch Theophilos III (Chairman)

Chief Supervising Scientist & Director of Materials & Rehabilitation Interventions Prof. Antonia Moropoulou

Project Manager Ir. Nikos Moropoulos

Site Manager Dr. Theodosios Mitropoulos

Director of Restoration Prof. Emmanouil Korres

Director of Reinforcement Prof. Kostantinos Spyrakos

Direct. of Geometric Documentation Prof. Andreas Georgopoulos

Deputy Site Manager Assist. Prof. Charalampos Mouzakis

Asst. Deputy Site Manager, Head of Restorers Vasileios Zafeiris

Administrative

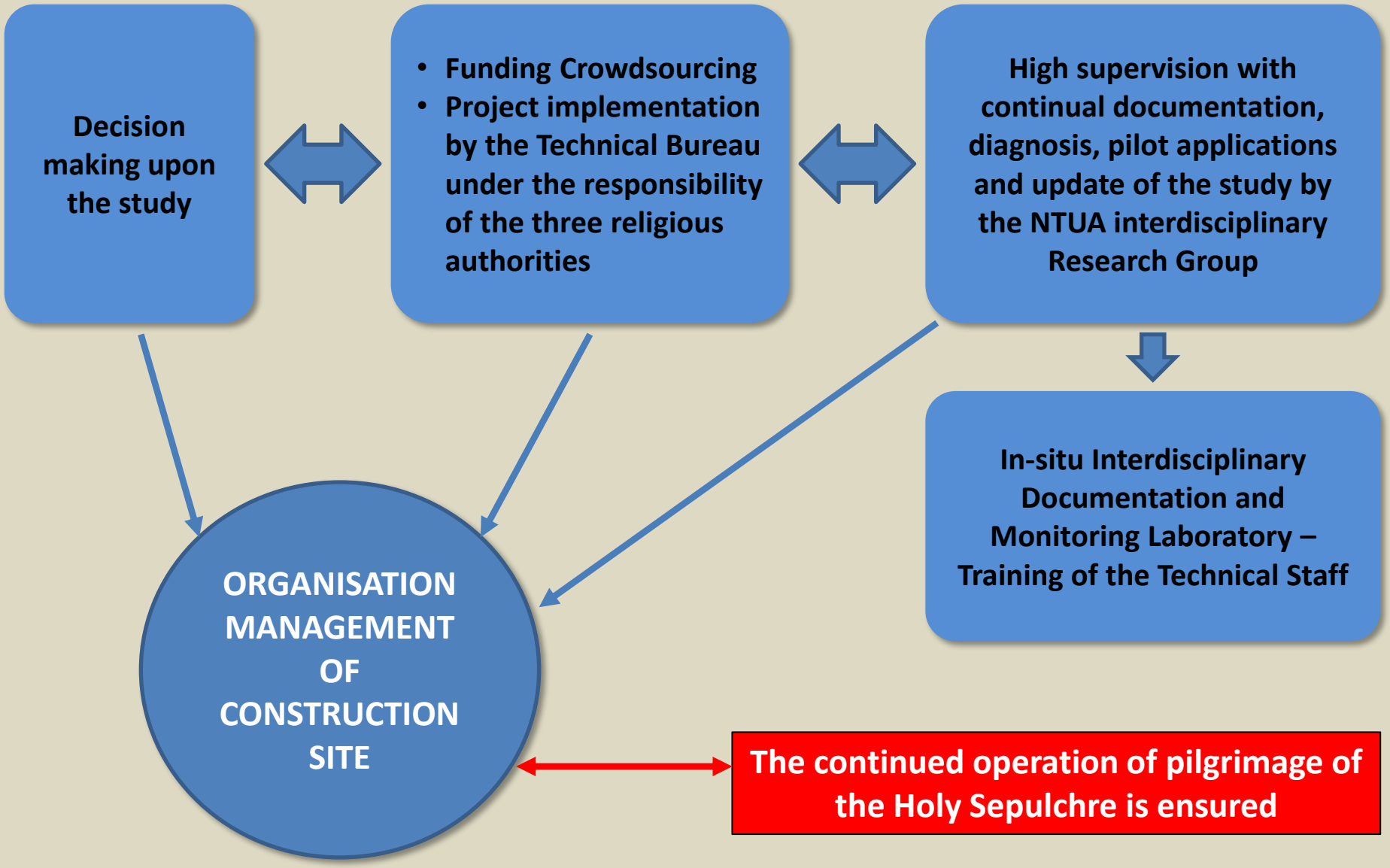
Scientific

Construction site management

At two rooms of the Rotunda, belonging to the Greek-Orthodox Patriarchate, the Interdisciplinary Documentation and Monitoring Laboratory has been established, continuously functioning under the NTUA interdisciplinary team's scientific responsibility

Jerusalem Patriarchate – National Technical University of Athens

Implementation methodology



INNOVATIVE MULTILAYERED DATA MANAGEMENT

The **Integrated Information System Platform**:

- ✓ establishes and develops transdisciplinarity among:
  - *relevant scientific and engineering fields*
  - *digital and non-digital layers of information*
  - *non-destructive and analytical information creation technologies*
- ✓ utilizes the information created through the rehabilitation project:
  - *sets interelationships*
  - *creates a digital infrastructure where information can be assigned spatially for further correlation with others*
- ✓ offers modular functionalities
- ✓ is extendable
- ✓ is applicable to other cases
- ✓ is transferable

This integration establishes transdisciplinarity

Innovative Multilayer Data Management – Platform Architecture

Content-Based Management through Semantic Data Integration

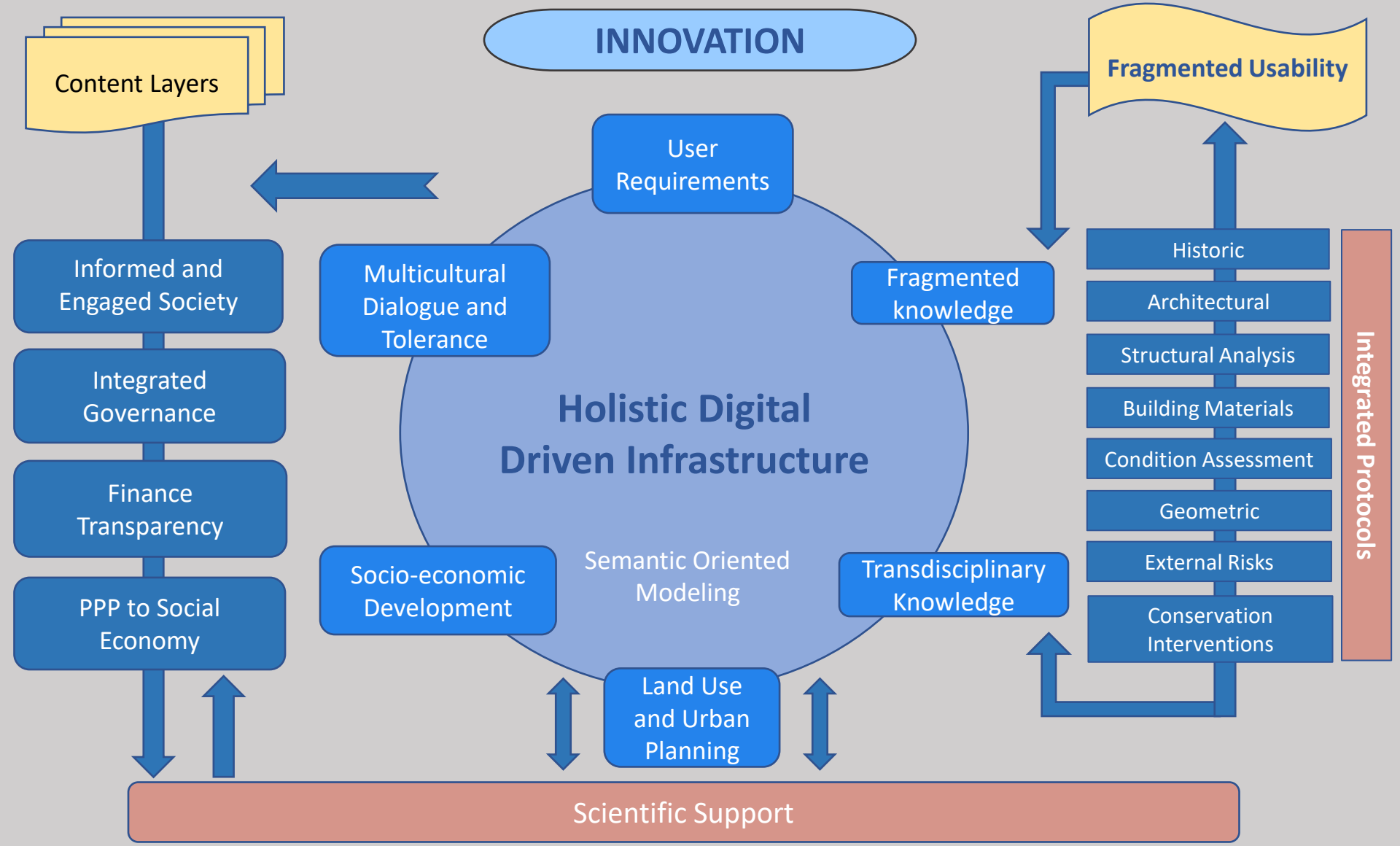
Multilayer Management of Information
Big Data Integration

- Non destructive Testing
- Analytical Techniques
- Spatial
- Historic
- Time, etc.

Multilayer Data Fusion

Platform as the **cornerstone** for data management, knowledge acquisition and information sharing

Usability of Digital Driven Preservation of CH



Towards Holistic Usability

INNOVATION ENHANCING SOCIAL ACCESSIBILITY: BRINGING THE WORLD TO THE TOMB OF CHRIST

Strategic cooperation of the National Technical University of Athens, the three Christian Communities and the National Geographic Society on the news for the opening of the Tomb of Christ and on to the Tomb of Christ Exhibition

Fredrik Hiebert, *National Geographic Archaeologist-in-Residence*
Kristin Romey, *staff writer covering archaeology and paleontology for National Geographic*

Exclusive: Christ's Burial Place Exposed for First Time in Centuries
by Kristin Romey, published October 26, 2016
https://news.nationalgeographic.com/2016/10/jesus-tomb-opened-church-holy-sepulchre/

Unsealing of Christ's Reputed Tomb Turns Up New Revelations
by Kristin Romey, published October 31, 2016
https://news.nationalgeographic.com/2016/10/jesus-christ-tomb-burial-church-holy-sepulchre/

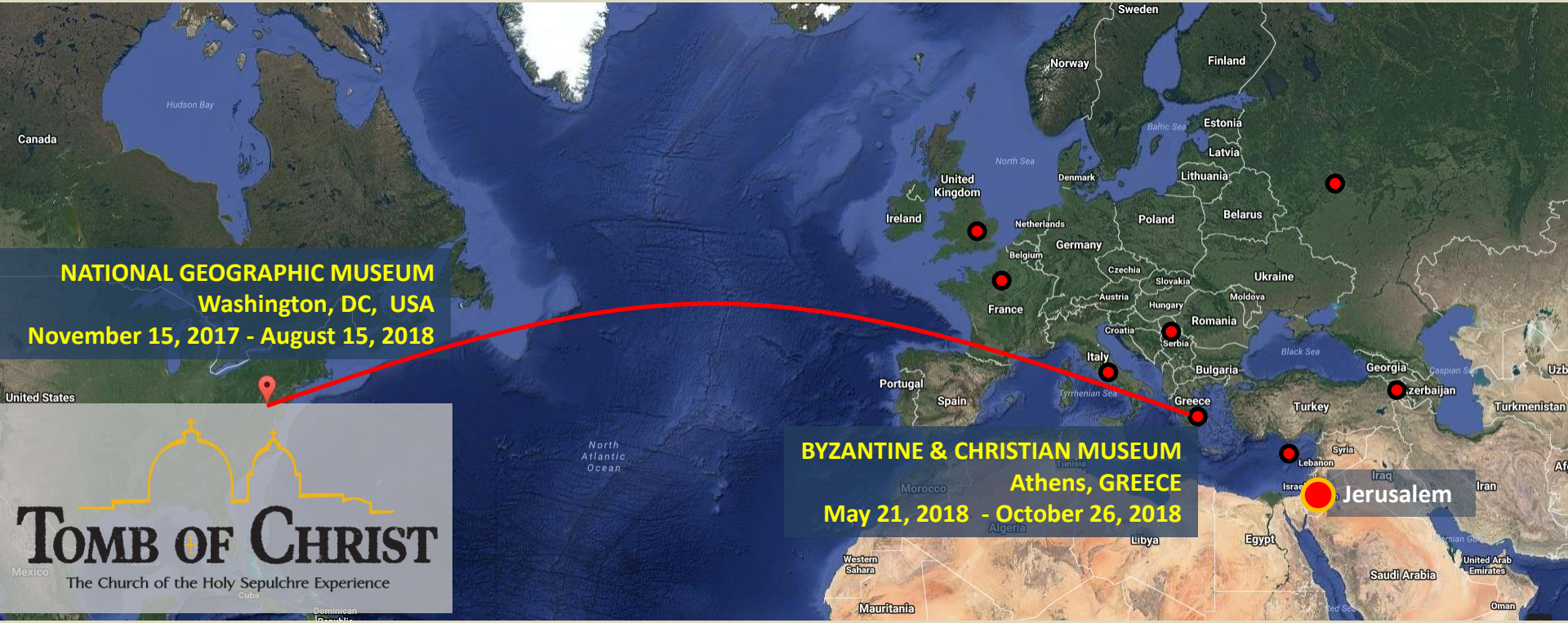
When the Tomb was opened after 500 years, two billion people kneeled, in spirit, in front of the Tomb of Christ

Fredrik Hiebert, *National Geographic Archaeologist-in-Residence*

CULTURAL HERITAGE BEYONG BORDERS

DIGITAL EXPERIENCE EXHIBITION

The digital solutions and multi layer data innovations in the rehabilitation of the Holy Aedicule are presented in emblematic museums all over Europe and the World towards creating a modern, open and pluralistic society building on Europe's cultural diversity, creativity and respect of creators' rights and its values, in particular democracy, religions & values diversifications, freedom of expression and tolerance



The exemplary project of the Holy Aedicule rehabilitation

The Holy Aedicule is a monument of unique value for the Christian World and not only, **emblematic for the values it transmits to humanity across borders**

It is an **achievement which** highlights Greek and European Know-how, Innovation and Expertise in **the field of cultural heritage protection**

Through the interest & media coverage it attracted, it demonstrates Greece and Europe's position as a **world leader in the digital transformation** of the **Cultural Heritage "Industry"**

It can function as a **flagship** for Europe in relation to objectives related to **digitally-driven interdisciplinary cultural heritage protection**

As demonstrated in the rehabilitation of the Holy Aedicule, **Cultural Heritage** has a potential to tear down walls, borders and stereotypes by **fostering dialogue and freedom in exchange of ideas, practices and people.**

The Holy Aedicule rehabilitation project, as well as the social accessibility achieved, highlights the role of Cultural Heritage protection in contributing to **cultural, religious and social inclusion and openness towards a multicultural and tolerant World.**

EDICULA

Educational Digital Innovative Cultural heritage related Learning Activities

Project Code: 2020-1-EL01-KA203-079108

NATIONAL TECHNICAL UNIVERSITY OF ATHENS [GREECE]

SAPIENZA UNIVERSITA DI ROMA [ITALY]

BEZALEL ACADEMY OF ARTS AND DESIGN [ISRAEL]

PerpetielSI SRL

PERPETIELSI SRL [ROMANIA]

ISRAEL ANTIQUITIES AUTHORITY [ISRAEL]

HELLENIC RESEARCH INSTITUTE OF THE ALEXANDRIAN CIVILIZATION [GREECE]

KNOWHOW TRANSFER

Co-funded by the Erasmus+ Programme of the European Union

OBJECTIVES

- **dissemination through education** of the interdisciplinary and innovative research and know-how developed in the rehabilitation of the **Holy Aedicule** under NTUA leadership
- **cooperation between NTUA, UNIROMA1, BEZ, IAA, HRIAC** and promote **transdisciplinarity as an educational lever**
- **advanced educational material** and dissemination by using **AR**, through cooperation with **PerpetielSI**
- **reform the curricula of the postgraduate programs (NTUA, UNIROMA1, BEZ)** that will lead to the promotion of a **Joint Master Degree** in the field of protection of monuments
- develop the **EDICULA Teachers' Course**
- organization of **multiplier events**, such as (i) **hands-on events in Jerusalem and Alexandria**, (ii) **special conference sessions** in Athens
- **promote** students to a **professional and entrepreneurship mentality**,

EDICULA PROJECT STRUCTURE

EDICULA project Management and Implementation

Transnational Project Meetings

- **Kick-off Meeting** *21.10.2020*
- **Review Meeting 1** *12.2021*
- **Review Meeting 2** *03.2022*
- **Final Project Meeting** *02.2023*

O1: EDICULA *EDUCATIONAL TOOLKIT*

O2: EDICULA *CURRICULA REFORMATION*

O3: EDICULA *HANDS-ON FRAMEWORK*

O4: EDICULA *DIGITAL GAMES*

O5: EDICULA *SYNTHESIS*

MULTIPLIER EVENTS

E1: The Holy Sepulchre Hands-on Experience

03.2022

E2: The Alexandria Immersive Experience

06.2022

E3: EDICULA Special Session - TMM_CH Conf.

Panel discussion 1:
The Holy Sepulchre rehabilitation project: An emblematic source of Innovation

Panel discussion 2:
Novel Educational Approach for the Preservation of Cultural Heritage

12.2021

EDICULA Teachers' Course
02.2023

Transfer of Know-How → contributes to the future trends of Cultural Heritage preservation at large

Social Accessibility / Narration

Diffusion of Innovation

Holy Sepulchre project