This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n°700191

STORM

Safeguarding Cultural Heritage through Technical and Organisational Resources Management

D9.3: STORM Assessment and Validation Mid-term Report

STORM Project

H2020- DRS-11-2015: Disaster Resilience & Climate

Ethical/Societal Dimension Topic 3: Mitigating the impacts of climate change and natural hazards on Cultural Heritage sites, structures and artefacts

Grant Agreement n°: 700191

Start date of project: 1 June 2016

Duration: 36 months

Document. ref.: STORM Assessment and Validation Mid-term Report/UNITUS/WP-9/1.3

Disclaimer

The STORM Consortium consists of the following partners:

Participant No	Participant organisation name	Participant short name	Country
1 (Coord.)	Engineering – Ingegneria Informatica S.p.A.	ENG	IT
2	INOV Inesc Inovação - Instituto de Novas Tecnologias	INOV	PT
3	Foundation for Research and Technology, Hellas	FORTH	GR
4	University of West Attica	UWA	GR
5	Resiltech	RESIL	IT
6	Soprintendenza Speciale Per il Colosseo il Museo Nazionale Romano e l’area Archeologica di Roma	SSCOL	IT
7	Università della TUSCIA	TUSCIA	IT
8	Kpeople ltd,	KP	UK
9	University of Stuttgart	USTUTT	DE
10	Ministero dell’Interno - Corpo Nazionale Vigili del Fuoco	CNVVF	IT
11	Mellor Heritage Trust’s	MAT	UK
12	Sparta technologies	SPA	UK
13	Salford University (Archaeology, Climatology)	USAL	UK
14	Nova Conservação	NCRS	PT
15	Troiaresort – Investimentos Turísticos, S.A.	TRO	PT
16	Portuguese General Direction of Cultural Heritage	DGPC	PT
17	Município de Grândola – Serviço Municipal de Proteção Civil	SMPC	PT
18	Zentralanstalt für Meteorologie und Geodynamik	ZAMG	AT
19	Ephorate of Antiquities of Rethymno, Hellenic Ministry of Culture and Sports	EFARETH	GR
20	Bogazici University	BU	TR

PROGRAMME NAME:	**DRS-11-2015**
PROJECT NUMBER:	**700191**
PROJECT TITLE:	**STORM**
RESPONSIBLE PARTNER:	UNITUS
INVOLVED PARTNERS:	ALL
DOCUMENT NUMBER:	D9.3
DOCUMENT TITLE:	STORM Assessment and Validation Mid-term Report
WORK-PACKAGE:	WP9
DELIVERABLE TYPE:	Report
CONTRACTUAL DATE OF DELIVERY:	31/05/2019
LAST UPDATE:	19/06/2019
DISSEMINATION LEVEL:	PU

Dissemination level:

PU = *Public,*

CO = *Confidential, only for members of the STORM Consortium (including the Commission Services)*

Document History

Version	Date	Status	Authors, reviewer	Description
v.0	12/01/2019	TOC	UNITUS	Table of contents definition and document structure
v.0.1	15/02/2019	Draft	UNITUS, KP	First draft
v.0.2	20/03/2019	Contribute ready	UNITUS, KP	Contribute collection
v0.3	05/04/2019	Structured draft	UNITUS, KP	Active draft
v0.4	30/04/2019	Draft	ALL	After exercise 1st draft
v0.5	20/05/2019	Draft	ALL	After exercise 2nd draft
v0.6	25/05/2019	Final draft	UNITUS, KP	Final draft
v0.7	27/05/2019	Further contribution section 2	INOV	Updated draft
v0.8	30/05/2019	Further contribution section 3	NCRS	Updated draft
v0.9	02/06/2019	Further contribution sections 4, 5, 6	UNITUS	Updated draft
v1.0	04/06/2019	Final draft for peer review	UNITUS, KP, ENG	Final draft for PR
v1.1	11/06/2019	Peer review	SSCOL	Peer reviewed 1
v1.2	15/06/2019	Peer review	CNVVF	Peer reviewed 2
v1.3	18/06/2019	Final	UNITUS, ENG, KP	Final peer review

Definitions and Acronyms

Acronyms	Description
BoD	Bath of Diocletian
CEA	Cost-Effectiveness Analysis
CH	Cultural Heritage
DRM	Disaster Risk Management
ERT	Electrical Resistivity Tomography
FBG	Fibre Bragg Grating
GPR	Ground Penetrating Radar
InSAR	Radar interferometry
NPC	Net Present Costs
QDA	Quick Damage Assessment
RRT	Roman Ruins of Tróia
SDR	Social Discount Rate
SHM	Structural Health Monitoring
TLS	Terrestrial Laser Scanning
WASN	Wireless Acoustic Sensor Network

Table of Contents

List of Figures

List of Tables

1 Executive Summary

The D9.3 deliverable "STORM *Assessment and Validation Report*" is the last deliverable to be produced under WP9. It aims to present an evaluation of all the work done during the three years of research and experiments within the STORM Project. The starting point are the objectives, to be used, together with the KPIs, with the aim of evaluating the technologies provided in STORM, but also all the services and the efficiency of the STORM approach that have been tested during the drills organised in each Pilot Site, useful to prove the efficacy of the innovations developed within the Project.

The starting point was the eight objectives of the project, thanks to which, also through the use of the KPIs, assessments and updates will be provided of all the technologies used in STORM, but also of all the services and the efficiency of the STORM approach during the simulations, which were useful to demonstrate the efficiency of all the innovations brought by the project.

The document is resulting from the following deliverables:

- D9.1 "*Experimental scenarios definition and planning*" in which all the experiments in progress or planned in the 5 pilot sites have been described and in which the KPIs useful for the evaluations to be carried out in D9.3 were identified.
- D9.2 "*Experimental Journal*" which is configured as a sort of diary of all the activities carried out, giving a description of the various phases of each one.

The results and updates coming from WP1 are also included in D9.3, in particular Tasks T1.2, T1.3, and T1.4, following the STORM testing iterative process (Fig.1).

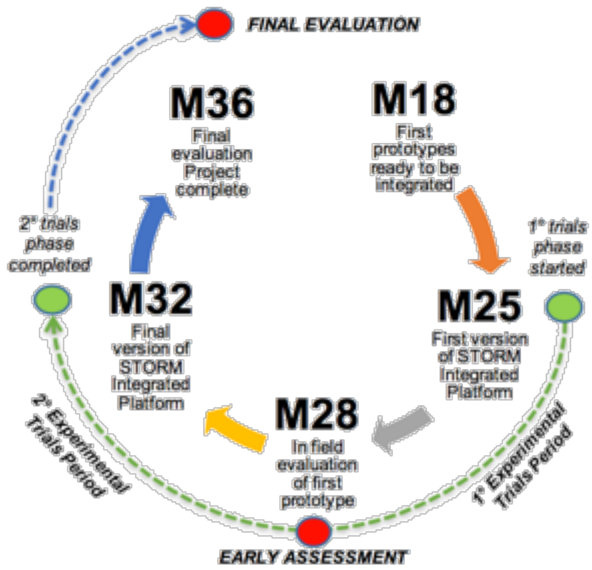


Figure 1 - Storm testing process

Because of the complicated structure of this deliverable and the enormous amount of material to be collected for its drafting, it was decided to divide the document into different sections:

- *Section 2* which presents the developments deriving from T1.2 *"Non-invasive and non-destructive methods of surveying and diagnosis"*, the lessons learnt and evaluation of the technologies and methodologies used in the five pilot sites of the Project, and gives an analysis of the data obtained through the use of technologies experimented in STORM;

- *Section 3* deriving from T1.3 *"Cost effective conservation and restoration methods"*, dedicated to the Cost-effective analysis and Risk Management for conservation of cultural heritage, with particular attention to the five cases of the Pilot Sites;
- *Section 4* linked to T1.4 *"Quick Damage Assessment methods"*, in which the Quick damage assessment methodologies are described, analysed and evaluated through the ten drills (two per site) organized during the last year, which allowed to test and validate the developed technologies in the different scenarios;
- *Section 5* dedicated to the description, analysis and evaluation of the Prevention and slow hazard experiments carried put in each Pilot site and the results obtained;
- *Section 6* dedicated to Processes, Services and Technologies evaluation, depending on the KPI identified in D9.1.

Due to the huge quantity of aspects to be reported and analysed, after several discussions within the working group, the responsible of each section agreed that a "table approach" could be the most functioning. This method turned out to be very useful not only to collect contribution from each partner involved, but also to create a less complex and more readable Deliverable. In Annex, all the studies and the documents needed for writing each section are presented.

The STORM assessment and validation strategy has considered, as starting point, the Project 8 Objectives presented in the very beginning of the program:

- Obj1: Select, evolve and integrate innovative environment assessment methodologies and services to effectively and accurately process, analyse and map environmental changes and/or natural hazards.
- Obj2: Define and implement an innovative methodology and a supporting service for the mitigation of natural hazards and climate change, and the assessment and management of corresponding threats while minimizing their impact.
- Obj3: Provide innovative, cost-effective, non-invasive and non-destructive methods and processes, as well as applications for survey and diagnosis based on the study of materials properties, particular environmental conditions, and profile of the cultural assets to be assessed.
- Obj4: Define and implement models and services for generating and managing a situational picture based on the data/information collected from the field by physical and human sensors and evaluations (crowdsensing).
- Obj5: Provide innovative methodologies, practices and software tools for a more reliable maintenance, quick restoration and long-term conservation of the Cultural Heritage assets, preserving their historic and cultural integrity.
- Obj6: Define a collaboration and knowledge-sharing framework for the community of stakeholders to co-create, share and maintain improved practices, knowledge and experience on cost-effective and eco-innovative solutions for sustainable management and conservation of Cultural Heritage in Europe.
- Obj7: Propose adaptations, changes in existing policies and validation of new knowledge in government processes.
- Obj8: Cost analysis for the sites protection against natural hazards managed by the STORM data analytics tools.

From that moment till today research has been done and the first best practices have been identified in literature and in the activities carried out by the Pilot Sites before the Project started. This has allowed the Partners to analyse the most relevant activities to be developed and updated. From the second year of research, several technologies and experiments have been carried out by the technical partners and by the Universities, that have had the chance to be tested in the pilot sites, in order to evaluate if the technologies developed could be identified as useful, implementing the ones identified as eco-friendly and low cost for the management and monitoring of Cultural Heritage (CH).

The most important goal has been, starting from each partner experiences and knowledge, to collect good practices, also thanks to all the lessons learnt during the project, that will be examined and described in the dedicated sections.

2 Technology evaluation and experimental feedback

Being a part of the *assessment and validation activity performed for each experimentation site* this section meets two additional formal requirements to the Project reporting: providing evaluation of non-invasive and non-destructive methods of surveying and diagnosis — based on the feedback from experimentation, as is envisaged within the framework of task T1.2 and deliverable D1.2 — and justifying the achievement of the target TRLs (Technology Readiness Levels) for the key technologies mentioned in Table 4 of the STORM Proposal (section *1.3.5 Positioning of the project*).

The *on-line* and *off-line* methods of surveying, diagnosis and monitoring are discussed in subsection 2.1.1 on a per site basis, with the exception of meteorological monitoring. This cornerstone activity, directly related to the purpose of the Horizon 2020 topic DRS-11-2015, under which the Project is financed, has been implemented at all pilot sites and thus receives special additional cross-site consideration and analysis in a dedicated subsection 2.1.2.

Subsection 2.2 extends the technology evaluation to the explicit and implicit crowdsensing methods based on the advanced information processing.

Finally, the achieved readiness levels of the key technologies mentioned in the STORM Proposal are discussed in subsection 2.3.

2.1 Non-invasive and non-destructive methods of surveying, diagnosis and monitoring

This subchapter represents per-site evaluation of the non-invasive and non-destructive methods of surveying, diagnosis and damage assessment, which were previously described, analysed and chosen for future consideration within the framework of task T1.2 (for further information, see *D1.2 – Non-invasive and non- destructive methods of surveying and diagnosis*) and are associated with the *off-line sensors* of the STORM system. Along these techniques, technologies for real-time monitoring, associated with the *on-line sensors*, have been also considered. *Off-line* and *on-line sensors* are described in *D3.3 – System Architecture*.

Main development was carried out in WP4 and reported in corresponding deliverable *D4.1 – Report on the results of application of the ground-based sensors* and *D4.3 – Report about capabilities of the implicit crowd sensing: screening*. The present subchapter is mainly related to the second stage of T1.2, serving as a second release of deliverable D1.2, providing the "feedback from experimentation", mentioned in the Description of Action – Annex I.

2.1.1 Per site method evaluation within the framework of occasional and long-period experimental drills

Per site method evaluation within the framework of occasional and long-period experimental drills is presented below in a concise table, followed, for each experimental site, by a narrative text summarising the technology application and providing experimental feedback.

2.1.1.1 Baths of Diocletian

The main achievements of the method application are summarised in Table 1 and in Table 2.

Table 1: Evaluation of non-invasive and non-destructive methods: Baths of Diocletian, Drill 2

Site	Baths of Diocletian	Area	Hall I	Items	Ancient pillar of the buildings. Several ancient sarcophagus stored in the Hall (inv. 112328; 112444; 115173; 115712; 124711)
Hazard	Earthquake	Intensity	3	Risk score	4
Surveying and diagnosis (off-line sources)					
Terrestrial laser scanning (TLS)	Laser scanning technique has been used to improve surveying of the structural conditions of Hall I. Three different scans allowed to monitor the structural behaviour of the ancient building, as well as to went to conclusion that the movements could be considered as "normal", due to the contraction and extension of the material caused by temperature changes. Comparing the recorded TLS data with a new one performed after an earthquake (real or, in the case of the drill, simulated) enables to understand, in a short time, if the building has suffered structural damage or not.				

Table 2: Evaluation of non-invasive and non-destructive methods: Baths of Diocletian, long-period drills

Site	Baths of Diocletian	Area	Michelangelo's Cloister and Hall I	Items	Every item displayed
Hazard	Extreme temperature variations, strong winds, biological infestation, vibrations/earthquakes, thunderstorms/lightning	Intensity	3 (extreme temperature variations, vibrations / earthquakes), 4 (strong winds, thunderstorms / lightning, biological infestation)	Risk score	Hall I: 4 (earthquakes), 2 (strong winds), 2 (thunderstorms/lightning), 2 (tornadoes), 3 (wind) Michelangelo's Cloister (south-western wing): 3 (earthquakes), 2 (strong winds, thunderstorms/lightning, tornadoes), 2 (wind)

Surveying and diagnosis (off-line sources)	
Terrestrial laser scanning (TLS)	The TLS allows to obtain point clouds of millimetre-scale accuracy of the surveyed spaces. More than ten surveys were carried out in the BoD premises. Feedbacks collected from CH experts confirmed its potential value to enhance cooperation at the very first moments after the earthquake, readily obtaining current 3D structure state and high-resolution images.
Ground penetrating radar (GPR)	The ground penetrating radar allows to detect structures hidden beneath walls and floors. GPR measurements in BoD revealed hidden drainage pipes underneath Hall 1 floor, which enabled the team to assess the size of the wall foundation and helped to understand the structural behaviour of the building.
Radar interferometry (InSAR)	The InSAR allows measuring sub-millimetre movements in real-time along the line of sight, which have to be correlated to the natural scatterometres of the monuments (normally concave corners). Only one survey was carried out in the course of the project, but that test triggered further activities in the emergency sector outside the project site (e.g., the Genova bridge collapse), where the same tool was used to evaluate the residual safety of the spaces under a strongly damaged structure.
Real-time monitoring (on-line sources)	
Wireless Acoustic Sensor Network (WASN)	The WASN is deployed in the Baths of Diocletian in Rome as a means of early detection of extreme weather phenomena, i.e. local storm/lightning-thunder, intense wind or intense rain. On top of being able to detect and record sound samples, the proposed WASN nodes also have the capacity to track diverse sensor data, like brightness, temperature, humidity and distance from lightning storms to provide useful environmental information. The WASN has been installed in the BoD site and has achieved to record sound samples that are forwarded to the Classifier server located within the UNIWA premises. During the time period of sound samples recording and classification, no events of extreme weather phenomena were captured. However, there have been reported events of human presence, including motorbikes and people laughing.

Fibre Bragg Grating (FBG) sensors	FBG sensors allow to measure strain of the lesions as well as the plaster on the wall and humidity of the wall to understand if the masonry has been affected by rising humidity and to evaluate the behaviour of the structural lesions. The data collection started in October 2017 and with a few discontinuations due to some problems faced and resolved during the instrument development, has been collecting data until the end of the project. Data collected allow to have a quite clear idea of the trend of the value over time, giving to the pilot site manager the possibility to know the registered values not only in real-time, but also in different periods. Data collected have been elaborated and correlated by TUSCIA, in order to give not only proper description of the condition of artworks conservation but also to carry out an evaluation of the risks, in order to improve the quality of Quick Assessment, as well as the restoration intervention.
Libelium weather station and environment sensor network	The Libelium weather station and environmental sensor network consist of several nodes for monitoring environmental and climatic conditions and a controller based on LINUX with a gateway for the data communication. Data has been collected throughout the project and enables the pilot site to monitor the microclimatic and environmental conditions. The application of sensor fusion techniques, thresholds and even simple rules has allowed the site manager not only to monitor and evaluate the conditions of the microclimate, but also the environmental pollution. Moreover, the relationship between the climatic and environmental parameters has ultimately allowed to carry out long-term assessments on the potential causes of degradation and on the catalysts capable of accelerating the processes. In view of that, the weather station and environmental sensor network allow the site manager to be warned in real time both on an extreme weather condition (e.g., strong wind) or on a slow hazard effect (e.g., salinization) which can cause damage to the CH items. The collected data has been processed by ZAMG to provide a climate analysis, showing reliability and relevance, as reported in section 2.1.2.1. In addition, on top of this data, ENG has developed a set of description and diagnosis data analytics that has been integrated into the Data Analytics platform service at BoD. With regard to the real-time alerting, the extreme weather event, which actually had occurred some months in advance, was simulated in the first and second drills at BoD to test the Fist Aid processes.
Sensor network Arduino	The data recorded by Arduino sensors are: temperature and humidity of both surface and environment, pressure, stress on the lesion, movements (pitch and roll) and vibrations of the wall. These sensors have been installed in October 2017 in Hall I, with the aim of monitoring the abovementioned parameters, with some discontinuation due to problems solved during the development of the instrument. All the collected data are analysed and correlated by TUSCIA, in order to give not only proper information about the wellness of the artwork and its conservation, but also to have a risk evaluation in order to understand the needs of restoration intervention, quality assurance, and first intervention.

The experimental feedback and brief conclusions are given below:

Terrestrial laser scanning (TLS)

Terrestrial laser scanning has been used for several years in the CH sector to retrieve accurate point clouds, to be then exploited both to extract 3D models for structural evaluation and to offer enhanced immersive 3D experience for final users (e.g., tourists). The Bath of Diocletian site was subjected to TLS survey well before the STORM project started. As well, many other major archaeological sites (e.g., Pompeii) were subjected to the all-encompassing survey through the very same technique (*Piano della Conoscenza del Grande Progetto Pompei*: http://www.md-tec.it/it/scheda-works.php?id=14). Therefore, the innovation of the approach is not in the use of the TLS technique per se, but in an **innovative process able to greatly improve the management of emergencies when involving CH** (which is sadly the case for almost all the emergencies in Italy). In fact, with the BoD STORM drill, the project successfully demonstrated that it is possible to use that technique in the very first phase of emergency, in particular for the case of earthquakes, when the prompt implementation of well-designed provisional works can reinforce damaged monuments and churches enough to sustain the subsequent stresses (e.g., triggered by aftershocks) without suffering further damages or collapsing, what happened to the Basilica of San Benedetto in Norcia on 30 October 2016, when the second shock stroke two months after the first. The drill demonstrated that, using a light-weighted low-cost laser scanning and imaging system, is it possible to obtain a 3D point cloud and, additionally, high-resolution images uploaded on a cloud within 20-30 min from the firemen arrival. The system complexity is minimal and compatible with the actual skills of rescuers, enabling both fireman on place and CH experts in safe remote locations to jointly evaluate the damages and indicate possible remedies — due to the comparison with the previously recorded point clouds.

Ground penetrating radar (GPR)

GPR was tested in the course of one session of the BoD drill and proved to be most useful to analyse structures hidden below the pavement. As such, this type of use was well known and proved to maintain its value. However, this was not the aim of the test. As in the case of TLS, the test aimed at evaluating the practicability of using such a system in the first phase of emergencies, in the very harsh conditions faced by rescuers. Considering the specific point of view, the test proved that GPR is still not a technique usable by rescuers in those conditions: the tools output is too complex to be understood without the help of specific experts in place and the added value of such tools did not find a straightforward, sustainable application to the very specific needs of rescuers in that emergency phase.

Radar interferometry (InSAR)

Terrestrial Radar Interferometry was tested in the framework of the BoD once. In the course of the STORM training activity ‘Summer School’, it was organised a further demonstration to explain to the rescuers, CH experts, and other stakeholders the pros and cons of the technique when applied to the first phase of emergency management. In fact, the tool can provide an invaluable help when any structure (CH or not), which has suffered damages able to compromise its structural stability, has to be continuously monitored for sub-millimetre movements. “Continuously” is the key term: in fact, the tool measures sub-millimetre movements along the line-of-sight between the instrument and specific spots of the monitored structure, but the actual identification of such spots is not certain and can only be qualitatively assessed based on the experience of the surveyor. Moreover, such tool does not allow for comparison of different structural states of the same building if the tool has been re-positioned or switched off in the time between the different surveys, because it only measures movements from the relative position at time T0, when the instrument is switched on and start surveying. As such, TInSAR was promptly adopted by CNVVF for operational use in several occasions, when rescuers have to operate in particularly risky conditions, when a structure could collapse in any moment over firemen who are working to rescue people under the debris. This was the case for both the collapse of the Genova bridge 'viadotto Morandi' on 14 August 2018, and the collapse of a building in the Balduina district of Roma on 14 February 2018. In fact, in both cases firemen had to search and rescue victims under compromised or potentially compromised structures, which could have collapsed on them at any moment. Placing the instrument, it was possible to monitor and quantify the movements of such structures continuously and consequently provide specific instructions to the rescuers, indicating when it was possible to carry out the rescue activities and when not. As it appears clear, while proving to be invaluable for rescue activities, TInSAR has still to prove to be beneficial for CH assets in particular. Of course, tests and analysis will be surely carried out for long after the project end, with the aim of making the best use of the tool, including the benefit of the CH heritage.

Wireless Acoustic Sensor Network (WASN)

As already mentioned, the aim of the WASN installed in BoD is to detect extreme weather conditions, i.e. strong waves, local thunders or storm, strong wind or rain, which might affect the health of the site building monuments and artefacts. The WASN is installed and is recording sound samples that are forwarded to the Classifier server located within the UNIWA premises. The Classifier server locally stores classification results while also updates the respective database of the STORM Cloud server. In this context, the WASN achieved to operate and successfully accomplish the forwarding of data samples to the Classifier server. In turn, the Classifier server achieved to successfully implement the classification procedure, store classification logs and upload results to the STORM Cloud server.

During the time period of measurements and classification, it was learned that the human presence in the vicinity of the WASN node installation point was common and prevalent. In this respect, the threshold level of the sound intensity that should be selected in order to allow the WASN node to transmit the sound sample to the Classifier server should be set quite low, in order not to flood the server with unnecessary human presence events. On the other hand, setting the sound threshold level too low, would result to no detection of extreme weather phenomena at all. Nonetheless, for the specific time period that the WASN node operated, it was not detected any extreme weather event; this observation is also verified by site management and staff. However, a large number of human presence was recorded and classified as such, but human presence detection was neither included in the goals of the WASN for the specific site nor resulted to any acts of vandalism or abnormal behaviour within the site area.

Fibre Bragg Grating (FBG) sensors

FBG sensors have been installed in autumn 2017 in Hall I and Michelangelo's Cloister: specific information and description of FBG Sensors have been included in several deliverables (D8.1, D6.3, D4.1). FBG sensors mentioned in the table are commonly used in several technological fields (i.e. spaceships, ships), but their use in Cultural Heritage monitoring, until now, was very rare. Thanks to their features TUSCIA decided to experiment them in Hall I and Michelangelo's Cloister. By adapting them to monitor the abovementioned parameters, their use has been proved to be **quite efficient in the research done within the STORM Project, in the monitoring of the chosen parameters (strain, rising humidity)**. Starting from several problems during the installation and the damages to the optic fibre, the quality of the measurement has been improved, all the problems encountered have been solved and understood, in order to avoid them in future installations, thanks to the lesson learnt. All data collected by the program in the interrogator tool are cleaned, elaborated and put into graphs in order to have a proper data analysis.

Libelium weather station and environmental sensor network

The Libelium sensor network (including a weather station) was installed at the BoD site from the 22nd to 24th of February 2018 by ENG, after a brief period of laboratory experimentation, which did not allow to fully verify all the components of the network, hence, some settings were carried out directly on the field. Several node firmware updates were needed. Moreover, for limited time period, some nodes were blocked due to malfunctioning resulted from extreme weather conditions, hence, in order to identify the problem, a laboratory verification was necessary at ENG, with consequent loss of data. In conclusion, the use of an open source hardware network made possible to select the most appropriate sensors for the acquisition of all those necessary physical quantities. The support from the Libelium Assistance Centre was good.

With regard to the analysis of the data done by ENG, data on temperature, humidity, wind and rain were acquired. The climatic parameters have been related to the main pollutants present in the air (e.g., CO_2, CO, O_2, Air pollution, VOC, H_2S, SO_2 PM 1.0, 2.5 and 10). The relationship and the combination have highlighted how the concentration of pollutants in the air varies according to the climatic conditions. Furthermore, through the monitoring of acoustic noise and vibrations it was possible to relate pollutants to vehicular traffic.

Finally, the analysis of the weather station done by ZAMG clearly shows the **benefit of this sensors to determine micro-climatic conditions as well as real-time monitoring of meteorological conditions (especially wind speeds)**. It should be noted that environmental sensors cannot replace a designated weather station sensor to monitor meteorological conditions.

Sensor network Arduino

The Arduino sensors (measuring temperature and humidity of both surface and environment, pressure, stress on the lesion, pitch and roll x y z, and vibration of the wall) have been installed in October 2017 in Hall I, with the aim of monitoring the abovementioned parameters, with some discontinuation due to the development of the instrument. Several problems have been encountered, in particular, with data transmission. The quality of measurement and collection of data have been improved and all the mistakes will be avoided in the next installations, thanks to the lesson learnt.

All the data collected by a computer connected to the Arduino, have been elaborated and put into graphs, in order to have a proper data analysis.

2.1.1.2 Mellor Heritage

The main achievements of the method application are summarised in Table 3, Table 4, and Table 5.

Table 3: Evaluation of non-invasive and non-destructive methods: Mellor, Drill 1

Site	Mellor	Area	MAT-02: Mellor Mill	Items	Item 6.1 (Drive shaft bricks)		
Hazard	Intense rainfall			Intensity	5	Risk score	8
Surveying and diagnosis (off-line sources)							
Photogrammetry (UAV based)	Used throughout the project and enables the site management to monitor the damage before and after the event. Scans taken before and after the drill allow to quantify the damage and take steps to correct.						
Real-time monitoring (on-line sources)							
Weather station	The weather station has been collecting data throughout the project and enables the pilot site to monitor the microclimatic conditions at the three Areas. The data has been shown to be reliable and relevant (see long term experiment MATEXP-02 in the Journal) and thus has shown that weather stations can be exploited at very low cost and ease of use to non-experts and sites where there may not be a lot of investment opportunities in this area. The site has benefited therefore hugely from this small investment. The data was not used in the first round of drills at Mellor – as the system was not fully integrated – we could see the data, but we couldn't receive warning based on the data being received. This integration was complete for round 2, where the full benefit has been assessed.						

Table 4: Evaluation of non-invasive and non-destructive methods: Mellor, Drill 2

Site	Mellor	Area	MAT-01: Old Vicarage	Items	Item 1.1b Iron-Age Ditch		
Hazard	Strong winds			Intensity	5	Risk score	5
Surveying and diagnosis (off-line sources)							
Photogrammetry (UAV-based)	Used throughout the project and enables the site experts to monitor the damage before and after the event. A scan was taken before and after the drill allowing the site to quantify damage and take steps to correct. Low cost drones are very useful to sites as they enable very high-quality models to be produced using photogrammetric methods. This enables us to monitor the asset before and after the drill. The drone was in action on the day of drill 2, to gather the information on damage immediately following the event.						
Terrestrial laser scanning (TLS)	Used in the drill to scan immediately after the damaged mesh was removed from the cross section of the ditch. This could be compared to baseline scans after the drill to highlight the volume of earthworks lost as a result of the event.						

Table 5: Evaluation of non-invasive and non-destructive methods: Mellor, long-period drills

Site	Mellor	Area	Areas 1-3	Items	Round house and related items, ditch and related items, Kerb stones, wheelpit and related items, drive shaft, engine and boiler beds		
Hazard	Rain, biological colonisation, change in freeze thaw events Heat waves, cold waves			Intensity	5	Risk score	2 3
Surveying and diagnosis (off-line sources)							
Photogrammetry (UAV-based and terrestrial)	Equipment ready available either to purchase or hire at a cost-effective day-rate. Camera cheapest whilst scanner most expensive. Drone is mid-range in cost. Training needed on the use of the laser scanning and drone equipment. Multiple staff need to be trained to use this equipment in order to ensure resilience. Software cheap to purchase, with free software (with reduced features) available. Desk-top computers and laptops need to be fitted with						

	appropriate graphic cards and RAM and long-term memory storage. Processing images can be time-consuming. Online free training available to run the most common types of software. Images for each Mellor monument have been captured over a 30-month period. Two forms of images have been created – cloud point data and photogrammetric images. Large amount of computer memory needed to store these images. Quality of data from laser scanning and photogrammetry broadly similar; free training available for photogrammetry software compare; using cameras more straight-forward and cheaper than hiring or buying a laser scanner. The images captured for a 30-month study period show clear degradation as a result of slumping and vegetation growth to the assets at the Old Vicarage site. Due to renovation of the Mill it is difficult to assess the use of photogrammetry on that area, both UAV and Terrestrial based because many of the items underwent significant prevention and mitigation measures and so any degradation is now not present. The positive result from the Old Vicarage site, however, mean that MAT and USAL are confident that continuation of UAV and terrestrial photogrammetry at the Mill will ensure that the expansive prevention-improved items will not fall into the same poor state of repair as they did previously.
Reflectance spectroscopy	Images for each Mellor monument captured over a 30-month period show clear advance and retreat of vegetation around the Shaw Cairn Area and involved items. Inexpensive equipment proves useful in monitoring vegetation. An unexpected discovery was the ability to use the NDVI camera to monitor below ground, unexcavated, archaeology. This becomes possible because of slight changes in vegetation resulting from differing topsoil depths where below-ground archaeology is present. Usually such discoveries are only made during long droughts, when surface vegetation begins to die.
Real-time monitoring (on-line sources)	
Wireless Acoustic Sensor Network (WASN)	The WASN is installed at the Old Vicarage of the Mellor Archaeological site with the aim of timely monitoring and reporting abnormal human activity that could result in acts of vandalism. Sound samples are recorded and forwarded to the Classifier server via the WASN. The WASN has achieved to successfully capture and forward sound samples from the site for a long-time period and is continuously doing so. Several events of human presence are recorded in the form of mechanical and electrical tools, but no acts of vandalism have been observed so far.
Weather station	Relative humidity, wind data seem sound (time series). Temperature data, precipitation data, and wind data seem sound (time series, frequency of occurrence plots, indices calculation). Note: precipitation sums for Shaw Cairn seem too low, especially after October 2017. This may either be due to an issue with the sensor starting late 2018, or due to the fact that the site is more exposed (illustrated by the

	higher wind speeds observed here as compared to Mellor Mill, Mellor Vicarage), which may result in underrepresentation of the actual precipitation sum (well-known issue for weather stations in general, also high-end models). Short data gaps (known to MAT) for the Mellor Mill weather station early 2019, Mellor Vicarage spring 2018 – problems were resolved. Issue with pressure sensor at Mellor Mill (unrealistic values – pressure constant over long period of time) – known to MAT, has been resolved. Overall, we can say with confidence that low cost sensors are a suitable application for this purpose. The sensors provided useful data showing the individual micro climates across the sites Areas.
Environmental sensor network Sensoro	The sensors provided useful data showing small changes in and around the archaeology that the site was not aware of before deployment. The Expected result was somewhat achieved, but the sensors did not have a long lifespan and the yearly fee to maintain the base station significantly increased the price needed to maintain such a network.

The experimental feedback and brief conclusions are given below:

Photogrammetry (aerial and terrestrial)

Photogrammetry, both UAV- and terrestrial- based, has been a **key improvement to monitoring and diagnoses of damages** at the Mellor site. The inexpensive and high-quality (up to 4k) camera on-board most inexpensive drones enables the site to create very high detail (sub-cm) models of areas and items throughout the Mellor Heritage Project. Comparison of photogrammetry using free-to-access software, means that damages are diagnosed very quickly and before they become an expensive problem to rectify. This is significant for Mellor who, outside of such projects, rely on small sums of money to run and operate. Early detection, therefore, ensures costs are kept to a minimum and assets are more likely to undergo prevention work than they would have prior to the introduction of photogrammetry techniques.

Terrestrial laser scanning (TLS)

TLS is a technique that has been well established and utilised in the STORM project. A key aim of its use in Mellor was to assess the relative use of laser scanning technologies with comparison to photogrammetry tools which are also in use and novel to the Mellor Pilot Site. The findings show that **Photogrammetry is the most cost effective and accessible technique for creating high quality 3D models of areas and assets**, especially when created utilising drones to cover wide areas. **Laser Scanning whilst being more expensive, does provide higher detail models**, but for this use-case the high detail is probably a premium that can be forfeited. Laser scans it is suggested should be utilised by STORM users, but on a less frequent basis as the scanner can be hired (keeping costs down) and the high detailed scans could be conducted at yearly intervals with the good quality photogrammetric models sufficing for the more frequent scans.

Reflectance spectroscopy (NDVI camera & UAV)

Over the 30-month data collection period and with specific focus on the Shaw Cairn Area of Mellor, the UAV based NDVI camera has been utilised to highlight the seasonal response of vegetation on the Kerb Stone item. Being a remote site previous scans were very rare and time consuming. With the introduction of UAV, the speed in which scans can be conducted has been significantly reduced with 15m a.g.l UAV flights over the area being completed within 20 minutes. Furthermore, before the introduction of NDVI, there was only human interpretation of vegetation density on top of Mellor Moor. The NDVI camera allows the experts to create thematic maps covering the entire area, and these can be uploaded to STORM and simply interpreted by non-expert volunteers who may be responding to hazards or conducting conservation measures of the Shaw Cairn Area. As mentioned in the above table, a novel and interesting finding of the NDVI was the ability for the site to monitor our unexcavated or re-buried archaeology. Essentially, below ground archaeology only appears in surface vegetation as a result of cropmarks or parchmarks during heatwaves and droughts. But the **NDVI camera enables the site to detect small changes in vegetation density and health even under normal conditions**. One key use of this was discovering the extent of the Iron-Age ditch, below ground, in areas that were never excavated during the original excavation in the 2000s.

Wireless Acoustic Sensor Network (WASN)

A WASN is installed at the Old Vicarage site of the Mellor Archaeological Trust. The aim of the node placement is to detect abnormal human activity and acts of vandalism. During months of measurements and classification, it is observed that human presence was often recorded in the form of mechanical and electrical tools, but no acts of vandalism were observed. Thereupon, it was decided to setup a high sound intensity threshold level that would stop the WASN from transmitting to the Classifier server a sound that falls below that threshold. This lesson learnt is mainly motivated by the need to minimize the consumption of scarce resources, like power and network data.

Weather station

The use of three inexpensive weather stations has proved to be a great asset to the pilot site. Excluding some periods of data loss due to sensor/connectivity issues out of the control of the site, the stations have performed extremely well and, as demonstrated in D9.2, the data is reliable enough to be used in conjunction with the long-term baseline data from the official UK weather service. This means that the thresholds set using the climate data can be used together with the site collected data and we can reliably assume that when the weather stations thresholds are overcome the data is useful information and we should respond. Having the three stations proved vital as the microclimatic differences across the pilot site are clear to see.

Environmental sensor networks

Environmental sensor networks gave the site great information about the change in temperature and humidity around their site areas and items enabling the site to produce heat maps of the area showing cold and hot spots. Such information is great when used in conjunction with the weather station as it gives site managers much more resolution information about the threats to items across the site.

2.1.1.3 Roman Ruins of Tróia

The main achievements of the method application are summarised in Table 6, Table 7 and Table 8.

Table 6: Evaluation of non-invasive and non-destructive methods: Roman Ruins of Tróia, Drill 1

Site	Roman Ruins of Tróia	Area	(D5.1) RRT-1b: Workshop 21	Items	(D3.1) RRT-03 – Wall with window in Workshop 21
Hazard	Rainfall, strong winds High tide, coastal erosion Landslide	Intensity	4 5 4	Risk score	5 5 4
Real-time monitoring (on-line sources)					
Wireless Acoustic Sensor Network (WASN)	The WASN is deployed in the Roman Ruins of Tróia as a means of early detection of extreme weather phenomena, i.e. local storm/lightning-thunder, intense wind or intense rain. The WASN has achieved to successfully record sound samples, record them and forward them to the Classifier server located within the UNIWA premises. During the time period of sound samples recording and classification, no events of extreme weather phenomena were captured. However, there have been reported events of human presence, including motorbikes and people laughing.				
Weather station	Online weather condition monitoring and establishing due thresholds for automated issuing the weather-condition related alarms. More specifically, during the exercise, the weather station simulated the report of the following conditions: P 1hr > 10 mm from the rain gauge, wind speed > 70 km/h through the anemometer, tide height > 3.8 m AMSL (Above Median Sea Level) from the tide gauge confirmed by acoustic sensor. The conjunction of these conditions caused the crossing of the acceptable thresholds and released a warning from the STORM platform.				

Table 7: Evaluation of non-invasive and non-destructive methods: Roman Ruins of Tróia, Drill 2

Site	Roman Ruins of Tróia	Area	BAS – Basilica (ref. D5.1: RRT-07 Basilica)	Items	RRT-BAS-m – Basilica wall with frescoes		
Hazard	Intense rainfall and strong winds causing humidity cycle shocks, wetting-drying cycles and salinisation			Intensity	4 5	Risk score	4 5
Real-time monitoring (on-line sources)							
Weather station	Online weather condition monitoring and establishing due thresholds for automated issuing the weather-condition related alarms. As in the case of the previous drill, the real-time data on the weather conditions — general wind speed, wind direction, temperature, relative humidity, pluviosity (rain gauge) sensors — enabled the alarm to be triggered. The alarming character of the weather conditions was supported by (i) the alternative source (Arduino, see below) and (ii) the historical data records, showing negative evolution.						
Sensor network Arduino	Online local environmental monitoring provided successful support to the automatic alarming, linked with the weather conditions. Additionally, these sensors provide real-time local data on temperature, relative humidity, light intensity, presence of water in the ground, rain, speed and wind direction. Detection of abrupt changes in the humidity affecting the frescoes. Previously defined threshold values for wind speed, temperature, relative humidity, and pluviosity were crossed. The risk of imminent intonaco detachment and painting layer loss was very high and an alert was emitted by the dashboard.						

Table 8: Evaluation of non-invasive and non-destructive methods: Roman Ruins of Tróia, long-period drills

Site	Roman Ruins of Tróia	Area	BAS – Basilica (ref. D5.1: RRT-07 Basilica)	Items	RRT-BAS-a – Basilica wall a (ref. D3.1: RRT_02 Northeast painted wall) RRT-BAS-m – Basilica wall m RRT-BAS-q – Basilica wall q

Hazard	Humidity cycle changes / wetting-drying cycles, excessive ground moisture, saline spray Salinisation, proliferation of microorganisms	Intensity	4 5	Risk score	5 5

Surveying and diagnosis (off-line sources)	
Induced fluores-cence spectros copy	**1. Portability and autonomy**, as stipulated on p. 81 of the Proposal and follows from the operational environment description, which implied: (2.1) being sufficiently lightweight and compact to be transported over a distance of ~1 km by one person → **weight ≤ 15 kg**, **volume ≤ 0.25 m^3**. Achieved values are **6.6 kg** and 15 × 34 × 35 cm^3 (**0.018 m^3**) (2.2) capability of functioning without any supporting infrastructure, being powered by a battery or battery pack → **power consumption ≤ 150 W**. Real power consumption is estimated at the level of **30 W**. **2. Low exploitation cost and eco friendliness**, to be achieved for methods under development. **Objective 3** of the Proposal are demonstrated as the sensor (3.1) **consumes only electric power** [no reagents] and (3.2) in contrast to numerous spectral devices that use **alkali-metal** and **mercury vapours**, is based on the discharge lamp filled by inert gas **xenon**. **3. Non-destructiveness and non-invasiveness (Objective 3)**, which in the current context means operating with the irradiation-light pulses that cannot destruct even the most fragile artefacts under analysis → irradiation-pulse **fluence** below the safe threshold of ca. **1 mJ/cm^2**. The 5-W lamp used in the developed SFS sensor has the fluence that is **less than declared by about 3 orders of magnitude**, varying from **2 µJ/cm2** in the ultraviolet range down to **1 µJ/cm^2** in the visible spectral range. The method of induced fluorescence does not require any invasive mechanical interaction with the artefact surface: For measurements, it is sufficient to attach the measuring head (made of soft plastic) to the surface of the object being diagnosed. In exceptional cases of a particularly fragile object, one can fix the measuring head at a distance of about 1 mm from the surface and carry out contactless measurements. **4. Selectivity**, which is stated as the target to be achieved in the preliminary comparative method analysis carried out in Task 1.2 (D1.2). This ability was confirmed by **evaluation of several greenish spots** on the painting surface. All have produced the SFSs that are qualitatively different from those detected for biological communities — and thus were classified as of non-biological origin.

	5. Sensitivity, also stated in Task 1.2 (D1.2), referring the capacity of **early** detection and characterization of biofilms. The SFS sensor demonstrated the ability of early detection of biological infestation, at stage in which the biofilm is invisible to the naked eye. The chlorophyll-contained communities (**phototrophs**) are characterised by specific peak in the vicinity of the **426/684 nm** point in the excitation/emission wavelength coordinates. **All biofilms** (with or without phototrophs) manifest themselves in the UV excitation area, yielding a peak in the vicinity of **282/395 nm** excitation/emission spectral point.
Real-time monitoring (on-line sources)	
Weather station	Real-time continuous recording and transmission of the atmospheric parameters to the STORM platform, started in October 2017, allowed to provide reliable assessment of the related hazards to the CH and aid the correction of previously proposed thresholds for automatic alarming. Temperature data, precipitation data, and wind data seem sound (time series, frequency of occurrence plots, indices calculation). Relative humidity data seem sound (time series). Missing data during parts of January/February 2018 (rainfall, temperature, wind) – due to technical problems successfully resolved.
Sensor network Arduino	The installation of the sensor network Arduino in the Basilica of Tróia (RRT-02) had the goal of more accurately establishing the impact of environmental conditions on the decay of the Basilica frescoes. This network consists of three nodes based on "Arduino Nano" open-source cards to which a series of environmental sensors are connected. Arduino receives the data from all the sensors and transfers them to the "Raspberry Pi 3 Model B+" card to which is connected a Wi-Fi antenna that allows the transmission of data to the STORM platform on which it is possible to monitor the evolution of three different wall paintings. The Raspberry is also connected to a visible camera that photographs the wall every time measurements are taken. The environmental sensor network has allowed monitoring the ambient parameters, characterising local conditions around three painted walls of the basilica, with automated-measurements every 15 minutes (96 per day). The parameters investigated are temperature, relative humidity, light intensity, pressure inside fractures, presence of water in the ground, rain, speed and wind direction. Being time-stamped and provided to the STORM platform, such set of measurements enables the conservators to highlight which parameters mainly influence the degradation of the walls, along with their synergistic impact. Each node is powered by solar panels and through a relay the circuits are powered every 15 minutes to perform timed and automatic measurements, monitoring the evolution of three different wall paintings resorting to environmental sensors coupled with image recording and crack-meters since December 2018. Data is transmitted to the STORM platform via Wi-Fi. The three different nodes can be briefly described as follows: • **Node A** was placed in the northeast wall (wall a), with some of the most valued paintings, monitoring the evolution of a crack, via crack-meter and high-resolution (HR) photographic recording, plus environmental data, including light intensity, temperature, and relative humidity sensors

	placed in direct contact with the wall. • **Node B** monitors the internal face of the northwest wall of the building next to the Basilica (wall m), which is exposed to the dominant winds from the North and Northwest, and whose paintings exhibit clear signs of active decay. To clarify the causes and rate of wall painting damages in this area, it was decided to monitor (i) microclimatic conditions in the close vicinity of the frescoes, including light intensity, temperature and relative humidity; (ii) wind speed and wind-driven rain affecting the wall, using an anemometer and a rain gauge, respectively; and (iii) material loss progression, registered by a time-lapse HR camera. • **Node C** monitors the external face of the southeast wall of the building next to the Basilica, directly exposed to weather hazards and in a very serious condition. Given its deterioration patterns, esp. missing elements, disaggregating mortars and cracks, the sensors – light intensity, temperature, relative humidity, crack-meter and an HR camera – were placed on the southeast face of the wall.

Table 9: Evaluation of non-invasive and non-destructive methods: Roman Ruins of Tróia, long-period drills

Site	Roman Ruins of Tróia	Area	W21 - (ref. D5.1: RRT-1b Workshop 21) W23 – (ref. D5.1: RRT-1b Workshop 23)	Items	RRT- W21- Workshop 21 SE wall (ref D3.1: RRT_03 Workshop 21: walls of the South corner) RRT- W23- Workshop 23: well (ref D3.1: RRT_01 Well of Workshop 23)		
Hazard	Intense rainfall, storms, strong winds, coastal floods, rain, wind-generated waves, coastal erosion, tides			Intensity	5	Risk score	5
Surveying and diagnosis (off-line sources)							
Photogrammetry	Photogrammetry was applied to the recording of archaeological items in use-cases RRT-01 and RRT-03. The testing consisted on the recording of the state of preservation of the items in different moments along three years, in six different surveys, for the purpose of diagnostics and analysis of the decay rate of those archaeological items through the comparison of the different surveys. Digital graphic recording was achieved, and 2D orthophotos and 3D models were produced. The digital conservation of archaeological structures reached by tide currents and sea waves was another major objective. Another goal was the integration of this cost-effective and rather easy surveying method in the current practice of the management of						

	an archaeological site by forming the site technicians. The two items monitored through photogrammetry for three years did not show any major decay and did not lose any element, showing that photogrammetry is a very accurate monitoring method.
Real-time monitoring (on-line sources)	
Wireless Acoustic Sensor Network (WASN)	The WASN has been deployed in the Roman Ruins of Tróia, with the following functionalities: Recording and transmitting audio signals of events of interest. Monitoring additional physical quantities from the network of deployed sensors (e.g. brightness, temperature, humidity). Classify sound samples to events of interest. Upload classification results to the STORM Cloud. It operates as a means of early detection of extreme weather phenomena, i.e. local storm/lightning-thunder, intense wind or intense rain. The WASN has achieved to successfully record sound samples, record them and forward them to the Classifier server located within the UNIWA premises. During the time period of sound samples recording and classification, no events of extreme weather phenomena were captured. However, there have been reported events of human presence, including motorbikes and people laughing.
Weather station	Real-time continuous recording and transmission of measurements of the atmospheric conditions to the STORM platform starting in October 2017 enabled to provide reliable assessment of the related hazards to the CH and aid the correction of previously proposed thresholds for automatic alarming.

The experimental feedback and brief conclusions are given below:

Photogrammetry

Photogrammetry is not a new technique, but it is new for the site of Tróia through the STORM project. Photogrammetry is **the most cost-effective method for 2D and 3D recording of archaeological assets**, particularly convenient for archaeological sites set in uneven terrain such as the Tróia sand dunes, where laser scanning is quite difficult to adjust. The recording of assets is particularly important in a site like Tróia where coast erosion is at work every day and storm surges may often cause visible damage. The purpose was to show the importance of digital recording of structures threatened by natural hazards and climate change. The second goal was to have the site team acquire the equipment and the capacity to perform the photogrammetric surveys, thus becoming independent of external acquisition of services and availability of funding. Acquiring the capacity was a slow process, and the aid of external teams was offered and accepted in the first campaigns, only to realise that photogrammetric surveys, for the purpose of comparison, need to be done in the exact same conditions. This goal was achieved since the team is doing the photogrammetric surveys and their processing, and an archive of surveys is being built for future reference. Photogrammetry is already being applied to other items of the site to record the current status and to aid future conservation works.

Regarding the specific experiments accomplished, consisting of the monitoring of two specific items, a well and a wall, the comparison of six different surveys had surprising results. Contrary to the impression of the site technicians, the two items monitored through photogrammetry for three years did not show any major decay and did not lose any element, showing that photogrammetry not only records the image, but it is a much more efficient monitoring method than the human perception.

Induced fluorescence

The induced fluorescence spectroscopy based on the pulsed lamp irradiation has proven to be an **efficient innovative method**, overpassing the traditional laser induced spectroscopy. Using the broadband lamp irradiation enables one to vary both the excitation and emission wavelengths, thus obtaining information rich spectral surfaces, rather than 1D graphs. In many cases such an approach bridges important informational gaps in target classification, that cannot be remedied by any mathematical trickery. The most important experimental feedback is the opportunity to focus the measurements in the ad hoc areas of interest on the excitation/emission wavelength coordinates. This sufficiently, about 10 times, reduces the measurement time and the amount of data to be analysed. The method versatility has already enabled the team to extend the technique to other applications, in particular: (a) development and validation of bio-optical ecotoxicological tests in marine phototrophs and (b) using the induced fluorescence spectroscopy as a part of a multisensory setup for non-invasive phenotyping of higher plants.

Wireless Acoustic Sensor Network (WASN)

The aim of the node placement in the Roman Ruins of Tróia was to detect extreme weather conditions, i.e. strong waves, local thunders or storm, strong wind or rain, which might affect the health of the site monuments. Moreover, the WASN was also programmed in order to detect abnormal human activity that could vandalize the site. In order to avoid unnecessary data network congestion and power consumption, a threshold sound level is set that filters out sounds below a certain intensity level. Sound samples have been collected for a multiple-month period and forwarded to the Classifier server located at the premises of UNIWA. Thereof, the Classifier server processed the samples, classified the corresponding sounds, and stored a log of the events. The WASN achieved to constantly record local generated sound samples and forward them to the Classifier server, while the Classifier server achieved to successfully process incoming data and upload summary results to the STORM Cloud server storage.

During those months of measurements and classification, it was observed that sea waves dominated but did not impose any health hazard to the site monuments due to their low level. On the other hand, human presence is scarce, therefore it may be useful to designate a high threshold sound intensity level with respect to weather phenomena, and a lower threshold level for human presence. Nevertheless, no extreme weather phenomena or acts of vandalism were detected during the time period of observation.

Weather station

The installation of a Weather Station in the site of Tróia transmitting real-time data to the STORM platform proved to be a valuable action since now it is possible to check the weather conditions at any moment, as well as consulting the historical record of data. Strong winds and intense rainfall present risks for the heritage assets, as they may cause the disaggregation of mortars and element loss in archaeological structures, as well as damaging of coverings, and high values in these factors indicate the need of visual inspection by the site team to assess damage and provide first-aid actions. To ease this process, warning thresholds have been set, not only of individual environmental hazards, but also of their conjunction. The STORM platform is set to send alarms in either situation. In the case of the Basilica, specifically monthly monitored since August 2017 with an induced fluorescence sensor to detect biological colonisation, the weather station data allow the comparison of results to weather conditions. The on-site weather station transmitting via Wi-Fi is therefore a powerful monitoring system that has eased the task of the site team.

Sensor Network Arduino

The monitoring of the site with Arduino for five months proved to reveal very specific conditions, and the evolution of those conditions from day to night, and through different weather conditions, helping explain the pathologies of the monitored items and suggesting different solutions for the site manager and conservators-restorers.

In all three monitored points the average relative humidity increases from December to February: 88.9 ± 2.3%, 89.9 ± 5.0%, 95.3 ± 4.7%. The humidity is consistent with the topographical features of the archaeological site and the increase in February is due to the frequent rains. Values recorded up to May change from a minimum of 39.4% to a maximum of 99.9%; these variations follow the day/night variations (since the site is semi-confined) and the humidity decreases in the time interval of 8 am - 5 pm and increases in the remainder. These long-term daily oscillations contribute to the detachments of the pictorial surfaces via wetting-drying cycles on the salt-laden walls.

Regarding the temperature, the three points run until February. From the beginning of March, node C, located outside the protective structure, receives more solar light, and so the masonry has a higher temperature than the internal one (around 20°C): it reached a maximum of 39.4°C in the month of April. Dangerous values highlighted by the data were recorded on January 3rd, when at 7am temperatures reached 5°C for the internal nodes and 7ºC for the outer one. Also, in this case the parameter follows the day/night trends, with 10°C-variations between maximum and minimum temperatures.

Measuring the relative pressure inside the lesions allows to investigate the phenomena of contraction and expansion of the lesions and therefore of the movements of the masonry. During the months of monitoring, no anomalous values were found simultaneously at all three nodes, indicating the absence of seismic shocks. However, sudden and sporadic increases in pressure were highlighted in all three nodes, and especially in node C, since March. This is due to the increase in temperature that caused the masonry to contract during the hours of direct light incidence.

The data on the presence of water and lighting made it possible to correlate the previously illustrated parameters and it is for this reason that they are indispensable. The anemometer has not yet produced significant data.

Monitoring is ongoing to enable the detection of seasonal trends.

2.1.1.4 Ancient city of Ephesus

The main achievements of the method application are summarised in Table 9 and Table 10.

Table 10: Evaluation of non-invasive and non-destructive methods: Ephesus, Drill 1

<table>
<tr><td>Site</td><td>Ephesus</td><td>Area</td><td>Great Theatre</td><td>Items</td><td colspan="3">Main Entrance wall</td></tr>
<tr><td>Hazard</td><td colspan="3">Earthquake</td><td>Intensity</td><td>5</td><td>Risk score</td><td>4</td></tr>
<tr><td colspan="8">Surveying and diagnosis (off-line sources)</td></tr>
<tr><td>Terrestrial laser scanning (TLS)</td><td colspan="7">High resolution and full-size point cloud data of the Great Theatre of Ephesus structure has been obtained, enabling the numerical model of the Theatre to be developed. This, in its turn, has made possible to understand and predict the structural behaviour of the monument, achieving the critical characterisation of the structure in terms of the following numerical thresholds:
● earthquake triggering value of PGA (peak ground acceleration): 2 mg, where g = 9.80665 m s^{-2} is the standard acceleration of gravity;
● sliding onset threshold: 200 mg;
● collapse threshold: 400 mg.
The recorded data provided digital preservation of the Theatre structure in its current state.</td></tr>
</table>

Table 11: Evaluation of non-invasive and non-destructive methods: Ephesus, long-period drills

<table>
<tr><td>Site</td><td>Ephesus</td><td>Area</td><td>Great Theatre</td><td>Items</td><td colspan="3">Main Entrance wall</td></tr>
<tr><td>Hazard</td><td colspan="3">Earthquake and prolonged dry period</td><td>Intensity</td><td>5</td><td>Risk score</td><td>3</td></tr>
<tr><td>Category</td><td>Methods</td><td colspan="6">Achievements</td></tr>
<tr><td colspan="8">Real-time monitoring (on-line sources)</td></tr>
<tr><td colspan="2">Earthquake and structural health monitoring (SHM)</td><td colspan="6">Proving the possibility and establishing the methodology for efficient SHM using low-cost accelerometers, which significantly improved the SHM system cost-effectiveness.</td></tr>
<tr><td colspan="2">Weather station</td><td colspan="6">Weather data (temperature, humidity, wind, precipitation and pressure) have been acquired since February 2018, establishing a basis for reliable long-period data collection and real-time monitoring.

Relative humidity, pressure, radiation data seem sound (time series). Temperature data seem sound (time series, frequency of occurrence plots, indices calculations). The precipitation sums seem too low, with no precipitation observed after April 2018 – this is known to Ephesus, and the proposed solution is to substitute the Ephesus observations with data from the Selçuk station, located in close proximity to the Ephesus site. Missing data during September 2018 correspond to some technical problems, successfully resolved afterwards.</td></tr>
<tr><td colspan="2">Environmental data analysis</td><td colspan="6">Substantial amount of climate data was collected using long-functioning nearby meteorological stations, especially one located in Selçuk, 2 km from the archaeological site. 156 consecutive dry days were determined as a threshold for reporting the extreme case of a prolonged drought for the Ephesus area under current climatic conditions (ZAMG). This slow onset disaster threshold is taken as a baseline suggestion for the site managers.</td></tr>
</table>

The experimental feedback and brief conclusions are given below:

Terrestrial laser scanning (TLS)

The terrestrial laser scanning has promptly provided indispensable information for the three-dimensional structure of the Great Theatre of Ephesus. This structure was subsequently analysed and proper mechanical description was attributed to each 3D area of the monument body, on the basis of measured mechanical properties and material identification. The entire dataset enabled the structural behaviour to be modelled and disaster outcomes predicted, using continuum and discrete FEA (Finite Element Analysis). The model is open for future improvements and amendments, accompanying the evolution of the monument structure, whose current state is digitally preserved in the form of a high-resolution 3D point cloud.

Earthquake and structural health monitoring (SHM)

An earthquake database has been compiled: a total of 64 earthquakes with the magnitudes $2 < M < 5.5$ have been recorded since March 2017. The high cost accelerometers were initially used for precise and reliable characterisation of the seismic events, suggested for the purpose of preparedness in short term (during the course of the project). The whole developed SHM system consists of two sets of low and high cost collocated accelerometers positioned at ground and structural points. They are characterised as follows:

High-Cost Accelerometers

- Force balance type, high precision, low noise levels
- Ideal for measuring ambient vibrations and capturing low magnitude earthquakes
- Relatively bigger sized, high maintenance cost, better suited for indoor uses

Low-Cost Accelerometers

- MEM type, relatively lower precision and higher noise levels
- Ideal for measuring high amplitude vibrations
- More suitable for damage assessment
- Relatively smaller sized, low weight, low maintenance cost, better suited for outdoor uses

The low-cost (co-located) accelerometers are found to be efficient in collecting data in long period. This is because the vibration amplitudes of stronger events are less frequent and usually have high amplitudes, readily detectable by less sensitive devices. Therefore, considering cost-effectiveness; light weight, small size and low cost such accelerometers are suggested to be used for long term measurements.

Real time data are monitored and checked for exceedance of the predefined damage threshold values. Automatic alarm messages are generated by comparing the measured peak acceleration value to the threshold value and reported through a resilient communication system.

During Drill 1, an automatic warning message has been produced and sent to the site manager to provide preliminary information about the level of damage at the site, which was kept updated by comparing the measured peak acceleration value to the previously determined structure specific damage threshold values. During the drill, synthetic signals were produced to simulate earthquake events. Expected level of damage was send to the responsible person via an automatic short SMS message and email. The drill was successfully completed and observed to be very efficient as it reduces the emergency response time in CH sites compared to conventional response operations. The procedure is considered innovative as there exist no such application related to the CH structures.

During Drill 2, the site manager received an alarm signal that there is earthquake damage in Ephesus through the STORM platform. He immediately initiated the emergency response process by informing the necessary units and moved to the site. When he reached the site, he activated the emergency box (EcoBox) to send critical instructions to the security teams about the damage situation. The box is designed to provide communication over a mobile application during an electric outage and also in the absence of the internet. For the simulation of this situation, mobile phones were left in the "plane mode" whereas, the WIFI and Bluetooth features were left on. Security officials received the critical message through the mobile application while their phones were on the plane mode and used radio communication to inform the first aiders to take the necessary measures in the theatre. First aiders reached the area and useed wooden shoring to temporarily stabilize the wall in order to prevent further damage to it due to the subsequent earthquakes. In this embodiment, the STORM platform has been used efficiently to generate the alarm signal and document the damage observed on the wall. In addition, the EcoBox's effectiveness in providing emergency communication has also been shown. This has been accepted as an innovative part in the second exercise.

Monitoring weather conditions

Long-term climate data has been provided from the nearby meteorological station located in Selçuk. After taking the climate reference period 1971-2000 and analysing the data, 156 consecutive dry days was determined (jointly with the expert from ZAMG) as an extreme case for the Ephesus area under current climatic conditions. This is taken as the threshold reported above. If the amount of consecutive dry days (days with less than 1 mm of rainfall or other precipitations) observed at Ephesus exceeds this threshold (after recalibration or repair of the precipitation sensor – see also D9.2), an alarm is generated to warn of a 'prolonged dry period' hazard. The above-mentioned threshold as defined for slow onset disaster can be taken as a baseline suggestion by the site managers, and then adjusted to take into account the knowledge and experience of the site managers.

2.1.1.5 Historical Centre of Rethymno

The main achievements of the method application are summarised in Table 11 – Table 13.

Table 12: Evaluation of non-invasive and non-destructive methods: Rethymno, Drill 1

Site	Historical Centre of Rethymno and the Fortezza Fortress		Area	Fortezza Fortress – St. Luca's bastion	Items	Wall, part of the façade of the double gun hole	
Hazard	Intense rainfall		Intensity	3	Risk score	3	
Real-time monitoring (on-line sources)							
Digital photogrammetry	Provided reliable monitoring and assessment of the surface structural damages using comparative analysis, in order to define preparedness actions to prevent potential collapse and/or future damages. Recent images were compared with those obtained in earlier periods. KPI: overall accuracy of the detected changes in the range of 1-5cm.						
Terrestrial laser scanning (TLS)	Provided alternative and complimentary method with respect to the digital photogrammetry for monitoring and assessment of the surface structural damages, pursuing the same objectives. KPI: overall accuracy of the detected changes in the range of 1-5 cm.						
Time-Lapse (4-D) Electrical Resistivity Tomography (ERT)	Monitoring soil infill conditions and internal water flow on the fortification walls in order to define restoration – conservation actions where necessary and suggest preparedness actions to prevent potential collapse. The recent data were compared to older measurements to identify the water saturation of soils and the possible increased pressure exerted on the walls of the Fortezza from the interior of it. KPI: resolution of the final images less than 0.3 m.						
Ground Penetrating Radar (GPR)	Assess structural discontinuities like cracks and voids on the walls in order to define restoration – conservation actions where necessary and suggest preparedness actions to prevent potential collapse. GPR data were able to check large size cracks and even voids filled with water that could result to problems regarding the structural integrity of the walls, due to the effect of the heavy rain episode. KPI: resolution of the final images less than 0.1 m.						

Table 13: Evaluation of non-invasive and non-destructive methods: Rethymno, Drill 2

Site	Historical Centre of Rethymno and the Fortezza Fortress	Area	St. Paul's bastion	Items	Fortification wall and watchtower
Hazard	Earthquake	Intensity	3	Risk score	2
Real-time monitoring (on-line sources)					
Digital photogrammetry	Assess and monitor the surface structural damages using comparative analysis to define preparedness actions to prevent potential collapse and/or future damages. Parts of the walls that have been fallen have been identified. Other parts that are becoming loose from the main integral bulk of the walls were recognized. KPI: overall accuracy of the detected changes in the range of 1-5 cm.				
Terrestrial laser scanning (TLS)	Assess and monitor the surface structural damages using comparative analysis to define preparedness actions to prevent potential collapse and/or future damages. Terrestrial laser scanning has been applied in a complementary way to the conventional digital photogrammetry techniques. KPI: overall accuracy of the detected changes in the range of 1-5 cm.				
Time-Lapse (4-D) Electrical Resistivity Tomography (ERT)	Monitoring soil infill conditions and cases of micro-tectonic movements of soils or stone blocks that constitute the infill material of the interior soil matric that exerts pressure on the Fortezza walls. The method was employed to define restoration – conservation actions where necessary and suggest preparedness actions to prevent potential collapse. KPI: resolution of the final images less than 0.3 m.				

Table 14: Evaluation of non-invasive and non-destructive methods: Rethymno, long-period drills

<table>
<tr><td>Site</td><td>Historical Centre of Rethymno and the Fortezza Fortress</td><td>Area</td><td>Fortezza Fortress, Venetian Port, Historical Centre</td><td>Items</td><td colspan="3">Fortification walls, Episcopal Mansion (Fortezza Fortress), Lighthouse (Venetian Harbor), Rimondi Fountain, Soap Factory (Historical Centre)</td></tr>
<tr><td>Hazard</td><td colspan="2">Earthquake, landslides, intense rainfall, wind, wind driven rain, solar radiation, prolonged wet and dry periods (weather stations – crack meters).
Earthquake, intense rainfall, flash flood, landslides (ERT)
Earthquake, landslides, intense rainfall, flash floods, strong wind, wind driven rain, solar radiation, heat waves, prolonged dry periods, salinization (sudden and slow onset) relevant to the changes the hazards may cause in the condition of the monuments (e.g. stone weathering, vegetation) (TLS)</td><td>Intensity</td><td colspan="2">4 (earthquake),
3 (landslides, salinization, wind),
2 (flash flood, wind driven rain, solar radiation, prolonged wet and dry periods)
1 (heat waves)</td><td>Risk score</td><td>5 (prolonged wet and dry periods, heat wave)
4 (salinization, intense rainfall)
4 (wind, wind driven rain)
4 (earthquake)
3 (landslides, solar radiation)
2 (flash flood)</td></tr>
<tr><td colspan="8">Surveying and diagnosis (off-line sources)</td></tr>
<tr><td>Digital photogrammetry</td><td colspan="7">Assess and monitor the surface structural damages using comparative analysis (with older photogrammetric images) to define preparedness actions to prevent potential collapse and/or future damages. KPI: overall accuracy of the detected changes in the range of 1-5 cm.</td></tr>
<tr><td>Terrestrial laser scanning (TLS)</td><td colspan="7">Assess and monitor the surface structural damages using comparative analysis to define preparedness actions to prevent potential collapse and/or future damages. The method is used in a complementary way to the conventional digital photogrammetry techniques.
KPI: overall accuracy of the detected changes in the range of 1-5 cm.</td></tr>
<tr><td>Ground penetrating radar (GPR)</td><td colspan="7">Assess structural discontinuities like cracks and voids on the walls in order to define restoration – conservation actions where necessary and suggest preparedness actions to prevent potential collapse. KPI: resolution of the final images less than 0.1m.</td></tr>
</table>

Time-Lapse (4-D) Electrical Resistivity Tomography (ERT)	Monitoring soil infill conditions, micro-tectonic displacement of soils or large building blocks within the soil matrix and internal water flow within the fortification walls. in order to define restoration – conservation actions where necessary and suggest preparedness actions to prevent potential collapse. KPI: resolution of the final images less than 0.3 m.
Surveying and diagnosis (off-line sources)	
Crack meters	Crack meters were installed at Bastion of St. Paul, Bastion of St Elia, Bastion of St. Luke and Episcopal Mansion (Fortezza fortress). A statistical ARX model (Auto-Regressive model with eXogenous input) has been employed to investigate the influence of the environmental parameters. The successful application of the methodology at the four monitored cracks has provided important information about their state of damage, possible causes and early warnings in case of hazard. Over the evaluated period, it appears that the bastion of St. Elias is in a stable condition, while the bastion of St. Loukas and St. Paul are vulnerable to rainfalls. Moreover, the Episcopal Mansion showed a destabilization response during the rainfall period, which can possibly result in the activation of an overturning mechanism.
Weather stations	Weather stations were installed at Counsellors building, Fortezza Fortress and Historical Centre of Rethymno: Arkadiou str. Ephorate of Antiquities of Rethymno. The raw data of the weather stations are being collected locally and simultaneously used in the crack meters monitoring methodology. Considering the fact that weather fluctuation has reversible effects at the structural integrity, it is of great importance to recognize the environmental and operational variation of the structure, and subsequently identify any separate structural change caused by damage. This has been achieved by employing a statistical ARX model (Auto-Regressive model with eXogenous input), calibrated for each case after several months. Once this process has been completed it is possible to detect possible active damage on the examined structures and estimate possible causes for them. Furthermore, the data are downloaded in graph form and are assessed in every occasion necessary. They were used during the February storms to view the rainwater precipitation in the area.

The experimental feedback and brief conclusions are given below:

Photogrammetry and Laser Scanning

Photogrammetry and laser scanning are well-known and consolidated methods for the documentation of CH. The proposed approach demonstrates the possibility to use methods and procedures to obtain quantitative and qualitative data of a given artefact. Such information, although still in need of manual (human driven) data analysis, can provide unique information for the state of monitored buildings and can as well strongly contribute to the identification of potential issues and relative solutions. In the specific case of the monitored building of Fortezza Fortress, the TLS and photogrammetry approach were capable to identify point-cloud differences below one centimetre. Examples have been given also for the structural analysis of single point-cloud (numerical deformation of damaged wall surface) and for possible use of such dataset for other purposes (like modelling for seismic analysis) or methods (e.g., calibration of geophysical measurements).

Ground penetrating radar (GPR)

An important fact regarding GPR method is its site dependency, as its performance can significantly vary from site to site, as well as the way that the data are collected, treated, processed and interpreted afterwards. The analysis of the GPR data revealed the wall thickness, the boundary between the two walls, as well as wall-air and wall-soil. No differences were observed to aid risk assessment, other than the higher water content. Overall, GPR can be employed as a complimentary method regarding risk assessment especially for monitoring historical buildings wall thickness.

Time-Lapse (4-D) Electrical Resistivity Tomography (ERT)

The 4-D ERT method was employed along individual lines, which were laid out in three different areas on the walls of Fortezza (Saint Paul's, Louka's and Nicola's Bastions). The aim of the specific survey was to extract the stratigraphy of the sediments in the interior of the walls, to map the thickness of the walls, to locate sections of increased moisture and define paths of moisture flow though resistivity monitoring. The 2D and 4D ERT results were quite promising and fulfilled the initial expectations regarding the efficiency of the method in assessing the integrity of standing cultural monuments.

Crack Meters

Structural health monitoring (SHM) consists of an elaborated technique, assisting the assessment of existing structures through the detection of active or sudden damages, as well as the diagnosis of possible causes for them. The SHM strategy selected for the assessment of the Fortezza fortress was the continuous crack monitoring of 4 different existing cracks of the structure, due to their relatively large width, located at the Bastions of St. Paul's, St Elias' and St Lucas as well as the Episcopal Mansion.

Besides the crack displacement measurements, several other environmental quantities are monitored at the weather stations, which are known to have a strong influence on the crack width. Considering the fact that weather fluctuation has irreversible effects on the structural integrity, it is of great importance to recognize the environmental and operational variation of the structure, and subsequently identify any separate structural change caused by damage. This has been achieved by employing a statistical ARX model (Auto-Regressive model with eXogenous input), calibrated for each case after several months. Once this process has been completed it is possible to detect possible active damage on the examined structures and estimate possible causes for them.

The successful application of the methodology at the four monitored cracks has provided important information about their state of damage, possible causes and early warnings in case of hazard. Over the evaluated period, it appears that the bastion of St. Elias is in a stable condition, while the bastion of St. Loukas and St. Paul are vulnerable to rainfalls. Moreover, the Episcopal Mansion showed a destabilization response during the rainfall period, which is possible to result in the activation of an overturning mechanism.

Weather stations

The use of two inexpensive weather stations has proved to be a great asset to the pilot site. As shown in D9.2, even between the areas within the site micro-climatic differences are present, illustrating the benefit of collecting a localized database for further analysis (such as e.g. the combined crack meter and meteorological observations described in the table above). Furthermore, after collecting sufficiently long-time series at the site level, these observations can be used for the bias correction of the climate analysis and future climate projections. In this way, the information about the future climate at site level can be refined and used to update the climate change risk assessment. In addition, the local observations can be used to adjust the warming thresholds for extreme weather events as defined, based on the long-term data from the nearest available meteorological station.

2.1.2 General evaluation of on-site meteorological monitoring

Two types of weather data were used in STORM: ‘offline’ long-term observational records (time series spanning at least 30 years) provided by the respective national meteorological organizations for stations closest to the sites, as well as the observations obtained with the on-site weather stations installed as part of STORM. Together with the climate model projections, the long-term observations were used to characterise the climate hazards as part of the risk assessment detailed in D5.1. In addition, thresholds to define extreme weather events were determined based on these long-term observations for each site separately (e.g. the occurrence of an unusually long dry period can be defined relative to the historical occurrence of prolonged dry periods). These thresholds can be used to raise a warning in case the on-site weather station data show a specific threshold is exceeded.

In D9.2 and D9.3, the on-site weather station data are presented, assessed and analysed for all pilot sites individually. Next to an assessment of data quality, the pilot site observations are compared to the long-term climatology in a procedure similar to the climate analysis included in D5.1.

Based on the analyses of the weather station data of all pilot sites, the following was concluded: “**The low-cost weather stations tested in STORM are suitable for the monitoring of cultural heritage, although quality checking the data prior to further analysis and comparison is recommended. The low-cost weather stations tested in STORM provide a clear benefit to the site**:

- Data are available in **real-time**, an important requirement for extreme event monitoring and prompt response, e.g. to assess damage and provide first-aid actions.
- Data reflect the site’s **micro-climate**. Micro-climatic conditions at the site may differ significantly from the official meteorological station, and even within the site important differences may occur (e.g.: temperature differences resulting in different numbers of freeze-thaw events even for heritage in close proximity, large differences in wind).

- Data from the low-cost weather stations can be used to supplement data from the nearest meteorological station: The **risk assessment** may be **refined** following a bias-correction of the long-term time series using the data obtained with the local low-cost weather stations.
- The data can support the attribution of weather/climate events to observed damage, and as such also be used to **support evidence-based decision making**."

2.2 Crowdsensing technologies based on the advanced information processing

This subsection covers evaluation of the *explicit* and *implicit* crowdsensing technologies implemented in STORM. The *explicit* crowdsensing approach aims to leverage on human perception and intelligence in recognising hazards threatening (e.g. rockslides) or currently damaging (e.g. soil erosion, salinization) cultural heritage assets, namely sites, areas and items. In essence, people act as *human sensors* in an online participatory sensing network, using special mobile applications. *Implicit* crowdsensing solutions represent the situational awareness capabilities resulting from the post-processing analysis of the collected data — to yield insights not explicitly provided by the involved users.

2.2.1 Explicit crowdsensing

The *explicit* crowdsensing mobile application has been tested in two STORM pilot sites: Baths of Diocletian and Historical Center of Rethymno to collect damage detections. The main achievements of the explicit crowdsensing application are summarized in Table 15.

Table 15 - Evaluation of Explicit Mobile Crowdsensing

Site	BoD	Area	Cloister of Michelangelo, south-western wing, Hall I	Items	Column I, S-W side wall of the cloister, cross vault, Front Hall I, Back Side masonry façade, Pillar S-W, cross vault Hall I, masonry facade between Hall I and II, Sarcophagus, Architectural element
Site	HCR	Area	Bastion of Saint Paul, Venetian Harbour	Items	Watchtower, Lighthouse
Surveying and diagnosis (off-line sources)					

Explicit Crowd-sensing	The explicit crowdsensing mobile application has been used throughout the project to enable the users to report threats or damages affecting CH assets, acting as *human sensors*. In that view, the explicit crowdsensing mobile app is specifically designed to improve "human sensors" accuracy, providing **context-specific information** about how to properly recognize clues of threat/damages affecting cultural heritage asset. When reporting a threat or damage detection, users are enforced to take a geotagged photo showing the asset threatened or affected by the degradation. Together with the mobile app it was developed the backend service needed to configure and provide the context-specific information. Validation Model was revised and tested during last drills, in order to process damage reports and generate Useful Information for the site manager. All reports related to a generated useful information are stored and accessible to site managers.

Only threats or damages that are easily detectable (i.e. visible and unambiguous) even by non-skilled users are **suitable** for explicit crowdsensing. Explicit crowdsensing participants can report only a set of predefined threats/damages detections, namely the ***explicit crowdsensing threat/damage detectable list*** (see table below), where each monitored asset is paired with each easily detectable threat/damage that may threat or affect the asset (item, area or site), according to the *hazard and risk map* of the site.

Asset			Detectable Threat/Effect
Site	Area	Item	
BoD	Area1	Hall1	Erosion
BoD	Area1	Hall1	Concretion
BoD	Area1	S-W Pillar	Biological patina
BoD	Area1	S-W Pillar	Efflorescence

Since damage detections are individual perceptions of threats or hazard effects, report of threat or degradation affecting a specific asset may be inaccurate or even fake. Thus, crowd sensed data need a cross-validation process, mainly intended for evaluating threats/damage detections reliability. For this reason, users are invited to validate damage detection reports of other users (confirming or not confirming it, Waze app like).

Using the STORM Information Model terminology, threats/damages detection reports are potential *useful information*, even *critical situation* detections, that need a Data Validation Process, mainly intended for evaluating damage detection reports reliability and, according to the validation rules, generate *useful information* that will be processed by the *Information Level* of the STORM platform.

At the end of the pilot's executions, the main qualitative outcomes of the experimental feedback are:

1. Damage detection reports accuracy is mainly dependent on how easy it is to unambiguously recognize the monitored damages.
2. Damage detection reports reliability is mainly dependent on the crowdsensing participant's skill/expertise in recognizing clues of damages.
3. GPS coordinates and a picture of the damage detail are not enough to localize effectively a damage affecting big assets (e.g. concretions on a wide façade).
4. The same damage could have different impact on the same asset, with different severity (e.g. a crack has a different impact at the bases or the top of a wall).

The final evaluation of the explicit crowdsensing technology in STORM is summarised as follow:

1. Users should be registered and classified as expert/not-expert: in this way the validation model can benefit of the different weight of users' reports and cross-validations.
2. In order to get more information about the damaged asset, damage detection and reporting should use a more effective way of modelling the asset, in this way users can report damages with higher accuracy.

To sum up, this technology could be usefully used by a "stable" group of registered crowdsensing participants for wide area monitoring (e.g. Pompei).

2.2.2 Implicit crowdsensing

The main achievements of the method application are summarised in Table 15.

Table 16: Evaluation of Implicit Crowdsensing

Site/ Area	RRT, MAT and extra test areas: Municipality of Athens, Florida, Texas, Haiti, L'Aquila, Nepal, Taiwan, Greensburg	Items	Walls, windows, doors, beams, pavements, benches and statues

Hazard	Vandalism Earthquakes, hurricanes, and tornadoes	Intensity	N/A	Risk score	N/A
Surveying and diagnosis (off-line sources)					
Implicit Crowdsensing	The implicit crowdsensing application was developed on July 2018. This application is used throughout the project to enable the site visitors, the site managers and stakeholders to annotate images in order to build a robust computer vision algorithm based on deep learning. A STORM dataset including annotated images containing at least one graffiti/tagging has been built on September 2018. The graffiti/tagging and spalling detectors were developed on November 2018. The implicit crowdsensing application was used in the RRT and MAT sites, to collect crowdsensed images. The collected images did not display any graffiti or spallings.				

The experimental feedback and brief conclusions are given below:

The implicit crowdsensing application empowers the site visitors, managers and stakeholders to survey manually the site areas, by providing images that probably contain conservation issues, using their smartphones. The successful application of the crowdsensing methodology at the municipality of Athens has provided more than one thousand annotated images containing graffiti/tagging, constituting, to the best of our knowledge, the first annotated image database for graffiti/tagging detection. Despite this was a wild data collection, it had as outcome a robust graffiti/tagging detector based on deep learning with mAP (mean Average Precision) of 65.2%. Moreover, having as input annotated images by civil engineers, containing spallings occurred to buildings due to earthquakes, tornadoes, and tsunami a spalling detector was also developed, having 58.8% as mAP.

From an architectural point of view, the detected spallings/graffiti are forwarded from the users’ smartphones to the STORM platform, where they are processed by the two object detectors, which are using a Faster R-CNN detector exploiting ResNet101 as classifier. In case of detecting a spalling or graffiti, the detectors send the according notification to the Information Processor in order to be accessible to the site managers.

The implicit crowdsensing application was used in Mellor and Tróia pilot sites through the gamification application in order to motivate the stakeholders to collect useful images displaying points of interest that may suffer from conservation issues. The players showed high level of engagement, however none of the collected images showed any damages to the assets.

2.3 Readiness level of the key technologies mentioned in the STORM Proposal

In view of the notes made in the Proposal with respect to the advancement in technological knowledge expected as a result of STORM (subsection 1.3.5 *Positioning of the project*), it is pertinent to complement the technology analysis with a brief overview of the key technologies focused on the achieved TRLs made in Table 16.

Table 17: TRL analysis of the principle STORM technologies mentioned in the Application

Component name	Technology	Start TRL	Target TRL	Achieved TRL	Justification
Social Network (SN) Crowdsensing extractors	Native SN APIs, high throughput back end engine based on node.js and espress.js.	6	8	8	Even if the last trend adopted by the main actors of the Social Networks landscape (Facebook, most of all) is changing their native APIs in order to "close" the access to their data, the TRL level 8 was technically achieved. Social Network extractors were successfully used in Implicit Social Media Crowdsensing experimentation, focusing on Twitter's data. Our node.js based service architecture guarantee high throughput and flexibility at the same time, since social network data extraction is heavily I/O bounded.
Social Network Crowdsensing filters	Native SN APIs, location base data, pattern matching image classifiers, social reputation ranking.	3	6	6	Target TRL 6 was technically achieved, even some filtering techniques have suffered the restrictive policy adopted by major Social Network players to access data using their APIs. With regards to pattern matching, deep learning object detectors to identify conservation issues (e.g., graffiti) was used to certain locations of interest. The requested TRL level 6 of the method is achieved by applying the pattern-based image classifiers to images collected from implicit crowdsensing application and the SN APIs (i.e., Instagram), by successful demonstration of the implicit crowdsensing in the *relevant environment* of the municipality of Athens, from Dec-2018 till the end of the project. Location based data filtering was successfully adopted during the experimentation of implicit social media crowdsensing, given that Twitter

					users are used to share location data by default. To prevent user's privacy, social reputation ranking was estimated considering the number of likes and retweet.
Induced fluorescence sensor	High-resolution spectral analysis of the induced fluorescence emission from the surface of the target under investigation (in the case in question, the artefact) providing early detection and characterisation of films of destructive contamination (primarily, of biological origin: algae, moss, etc.).	4	7	7	Requested TRL level 7 of the method is achieved with the Spectral Fluorescence Signature (SFS) sensor, by successful demonstration of the sensor prototype in the harsh *operational environment* of the Tróia site, from 3 August 2017 till the end of the Project.
Wireless Acoustic Sensor Network (WASN) / Acoustic signals classification	High-fidelity microphones to capture the full spectrum at high SNR, processor/DSP to pre-process/process/analyse the signal, OTA upgrade capability, Wi-Fi for message and audio transmission, smart energy management / use of renewables to increase service time. The WASN employing multiple time and frequency domain feature extraction and ANN classification will be able to alert in case of hazardous weather conditions.	4	7	7	The aim of the WASN is to detect extreme weather conditions and abnormal human activity. Following the outdoor installation in three sites (RRT, BoD, Mellor), all using 3G connectivity, one connected to grid power and two off-grid, sound samples were collected and forwarded to the Classifier server. Thereof, the Classifier server processed the samples, classified the corresponding sounds, and stored a log of the events. The WASN achieved to record local generated sound samples and forward them to the Classifier server, while the Classifier server achieved to successfully process incoming data and upload summary results to the STORM Cloud server storage. Thus, the prototype WASN has been demonstrated in an *operational environment*.
UAVs equipped with LiDAR	LiDAR sensors are quite powerful and flexible tools for the study of Cultural Heritage. Their capabilities span from accurate three-dimensional measurements of known artefacts or monuments until the discovery of new structures. New technological development allowed to reduce the size of sensors still keeping the same or compatible capabilities and accuracy. Thus	4	7	7	The intensive study of the two competitive techniques related to the 3D characterisation of the CH, LIDAR and photogrammetry, led us to the conclusion that for the case in question — in which exceptional spatial resolution or very fast results are not required — the photogrammetry provides the same or better results at a lower cost (see, e.g., https://geoawesomeness.com/drone-lidar-or-photogrammetry-everything-your-need-to-know/, section *Cost*). For this reason, the developed three-dimensional characterisation of the artefacts at the Mellor site was developed on the basis of the UAV-compatible photogrammetry equipment (cameras),

	UAVs equipped with LiDAR can now be employed in the precise documentation of built structures or landscapes with much reduced operative costs with respect to traditional surveys. Further, recent research demonstrated the applicability of laser beans for the monitoring of polluting elements in the atmosphere, because of the short wavelength of LiDAR sensors.				which has provided valuable results reported within the framework of deliverable D4.1, during the experimental campaign carried out in the corresponding *operational environment*, as requested for TRL 7. The UAV application at the Mellor pilot site using the latest 4k camera technologies demonstrate very high (up to mm) accurate 3d-models. This highlights the lack of need to utilise the UAV LiDAR which would be far more expensive. The 30-month data collection campaign demonstrated in an operational environment at the Mellor pilot site illustrates that the aims of the original technique have been achieved whilst still using innovative technologies but also those which are cost-effective – a key aim of the STORM project. Therefore, the TRL of 7 has been achieved.
UAVs equipped with infrared sensors	Multi band and infrared sensors are meant to highlight stress areas in spontaneous vegetation and homogeneous cultivations. Indeed, such sensors are capable of boosting minimal chromatic differences (normally not perceivable with naked eye or regular RGB sensors) due to different absorption of light waves by healthy and stressed vegetation. Those differences are normally related with buried structure (weather manmade or natural). The possibility to map these variations and analyse them in relation with known architecture may importantly contribute to the understanding of the state of the art of the artefact under investigation and its relation with potential surrounding buried structures or geological formations.	4	7	7	The requested TRL has been achieved thanks to the demonstrative uses of the drone equipped multiband sensor. First, the sensor allows the site to be guided, with the help of experts, to see minute differences in the vegetation density, that otherwise could not be seen with simple RGB photography. Second, the camera has opened up novel methods for monitoring below ground archaeology at the Mellor site, specifically mapping the below ground iron-age ditch. This is possible as the sensor can detect differences in vegetation density at minimal differences and therefore, can spot “parch marks” that would only be noticeable to the human eye during heat waves and prolonged droughts.
Web – based GIS services for risk	Updated GIS (Geographic Information System) data per micro-site, innovative socio-	5	7	7	An in-depth analysis related to the implementation and use of web-based GIS services for providing geographical information can be found in D7.9. The

assessment modelling	natural risk assessment tools and methodologies supported by GIS web-based services.				architectural schema for the provision of STORM web-GIS services was implemented as a set of free and open-source components. STORM web-GIS services are currently utilized to provide thematic web maps through the STORM Dashboard, as well as to access and manage geospatial data for any Cultural Heritage site hosted by the STORM platform, as defined in deliverable D7.8. STORM web-GIS services can provide management and visualization of geospatial data associated with each STORM pilot site, and further provide support for the visualization of (dynamic) geographic information of other platform services and tools, such as the Risk Assessment and Management (RA&M) tool, the Surveillance and Monitoring (S&M) and the Quick Damage Assessment (QDA) services.
Complex Event Processing (CEP)	The CEP is a Java based SW component that allows detecting anomalous situations to be highlighted when the received information is revealed in line with models that define an anomaly. It provides special Event Stream Processing techniques that enable rapid development of applications for the processing of large volumes of messages or events in real time, or near real-time.	4	7	7	Data processing techniques and methodologies have been defined and implemented to detect hazardous events or anomalous situations. The CEP component applies the first level of rules to data coming from multimodal sources to obtain Useful Information, then it correlates them through the second level of rules to generate Simple Events. Techniques of event processing are applied to aggregate similar events, enrich them considering several sources of information, and correlate them with each other (e.g., spatiotemporal relationship), obtaining Complex Events. The software architecture of the CEP component and its interaction with other components of the STORM platform have been described in D6.2 and D6.3. The CEP prototype has been demonstrated in operation environment during several drills organised for the STORM Platform assessment.

Surveillance and Monitoring services	Surveillance and monitoring services from the SOTA will be studied aiming to know the commonly monitoring systems used in the context of Cultural Heritage and propose innovation. Main technologies involved will be algorithms for the anomaly detection in the signals produced by the sensors and crowdsourcing of information from social medias.	3	6	6	Surveillance and Monitoring technologies have been defined and implemented to provide a picture of the critical situation, indicating which site, area and item is involved in the emergency and what the site manager should do to face the emergency situation. Causal inference has been utilised to assess the cause/effect relationships for historical events and geographical representations has been provided to help site managers and first responders to locate the critical situation. The software architecture of the Surveillance and Monitoring component and its interaction with other components of the STORM platform have been described in D6.4. The Surveillance and Monitoring component has been integrated in the STORM platform and demonstrated in a relevant environment during several drills organised for the STORM Platform assessment.
Quick Damage Assessment services	Techniques and methods to i) show the operator the result of the information fusion in order to derive the maximum knowledge about the observed phenomenon, ii) to analyse and derive the meaning of these observations to assess damages severity and predict the possible consequences of the observed situation, iii) to select the best actions to deal with the emergency considering the known risks, and iv) control the evolution of the critical situation and support maintenance.	3	6	6	In STORM, the Quick Damage Assessment process has been defined by experts to cover the activities of collecting information, assessing damages, selecting the emergency actions and managing the evolution of the situation. A database containing the data involved in all the activities has been implemented. Data are collected and displayed through the dashboard and the crowdsourcing mobile application before and during hazardous events to guide the emergency intervention and to allow the debriefing after the disaster. The software architecture of the Quick Damage Assessment component and the interactions with the other components of the STORM platform has been described in D6.6. The Quick Damage Assessment component has been integrated in the STORM platform and demonstrated in a relevant environment during several drills organised for the STORM Platform assessment.

3 Cost-effective Disaster Risk Management for Conservation

3.1 The STORM CEA methodology[1]

3.1.1 Introduction

Managing a historical site entails daily decisions on interpretation, access and conservation and, albeit each site is unique, decisions must be framed by shared principles on heritage care. The social importance of heritage, as well as scarcity of resources, require transparent and consistent decision making, which may be supported by weighing the costs against the benefits of the different options considered for a given policy or strategy. Cost-benefit analysis, arguably more common in policy comparisons, prices both costs and benefits; Cost-Effectiveness Analysis (CEA) resorts to monetary units solely for cost valuation, thus being preferable for projects involving benefits that are difficult to monetise[2], such as those developed in heritage contexts[3].

The primordial objective behind the CEA developed in STORM is to **support decision making in the Conservation of cultural assets**; it can be similarly applied to **support decision making for the Disaster Risk Management (DRM)** of those assets[4].

In its widest sense, heritage Conservation may be defined as "All actions designed to understand a heritage property or element, know, reflect upon and communicate its history and meaning, facilitate its safeguard, and manage change in ways that will best sustain its heritage values for present and future generations"[5]. In archaeological assets, such as the STORM pilot sites, which mainly embody scientific/evidential and historical values, conservation actions are typically undertaken to safeguard the fabric as main value repository, whilst minding 'present and future' interpretation and fruition. When approached from a DRM perspective, the objective is the same, with conservation actions framed as the control of risks threatening the values of the heritage element, their fruition and/or interpretation/communication.

A given policy/strategy is cost effective if it represents the least cost solution to reach a predefined target. A CEA weighs the costs against the effectiveness of different options and, while costs are generally more or less straightforward to obtain, the effectiveness of interventions in heritage contexts is not similarly clear-cut, because heritage conservation is, first and foremost, a social endeavour, where decision making is intersubjective at best[6]. In STORM, effectiveness is assessed via expert discussion following several reference examples used in the heritage conservation field[7].

---

1 The STORM CEA methodology is described and illustrated in STORM Consortium. 2017. "D1.3: Cost-Effective Conservation and Restoration Methods"; it was nevertheless deemed convenient to briefly summarise it here, so as to provide context for the current chapter.

2 EC. 2008. "Guide to Cost-Benefit Analysis of Investment Projects: Structural Funds and Instrument for Pre-Accession." Brussels: European Commission - DG Regional Policy.

3 Klamer, Arjo, and Peter Wim Zuidhof. 1998. "The Values of Cultural Heritage: Merging Economic and Cultural Appraisals." In *Economics and Heritage Conservation*. Martha de la Torre and Randall Mason (Eds.), 23–61. Los Angeles: The Getty Conservation Institute. http://www.bblp.eur.nl/bbcswebdav/pid-378414-dt-content-rid-3055926_1/courses/CC2017-14/Klamer_Zuidhoff_econrpt-1.pdf.

4 It should furthermore be noted that the STORM CEA is specific to support decision making at site management level: it does not consider impacts outside the site, nor does it allow for comparisons among different sites.

5 Nara+20. 2016. "Nara+20: On Heritage Practices, Cultural Values, and the Concept of Authenticity." *Heritage & Society* 8 (2): 144–47. https://doi.org/https://doi.org/10.1080/2159032X.2015.1126115, p.147.

6 Muñoz Viñas, S. 2005. *Contemporary Theory of Conservation*. Oxford: Elsevier Butterworth-Heinemann.

7 See, for instance, Sasse, H.R.; R. Snethlage. 1997. "Methods for Evaluation of Stone Conservation Treatments." In *Saving Our Architectural Heritage: The Conservation of Historic Stone Structures*, N.S. Baer, R. Snethlage (Eds.), 223–43. Chichester: John Wiley & Sons Ltd.; Delegou, E.T., C.Kiranoudis, J.Sayas, A. Moropoulou. 2012.

3.1.2 CEAs within the STORM DRM approach to heritage conservation

Given the focus of STORM, and although the STORM CEA procedure was originally defined to support decision making within the scope of conservation and restoration planning for archaeological structures, it was decided to frame it within a DRM perspective, whereby the CEA is used to support decisions on interventions targeting the risk treatment of heritage structures, including – but not limited to – conservation-restoration actions.

This STORM CEA application follows *D5.1. Risk Assessment and Management*[8], which presents the STORM Risk Assessment (RA) methodology, as well as the results of its application to each STORM Pilot Site; and *D5.3. Risk Management Guidelines*[9], which defined guidelines for the planning and implementation of Risk Control Strategies in each of the STORM Pilot Sites. The RA procedure enabled identifying and characterising, for each site – and for each area within that site – hazards, exposure and vulnerabilities. Subsequently, D5.3. provided guidance when devising risk treatment strategies that may be applied at site, area and, eventually, item level.

That is to say: once the pilot sites (i) have their risks assessed and prioritised, as per D5.1; and (ii) have devised risk treatment options, as per D5.3.; the next step (iii) entails choosing between different the risk treatment options by applying the CEA.

3.1.3 STORM CEA: methodological steps

While minimum criteria for the development of a CEA within a DRM framework are not yet consensual among experts[10], there are four critical elements to any CEA: objectives; costs; effectiveness (outcomes); and comparisons[11]. The steps for the application of the STORM CEA to risk treatment options targeting the preservation of archaeological structures are described in the subsections below.

3.1.3.1 Step 1: Specify the Objectives and the Timeframe of the intervention

Risk treatment strategies may be designed for the medium and long term or for the short term. Typically, short-term strategies are aimed at obviating emergency situations, be it in the Preparedness or in the Response phases; whereas long-term strategies will make more sense within the Prevention or Recovery phases. Specific objectives should be defined: even if the general objective of any risk control measure will generically be *to treat the risks* affecting a given structure/area/item, each DRM phase will have different specific goals, which will have to be detailed for the context and timeframe at hand.

For example: a hazard potentially leading to sudden-onset disasters, e.g. a flood, will require preventive (long term) and preparedness (short term) measures, to make the concerned

"Developing an Integrated Decision Making System for the Assessment of Cleaning Interventions on Marble Architectural Surfaces." In *12th International Congress on Deterioration and Conservation of Stone*. New York: Columbia University; or Sanna, U., C. Atzeni, N.Spanu. 2008. "A Fuzzy Number Ranking in Project Selection for Cultural Heritage Sites." *Journal of Cultural Heritage* 9: 311–16. https://doi.org/10.1016/j.culher.20070.12.004.

8 STORM Consortium. 2017. "D5.1. Risk Assessment and Management." Project STORM - Safeguarding Cultural Heritage through Technical and Organisational Resources Management.

9 STORM Consortium. 2018. "D5.3. Risk Management Guidelines." Project STORM - Safeguarding Cultural Heritage through Technical and Organisational Resources Management.

10 Shreve, C. M., I. Kelman. 2014. "Does Mitigation Save? Reviewing Cost-Benefit Analyses of Disaster Risk Reduction." *Int.Journal of Disaster Risk Reduction* 10 (PA): 213–35. https://doi.org/10.1016/j.ijdrr.2014.08.004.

11 Canoy, M., J. Rampton, J. Sennett, M. Gossett. 2013. "Study on Cost-Effectiveness of Education and Culture Spending Programmes. Final Report to the European Commission." Brussels: EC - DG Education and Culture. https://doi.org/10.2766/3884.

structures more resilient. In this context, a possible objective for preventive measures would be, for instance: *to mitigate the flood risks of the site/area/item for a period of 30 years*. Preparedness measures, on the other hand, would address, for instance: *arrangements in advance to enable timely, effective and appropriate responses to the impacts of a flood in the site/area/item*[12].

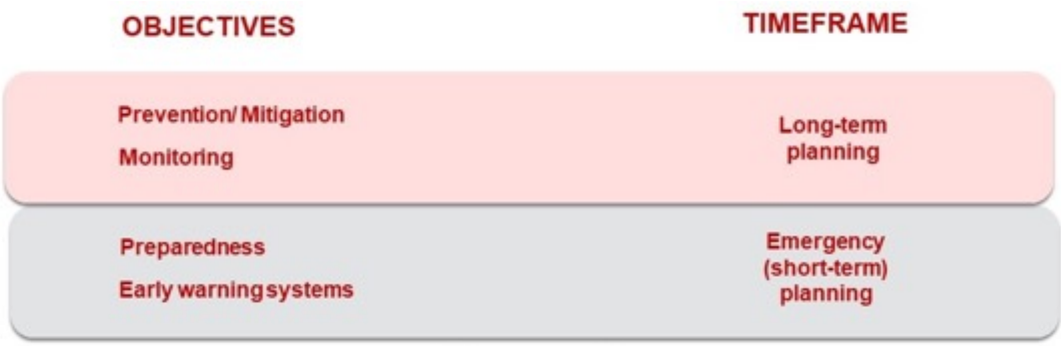


Figure 2: First step of the STORM CEA: specification of objectives and respective timeframes for the concerned heritage structures and hazards/risks.

Preventive or preparedness measures may also be related with monitoring or survey systems enabling early warnings (in the case of emergencies) and/or timely warnings of concerning environmental or conservation conditions (in the case of long-term planning). Because these will also have potential effects on the heritage fabric, they can be tackled by the STORM CEA.

3.1.3.2 Step 2: Specify DRM Strategies

Once the objectives and timeframes are defined, it is possible to define which strategies, interventions or actions will address said objectives in the intended timeframes. Considering the STORM risk definition, risk treatment strategies will typically address the hazard(s) affecting the heritage items and/or their susceptibility towards those hazards. Please note that, seeing as *exposure* was defined as "elements at risk" and it relates to the cultural value of the heritage items, and to avoid misunderstandings, interventions targeting the exposure of the asset to the hazard will be tackled under either 'hazard' or 'susceptibility', depending on which is found more adequate. Step 2 of the CEA application is graphically described in Fig.3.

[12] Adapted from United Nations General Assembly. 2016. "Report of the Open-Ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction." Sustainable Development: DRR. UN. https://doi.org/https://www.preventionweb.net/files/50683_oiewgreportenglish.pdf., p.21.

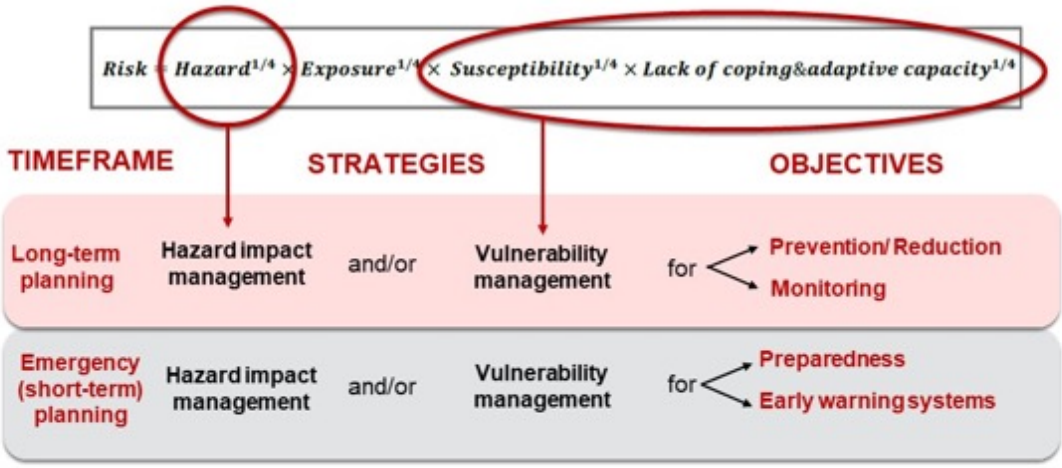


Figure 3: Second step of the STORM CEA: whether long term or short term, risk treatment options may address the hazard, the vulnerability of the heritage element, or both.

3.1.3.3 Step 3: Estimate costs for each of the devised strategies

The cost characterisation of each planned intervention should include all involved costs, including planning, administrative, logistical and infrastructural costs. Costs are divided into 'Initial investment costs' and 'Future costs', since interventions may imply further actions, e.g. regular maintenance, where the costs will only be charged in the future. These costs should be discounted to the present moment, and the Social Discount Rate (4%)[13] should be used to obtain the Net Present Costs (NPC).

3.1.3.4 Step 4: Estimate the effectiveness of each of the devised strategies

In a CEA, effectiveness should be represented by simple indicators, which will depend on the expected (beneficial) outcome(s). In STORM, effectiveness is defined as follows:

> **Effectiveness**
>
> Degree to which heritage significance, authenticity and integrity (levels) are preserved and/or enhanced by the implementation of a given project (or action, method, or product).

As clarified in D1.3, 'effectiveness' is often decomposed into two different analytical categories: efficacy and compatibility. Within the STORM CEA, efficacy is presupposed for the considered treatment alternatives and the notion of compatibility is used to assess to what extent each option enables the conservation of the material and immaterial dimensions of the heritage object, thus incorporating the notion of non-harmfulness towards cultural significance in the short and long runs[14]. The compatibility of the alternatives must therefore be <u>evaluated in terms of expected material and immaterial impacts</u>: heritage materials are cultural significance vehicles, and therefore damage to or loss of these materials decreases their significance; additionally, significance is an immaterial concept, and may be impaired even if materials are safeguarded, e.g. when fruition becomes compromised. Each effectiveness assessment should be rated by a sufficient number of relevant experts and stakeholders, including of course the site manager. Albeit no rigid rules regarding their number and required

---

[13] EC. 2018. "Tool #61: The Use of Discount Rates." *Better Regulation*. https://ec.europa.eu/info/sites/info/files/file_import/better-regulation-toolbox-61_en_0.pdf.

[14] Revez, M.J., and J. Delgado Rodrigues. 2016. "Incompatibility Risk Assessment Procedure for the Cleaning of Built Heritage." *Journal of Cultural Heritage* 18: 219–28. https://doi.org/10.1016/j.culher.2015.09.003.

specialties, as the necessary experts/stakeholders are context-contingent, a minimum of three heritage consultants is recommended, who should have no vested interest in any of the proposed strategies; plus the site manager's opinion. Expert assessments may be weighted or simply averaged into a final value, using standard deviations as an uncertainty measure, as done here.

It is furthermore recommended that a minimum level of effectiveness is put forth, below which no option should be chosen. Following the application of the methodology to a case-study in Tróia (see D1.3), it is suggested that a minimum value of 5 is set for each effectiveness parameter (M, I, and O), below which the option should be excluded.

3.1.3.5 Step 5: Calculate the cost-effectiveness

The most immediate form of presenting the results of a CEA is to calculate C/E ratios, i.e. cost-to-effectiveness ratios: C/E, which allow for a direct comparison of different project alternatives: the lower the ratio, the more cost-effective is the option.

When several options are considered, it is also possible for CEAs to include incremental analysis: ratios of incremental costs to incremental outcomes allow determining at what additional cost will the added benefit come; nevertheless, these were not used here since sites typically considered a maximum of three options for each analysed measure.

3.2 Applications within STORM

The following sections present the STORM CEA application to DRM measures undertaken at some of the STORM pilot sites. A fully detailed example of this application is presented for the Tróia site, where CEA was used to support the planning of experimental campaigns carried out concerning Prevention and Preparedness measures. Less detailed examples are given for the Baths of Diocletian and for the Historic Centre of Rethymno, to illustrate other contexts where the CEA may find applicability; it was considered that one in-depth case and two complementary cases would sufficiently clarify the methodology application.

3.3 Application at the Roman Ruins of Tróia

3.3.1 Introduction: chosen use cases

The risk assessment of all the Roman Ruins of Tróia (RRT) areas allowed their prioritising in terms of risks, characterising their hazard and vulnerability parameters[15]; risk treatment strategies were proposed for the most pressing site risks[16]. Albeit there are many concerning risks in the Tróia site, two of the most alarming situations were selected for more in-depth analyses:

- the tidal and wave action and consequent coastal erosion, impacting upon the shoreline structures (Workshops 21 and 23, both in the STORM reference area RRT-1b);
- the environmental conditions contributing to the damage or loss of the Basilica frescoes (RRT-7).

[15] STORM Consortium. 2017. "D5.1. Risk Assessment and Management." Project STORM - Safeguarding Cultural Heritage through Technical and Organisational Resources Management.
[16] STORM Consortium. 2018. "D5.3. Risk Management Guidelines." Project STORM - Safeguarding Cultural Heritage through Technical and Organisational Resources Management.

Figure 4: Areas chosen for the application of CEA at the Roman Ruins of Tróia.

3.3.2 CEA x Prevention: the treatment of risks in Workshops 21-23

3.3.2.1 Context and trial scenario description

As mentioned, the shoreline structures are among the most threatened items in the Tróia site. Among these, the structures in Workshops 21 through 23 are the most concerning, largely because they correspond to a relatively large ensemble, including particularly valuable assets, such as one of the tallest walls in any fish-salting workshop in the site, still including a window, in Workshop 21; and the well in Workshop 23 (Figure 5).

Figure 5: Wall with window in workshop 21 (left) and well in workshop 23 (right).

According to the performed risk assessment, _waves and tidal action_, which (a) have direct physical and chemical impacts upon the structures and (b) lead to _coastal erosion_, also affecting the Roman workshops, are among the most serious hazards affecting the shoreline constructions of the Tróia site. The effects of these hazards upon these fragile structures cause instabilities that can be catastrophically enhanced by _strong winds_, _earthquakes_ and/or _intense rainfall_. Furthermore, the progressive dune sand depletion caused by the tides may additionally cause _landslides_.

Figure 6: Shoreline structures of the Roman Ruins of Tróia: Workshop 21 (centre) and partial view of workshop 22 (to the left); the high tide reaches the base of all workshops in this area.

Thus, all items in Workshops 21 through 23 face a very high risk of loss due to waves and tidal action, which are slowly eroding the foundations of the structures and, consequently, have led to occasional collapses and relevant losses of stone masonry components in a relatively short lapse of time[17].

The main objective for the shoreline structures of Tróia is the long-term conservation of their cultural significance, which mainly translates into the long-term preservation of the existing material remains. Considering the main threats affecting this area, a number of possible mitigation strategies was devised that would allow the halting of the main degradation agents – tidal and wave action, leading to coastal erosion – for a reference timeframe of 30 years.

Solutions for the management of these risks may act on the hazard and/or on the vulnerability of the asset; and may be implemented at area or item level. Solutions for the vulnerability of the asset would typically consist of conservation-restoration interventions recovering the stability of the structures; these interventions could be analysed at item level (e.g. specific walls). Conversely, hazard impact mitigation strategies make more sense at area level, due to scale issues: if realised, the mitigation of tidal action and coastal erosion should be planned for all the workshops in this section of the site.

[17] Brum, P.; I. Vaz Pinto, A.P. Magalhães, F. Santos, and J. Müller. 2017. "The STORM Project and Coastal Erosion: The Case of Tróia (Portugal)." *Skyllis* 17 (1): 62–68. http://www.deguwa.org/?id=297.

In this particular context, measures are needed to act both on the hazards and on the vulnerability of the archaeological structures, i.e., both the conservation-restoration of the structures (vulnerability management) and the halting of the beach sand depletion (hazard management) are essential for the 30-year conservation of the structures – neither will guarantee this preservation on its own. Since the site manager is very much interested in finding cost-effective solutions for managing the risks to these structures, it was decided to perform a CEA of the options for the mitigation of the tidal action and coastal erosion risks affecting this area.

3.3.2.2 Analysed strategies

Tides are semi-diurnal and have great amplitude, varying between 3m (average of highest tides) and 1.4m (average of lowest tides) in the harbour of Setúbal[18]. Along the site the tide current field is very strong due to the proximity of the south canal of the estuary, where currents may attain a speed of 1m/s in ebb tide. Moreover, the coastal area is exposed to the predominant winds of north quadrant that, in conjunction with the large area of generation, c. 2 km of the estuary, generate waves of low amplitude but high frequency[19]. Therefore, the long-term preservation of the Tróia shoreline structures requires the management of the threats ensuing from their proximity to the estuary waters – tidal and wave action – causing direct physical impacts and ultimately leading to coastal erosion. Strategies considered to deal with these hazards include:

i. the construction of a seawall/barrier of geobags

Following an in-depth hydraulic study of the coastal line dynamics, and with the permission of the concerned authorities, a breakwater barrier would reduce the force of the waves hitting the structures and force local sedimentation, thus reducing coastal erosion.

This barrier could be built using geotextile bags (geobags) filled with sand. Many commercial solutions, featuring eco-friendly and high durability bags, are available for this purpose.

ii. a beach re-nourishment

The deposit of sand for the re-nourishment of sand-depleted areas has been attempted at Tróia before, slightly downstream from the Workshops 21-23 area, behind the paleo-Christian Basilica (see fig. 7). In 2007, following this sand deposition, which utilised sand dragged from the nearby Marina, many of the archaeological structures were covered in sand, i.e. reburied. In practice, the amount of sand needed for the building of the required beach profile in the area under analysis here would entail the reburial of all shoreline structures.

On the other hand, experience demonstrates that, due to the coastal dynamics in this area – wave action, tides and currents –, this solution will have an expected durability of c. 10 years; after 12 years the deposited sand will have been transported away in full.

[18] Andrade, C.; Rebêlo, L.; Brito, P. O.; Freitas, M. C. 2006. “Processos holocénicos; aspectos da geologia, geomorfologia e dinâmica sedimentar do troço litoral Tróia-Sines”. *Geologia de Portugal no contexto da Ibéria*, Universidade de Évora.

[19] Silveira, T.; Andrade, F., Pinto, I. V.; Magalhães, A. P.; Cabedal, V. 2014. “Enchimento de praia para protecção das ruínas romanas de Tróia: projecto e acompanhamento arqueológico”. *Setúbal Arqueológica* 15: 259-305.

Figure 7: Beach re-nourishment with reburial of shoreline structures behind the Tróia Basilica.

iii. the installation of an artificial reef

An artificial reef, built using elements designed to promote the development of marine ecosystems, would help reduce the force of waves and contribute to sedimentation, thus reducing coastal erosion. Although the geobags mentioned in (i) are expected to be environmentally friendly and not to discourage the growth of aquatic organisms, an artificial reef developed to foster this growth may be better suited in a natural park such as Tróia.

On the other hand, these elements typically stay below the water line, and are therefore less visually intrusive than geobags.

Figure 8: Examples of reef ball systems deployed in Italy. Sources: www.ilrestodelcarlino.it (left); www.reefballitalia.it (right).

The table below summarises the objectives, timeframes and the (long-term) Prevention/ mitigation options considered for the 30-year management of the hazards threatening Workshops 21 through 23, as well as for their monitoring.

Risk mitigation options for Workshops 21-23			
Area	RRT-1b – Workshops 21-23	**Item**	-
Long-term Objectives	Preserve the shoreline structures	**Timeframe**	30 years
Primary hazards	Slow-onset: Coastal erosion; tidal and wave action; wind-generated waves	**Related hazards**	Sudden-onset: Storm surges; tsunamis; coastal floods; landslides; strong winds, intense rainfall
			Slow-onset: sea level rise
DRM Step	**Strategies**		
Prevention/ Mitigation	**Option A**. seawall/ module barrier in geobags		
	Option B. beach re-nourishment / reburying of the structures		
	Option C. installation of an artificial reef		
Monitoring	**Option A**. photogrammetry		
	Option B. beach sections (topographic analysis)		
	Option C. Laser scanning		

Cost and effectiveness analyses were performed for the strategies listed above for Prevention/ Mitigation and for Monitoring; the results are summarised in the table below.

The lower C/E ratios correspond to the most cost-effective strategies; these are highlighted in a different shade of blue.

3.3.2.3 Cost-effectiveness analysis of Prevention strategies at the Roman Ruins of Tróia

Table 18: Cost-effectiveness analysis of Prevention strategies at the Roman Ruins of Tróia

Site	RRT	**Area**	RRT-1b – Workshops 21-23	**Item**	-	**Timeframe**	30 years
Hazard	Slow-onset: Coastal erosion; tidal and wave action; wind-generated waves			**Susceptibility**	5	**Risk score**	5
STEP	**Options**	**Products/ Equipment**	**Human Resources**	**Initial costs (Ci)**	**Discounted future costs (Cf)**	**Estimated effectiveness (E)**	**C/E = (Ci+Cf)/E**
Monitoring	Option A. Photogrammetry	Camera; PC; software	2 archaeologists 1 computer expert	8 101,16 €	17 292,03 €	8,92 (+/- 0,3591)	2 846,77
	Option B. Subcontracting a beach section team (topographic analysis, sand quality and deposition control)	Subcontracted (Total station)	Subcontracted (1 topographer 1 expert)	7 791,00 €	26 944,45 €	7,08 (+/-0,5000)	4 906,14
	Option C. Subcontracting a laser scanning team	Subcontracted (Camera; Laser; PC; software)	Subcontracted (2 technicians)	10 000,00 €	34 584,07 €	9,41 (+/- 0,6872)	4 737,95
Hazard impact management							

Barrier	Option A. geobag seawall / module barrier	vehicles; heavy machinery; geobags	1 hydraulic engineer 1 project manager 5 technicians	9 315,75 €	13 367,71 €	7.25 (+/- 0,2887)	3 128,75
	Option B. beach re-nourishment / reburying of the structures	vehicles; heavy machinery, sand	1 geologist / project manager 1 archaeologist 3-5 drivers	184 880,00€	299 913,03 €	8.17 (+/- 0,4647)	59 338,19
	Option C: reef balls	vehicles; heavy machinery; reef ball moulds; filling materials	1 hydraulic engineer 1 team leader 5 technicians	130 356,00 €	32 707,36 €	9.75 (+/- 0,3191)	16 724,45

3.3.2.4 Remarks

When it comes to hazard impact management, the most cost-effective strategy for the safeguard of the shoreline workshops is the building of a geobag barrier. Although its effectiveness is the lowest, mainly due to its visual impact upon the shoreline, which is expected to somewhat impair fruition; and due to its less-than-optimal sustainability features; its much lower costs dictate its higher cost effectiveness. The re-nourishment of the beach, largely because of the very high costs in terms of equipment and materials (sand), coupled with the fact that it would always be a more or less temporary solution (i.e., it would demand regular repetition), is not a viable option for hazard mitigation. Finally, the reef balls, albeit very appealing as the most effective solution, also represent significant deployment costs, which do not compensate the added effectiveness. It should be noted that, in the course of analysing the cost effectiveness of reef balls, it was verified that these would not in fact be a solution in this specific context, since the tidal amplitude of Tróia is excessively large for the reef tops to be consistently close to the surface, as required for wave attenuation. Regardless, it was decided to keep the example in order to illustrate the CEA. A further development of this study will compare geobags with submerged breakwaters made of more traditional materials (e.g. stone or cement blocks).

In terms of monitoring options, the beach section topography fared very poorly in terms of immaterial effectiveness, as it does not allow for the monitoring of the actual structures (it would, nevertheless, be adequate if the reburial was to be chosen). Photogrammetry was the preferred option, particularly because it can be implemented by the site staff, which provides for a much regular and cost-sensible monitoring solution: yearly laser scanning would not be justifiable in terms of expenses, and 5-year monitoring was considered insufficient by half of the consulted experts.

3.3.3 CEA x Prevention: biocolonisation on the Basilica frescoes

3.3.3.1 Context and trial scenario description

The frescoes of the Basilica are sheltered from rainfall and direct solar light but are exposed to other natural hazards such as wind, saline spray and salinisation, air humidity, rising damp, biological colonisation.

In the Northeast wall, where some of the most valuable Basilica frescoes are located, biological colonisation can be particularly damaging; the early detection of developing biofilms may prevent that damage by enabling more timely treatments. Walls *a* through *c* (in the Northeast wall) underwent sequential conservation campaigns, generally in post summer months, between 2012 and 2016. At the time of their respective interventions a biocidal product was sprayed on the frescoes, with an expected durability of ~1 year.

Figure 9: Algae in Wall c in the Tróia Basilica, before biocide application.

Until very recently, the general detection and evaluation of biological infestations on the Basilica frescoes was tackled via indirect measurements of related ambient parameters (temperature and relative humidity) and visual observation. Since STORM, real-time values for these parameters are now provided both by the nearby (outdoors) weather station and by the environmental sensors network (node A). Nevertheless, information on these parameters is unable to guarantee the early detection of developing biofilms. On the other hand, traditional methods of biological analysis on heritage surfaces are more or less lengthy operations involving the inoculation of adequate culture media and subsequent lab analysis; and generally do not provide information on the intensity of colonisation. These features discourage their routine use as part of a monitoring programme.

In the frame of the STORM project, a spectroscopic analytical method was tested for this task, based on a lamp-induced fluorescence sensor, which allows scanning both excitation and emission wavelengths. This induced fluorescence spectroscope is sufficiently sensitive to identify early stage biofilms, invisible to the naked eye, and to detect the signals at which prevention measures, and namely biocides, should be applied on the frescoes before biodeterioration is too advanced. Several measurement points were chosen on different walls in the Basilica, both treated and untreated, for monthly assessments of microorganism presence. Results were periodically reported and uploaded in the STORM platform.

3.3.3.2 Analysed strategies

The table below describes the strategies contemplated for the monitoring of biological colonisation on the Basilica wall paintings, as described above.

Biocolonisation monitoring of the Basilica frescoes			
Area	RRT-7 – Basilica	**Item**	-
Long-term objectives	Prevent biocolonisation of the frescoes	**Timeframe**	30 years
Primary hazards	Slow-onset: biocolonisation	**Related hazards**	Slow-onset: high relative humidity; high temperature
DRM Step	**Strategies**		
Monitoring	**Option A**. SFS spectroscopy		
	Option B. visual observation		

Cost and effectiveness analyses were performed for the Monitoring strategies listed above; the results are summarised in the table below. The lower C/E ratios correspond to the most cost-effective strategies; these are highlighted in a different shade of blue.

3.3.3.3 Cost-effectiveness analysis of monitoring strategies at the Basilica

Table 19: Cost-effectiveness analysis of biocolonisation monitoring strategies at the Basilica

Site	RRT	**Area**	RRT-7– Basilica	**Item**	-	**Timeframe**	30 years
Hazard	Slow-onset: biological colonisation		**Susceptibility**	Very high (5)		**Risk score**	Very high (5)
STEP	**Options**	**Products/ Equipment**	**Human Resources**	**Initial costs (Ci)**	**Discounted future costs (Cf)**	**Average estimated effectiveness (E)**	**C/E = (Ci+Cf)/E**
Monitoring	**Option A**. SFS four times a year	Subcontracted (SFS equipment)	1 spectroscopy expert	2 120,00 €	36 659,11 €	**9,42** (+/- 0,3591)	**4 118,14**
	Option B. visual observation twice a year	-	1 conservator-restorer	500 €	8 646,02 €	**8,75** (+/- 0,3591)	**1 045,26**

3.3.3.4 Remarks

The most cost-effective way of monitoring the biological colonisation of the Basilica frescoes is to resort to visual inspections by duly trained conservator-restorers. The financial effort required for the SFS sensor monitoring, essentially due to the highly specialised expertise required and to the sophistication of the necessary equipment, is too large to justify the added effectiveness.

Implementing a yearly biocidal treatment protocol, at least in the areas most prone to biocolonisation, would remove the need for regular surveys, but it would likely cause an excessive application of biocide, which is undesirable both for conservation and ecological reasons. Further developments on natural (plant-based) biocides will show if these could be a future option for the control of biological colonisation in Tróia.

3.3.4 CEA x Preparedness: RRT Drill 1

3.3.4.1 Context and trial scenario description

As mentioned earlier, one of the most aggressive hazards for the site of Tróia is the tidal and wave action, enhanced by sea-level rise. These hazards have a direct impact upon the Roman structures located on the estuary of the Sado River; and additionally, cause severe coastal erosion, which is slowly exposing the foundations of the masonry structures; this effect is maximised when intense rainfall, strong winds and high tides coincide. The geological substrate of Tróia is sand, and it is very obvious that in the past centuries the tide currents removed great quantities of sediment from the seashore, exposing Roman buildings and structures and causing their partial or total destruction. Workshop 21, located on the shoreline, has already been partially destroyed by tidal action and shows fractures that were likely caused by the pressure of the sand dunes.

The items to protect within the scope of the first Tróia drill were: the southeast wall of fish-salting workshop 21, which is one of only two workshop walls preserving their original height; and the vat wall immediately parallel to the southeast wall. The top of the southeast wall preserves the cavities to insert the wooden beams of the roof and the open space of a window, also the only case of a window preserved in a fish-salting workshop in Tróia. The uniqueness of these preserved masonry elements dictated the selection of this area as a STORM case study.

The drill consisted of an extreme situation caused by the forecast conjunction of intense rainfall, strong wind, and an impending high tide. It is considered that the potential impacts of this conjunction of factors may be catastrophic for the already structurally fragile workshop walls, and the decision to build a u-shaped sandbag barrier before the high tide, to protect the archaeological structures from wave impact, ensues. Concurrently, a system for the temporary stabilisation of the window is implemented.

3.3.4.2 Analysed strategies

The table below describes the strategies contemplated for a pre-impact stabilisation of the wall with window in Workshop 21, as described above.

<table>
<tr><th colspan="4">Risk treatment options for Workshops 21</th></tr>
<tr><td>Area</td><td>RRT-1b – Shoreline structures</td><td>Item</td><td>Wall with window</td></tr>
<tr><td>Short-term objectives</td><td>Prevent (further) masonry loss</td><td>Timeframe</td><td>short-term (< 1 year)</td></tr>
<tr><td rowspan="2">Primary hazards</td><td rowspan="2">Slow-onset: Coastal erosion; tidal and wave action; wind-generated waves</td><td rowspan="2">Related hazards</td><td>Sudden-onset: Storm surges; tsunamis; coastal floods; landslides; strong winds, intense rainfall</td></tr>
<tr><td>Slow-onset: sea level rise</td></tr>
<tr><td>DRM Step</td><td colspan="3">Strategies</td></tr>
<tr><td rowspan="2">Preparedness
(Structure safeguarding)</td><td colspan="3">Option A. geobags barrier</td></tr>
<tr><td colspan="3">Option B. Jute+raffia sandbag barrier</td></tr>
<tr><td rowspan="2">Preparedness
(temporary shoring)</td><td colspan="3">Option A. brick up the window</td></tr>
<tr><td colspan="3">Option B. wood shoring</td></tr>
</table>

Cost and effectiveness analyses were performed for the Preparedness strategies listed above; the results are summarised in the table below. The lower C/E ratios correspond to the most cost-effective strategies; these are highlighted in a different shade of blue.

3.3.4.3 Cost-effectiveness analysis of Preparedness at the RRT – Drill 1

Table 20: Cost-effectiveness analysis of Preparedness at the RRT – Drill 1

Site	RRT	**Area**	RRT-1b – OF21	**ITEM**	Wall with window (+ adjacent vat)	
Hazard	Coastal Erosion + Intense rainfall + Strong winds + High Tide		**Susceptibility**	Very high	**Risk score**	5
STEP	**Action type**	**Products/ Equipment**	**Human Resources**	**Costs (C)**	**Effectiveness (E)**	**C/E**
Pre-impact activities						
Stabilisation of immovable elements	Structure safeguarding	Geobags barrier: - geobags - vehicles and machinery - other materials: geotextile; metal fence; metal tubes; wood planks	15 persons with emergency training 1 civil engineer 1 civil protection expert 1 conservator-restorer	**3229,00 €** (N.B.: some of the labour was provided on a volunteer basis)	**7,25** (+/-0.2887)	**445,38**
		Jute/raffia bags barrier: - jute/raffia_bags - vehicles and machinery - other materials: geotextile; metal fence; metal tubes; wood planks	15 persons with emergency training 1 civil engineer 1 civil protection expert 1 conservator-restorer	**1 726,50 €** (N.B.: some of the labour was provided on a volunteer basis)	**7,06** (+/-0,4137)	**244,46**
	Temporary shoring	Brick up the window: bricks; mortar + local stabilisation of the window with hydraulic lime mortar	1 Conservator-restorer 1 conservation technician	**366,50 €**	**8,63** (+/- 0,5685)	**42,49**

		Close the window with wooden poles + shock absorbing materials + local stabilisation of the window with hydraulic lime mortar	1 Conservator- restorer 3 carpenters	**360,00 €**	**9,00** (+/- 0, 6667)	**40,00**

3.3.4.4 Remarks

In terms of protection against the direct impact of waves in the high tide, the most cost-effective strategy for the shoreline walls in Workshop 21 is to build a barrier using jute+raffia sandbags. The knowledge and experience related to this temporary barrier, including the decision of the most cost-effective option, are replicable for the protection of the remaining shoreline structures in case of a similar threat.

It should be noted that the only difference between the two solutions considered for this specific risk resided on the material used to build the sandbag barrier: either a more resistant geotextile bag, specifically manufactured for marine environments; or a combination of jute and raffia bags, one inside the other for added resistance (but still less resistant than geobags). As explained in the respective analysis (see Appendix 2), the differences in effectiveness between these two options lie in the fact that plastics (present in the white raffia bags) are generally less environmentally friendly. However, in the short-term timeframe considered here, these ratings are not low enough to justify the spending in the more expensive geobags, and thus the jute+raffia sandbags were chosen for the building of the sandbag barrier during the drill.

Conversely, the temporary shoring options did not differ substantially in terms of costs, but their effectiveness was more contrasted, essentially due to the impacts in terms of fruition and easiness of removal, which both tipped the scale in favour of shoring the window with wooden poles, and in detriment of bricking up the wall.

For the window shoring, it could be argued that the results, and namely the C/E ratios, are within the uncertainty threshold; the fact is that both solutions are very similar, both in terms of costs and in terms of effectiveness and, in this situation, the immaterial non-harmfulness was given particular attention and the wooden-pole shoring, albeit only marginally more cost-effective, was the implemented option.

3.3.5 CEA x Preparedness: RRT Drill 2

3.3.5.1 Context and trial scenario description

Due to their proximity to the ocean, the Basilica is extremely exposed to saline spray and salinisation via capillary ascension of contaminated water. Moreover, the site is daily subjected to large relative humidity variations; and, in certain locations, the Basilica walls are additionally subjected to drafts created by the position of the shelter (protective structure) walls relatively to the direction of the incident winds.

Wall m is a low-height wall located at the entrance of the sheltered structure that gives access to the Basilica. In spite of a neighbouring structure, the height above Wall m allows wind gusts blowing from the north to hit the shelter wall facing the frescoes, creating an air tunnel effect that promotes the occurrence of rapid changes in relative humidity values on the painted surfaces. These repetitive wetting-drying cycles on the painted surfaces, coupled with the heavy wall salinisation, are responsible for the extreme fragility of the Wall m frescoes, which already caused extensive losses of painted and intonaco layers. The frescoes in this wall are among the most fragile and damaged of all the Basilica wall paintings.

The ambient environment surrounding Wall m is, since December 2018, monitored in permanence by one of the STORM environmental sensor nodes, providing readings on temperature; relative humidity; wind direction and speed; rain hitting the back of the wall; and incident light; a camera registers the condition of a segment of the wall in short intervals. Coupled with data on analogous parameters for the outside environment, provided by the weather station installed close by, it is possible to define ambient environment thresholds above which the situation requires rapid assessment and, eventually, an emergency intervention to secure the fresco layers.

For the second drill in Tróia, it is considered that these thresholds are crossed, indicating a heavy rain immediately followed by wind that is strong enough to induce a sudden superficial drying. Given the extreme fragility of the salt-laden wall paintings, with active material loss, a quick stabilisation action is carried out to safeguard the frescoes until a more in-depth conservation intervention is planned.

3.3.5.2 Analysed strategies

The table below describes the strategies contemplated for the aforementioned pre-impact stabilisation of the Wall m frescoes.

<table>
<tr><th colspan="4">Drill 2: (pre-impact) Stabilisation of detaching wall paintings at the RRT Basilica</th></tr>
<tr><td>Area</td><td>RRT-Basilica</td><td>Item</td><td>Wall m</td></tr>
<tr><td>Short-term Objectives</td><td>Prevent further fresco detachment</td><td>Timeframe</td><td>< 1 year</td></tr>
<tr><td>Primary hazards</td><td><u>Slow-onset</u>: Humidity cycle changes/ shocks; wind; wetting-drying cycles; salinisation; saline spray</td><td>Related hazards</td><td><u>Sudden-onset</u>: intense rainfall; flooding (on external wall)
<u>Slow-onset</u>: rain</td></tr>
<tr><td>DRM Step</td><td colspan="3">Strategies</td></tr>
<tr><td rowspan="2">Preparedness</td><td colspan="3">Option A. application of cyclododecane spray (temporary consolidant; expected to last 1 to 2 months)</td></tr>
<tr><td colspan="3">Option B. application of a Paraloid®B72 + gauze facing
(to be removed after 6 months at most)</td></tr>
</table>

Cost and effectiveness analyses were performed for the Preparedness strategies listed above; the results are summarised in the table below. The lower C/E ratios correspond to the most cost-effective strategies; these are highlighted in a different shade of blue.

3.3.5.3 Cost-effectiveness analysis of preparedness at the RRT – Drill 2

Table 21: Cost-effectiveness analysis of preparedness at the RRT – Drill 2

<table>
<tr><td>Site</td><td>RRT</td><td colspan="2">Area</td><td colspan="2">RRT-7 BAS - Basilica</td><td>ITEM</td><td>Wall m</td></tr>
<tr><td>Hazard</td><td colspan="3">RH shocks; Salinisation; saline spray; wetting-drying cycles</td><td>Susceptibility</td><td>Very high</td><td>Risk score</td><td>5</td></tr>
<tr><td>STEP</td><td>Action type</td><td colspan="2">Products/ Equipment</td><td>Human Resources</td><td>Costs (C)</td><td>Effectiveness (E)</td><td>C/E</td></tr>
<tr><td colspan="8">Pre-collapse activities</td></tr>
<tr><td rowspan="2">Stabilisation of immovable elements</td><td rowspan="2">Application of temporary cohesive/adhesive materials (incl. facing)</td><td colspan="2">2 cycles of cyclododecane spray</td><td>1 Conservator- restorer</td><td>299,82 €</td><td>9,75 (+/- 0,3591)</td><td>30,75</td></tr>
<tr><td colspan="2">Paraloid®B72 + gauze facing</td><td>2 Conservator- restorers</td><td>384,00 €</td><td>7,92 (+/- 0,5913)</td><td>48,51</td></tr>
</table>

3.3.5.4 Remarks

Albeit the degradation agents that caused the current fragility of the Wall m frescoes are generally classified as giving rise to slow-onset events, and therefore would not normally warrant an emergency intervention, the near-collapse situation in which these frescoes have come to be prompted the development of this drill protocol. The solution tested here will be transposable to any events generating instability on the Basilica frescoes.

Between the two solutions contemplated for the rapid stabilisation of these very fragile wall paintings, the cyclododecane spray was better ranked in terms of both costs and effectiveness, making it the clearly better option in this specific context.

3.4 Application at the Baths of Diocletian

3.4.1 CEA x Prevention: Biocides

3.4.1.1 Analysed strategies

The table below summarises the objectives, timeframes and the (long-term) Prevention/ mitigation options that may be considered for the 10-year management of the biological colonisation threatening the marble items (mostly sculpted single objects) in the Michelangelo Cloister, as well as for their documentation and monitoring.

Biocolonisation mitigation options for Marble items in Michelangelo's Cloister			
Area	**Michelangelo's Cloister**	**Item**	Marble items
Long-term Objectives	Biological colonisation control	**Timeframe**	10 years
Primary hazards	Slow-onset: biological colonisation	**Related hazards**	-
DRM Step	**Strategies**		
Documentation	**Option A**. Catalogue recording		
	Option B. 3D relief, video		
Monitoring	**Option A**. Visual control, SC record, photo		
	Option B. Biological analysis, digital microscope video and photo, visual control		
Prevention/ Mitigation	**Option A**. Synthetic biocide		
	Option B. Natural biocide		

Cost analyses were performed for the strategies listed above; effectiveness was assessed via expert discussion, and only the final consensus is presented. The results are summarised in the table below, where the lower C/E ratios correspond to the most cost-effective strategies.

3.4.1.2 Cost-effectiveness analysis of Prevention

Table 22: Cost-effectiveness analysis of biocolonisation prevention

Site	BOD	Area	Michelangelo's Cloister Garden	ITEM	Marble items in Michelangelo's Cloister	Timeframe	10 years
Hazard	Biological degradation			Susceptibility	High (4)	Risk score	
STEP	**Options**	**Products/ Equipment**	**Human Resources**	**Initial costs (Ci)**	**Discounted future costs (Cf)**	**Estimated effectiveness (E)**	**C/E = (Ci+Cf)/E**
Documentation	Catalogue recording	Catalogue record Cards, SC record, PC, photo	1 archaeologist 1 restorer	5000,00 €	9 327,53 €	5	**2 865,51**
	3D relief, video	3D relief, video	1 expert 1 restorer	7000,00 €	12 166,34 €	7	**2 738,05 €**
Monitoring	Visual control, SC record, photo	Visual control, SC record, photo	1 restorer	2000,00 €	16 221,79 €	6.5	**2 803,35**
	Biological analysis, digital microscope, visual control	Biological analysis, digital microscope video and photo, visual control	2 expert technicians 2 restorers	5000,00 €	16 221,79 €	8	**2 652,72**
Hazard impact management							
Biocolonisation control	Synthetic biocide	Benzalkonium chloride 1%	2 restorers	7800,00 €	27 577,05 €	7	**5 053,86**

Site	BOD	Area	Michelangelo's Cloister Garden	ITEM	Marble items in Michelangelo's Cloister	Timeframe	**10 years**
Hazard	Biological degradation		**Susceptibility**	High (4)	**Risk score**		

STEP	Options	Products/ Equipment	Human Resources	Initial costs (Ci)	Discounted future costs (Cf)	Estimated effectiveness (E)	C/E = (Ci+Cf)/E
	Natural biocide	Biocide based on natural essences or bacterial products	2 restorers 2 expert technicians	9000,00 €	31 632,49 €	9.5	**4 277,10**

3.4.1.3 Remarks

Regarding biological colonisation affecting the marble items at the Michelangelo Cloister, the best solutions according to the cost-benefit analysis are:

- Documentation = 3D relief and video;
- Monitoring = Biological analysis;
- Biocide = Natural biocide.

For documentation it was considered that 3D relief and video might be more suitable for checking and documenting the state of degradation. A solution that could integrate the two options (Catalogue recording and 3D relief plus video) would be too expensive to be envisaged.

For the monitoring, biological analysis was found to be more suitable and informative, and the higher costs compensate the added effectiveness.

Finally, for biocolonisation treatment, both options are similar in performance, but natural biocides were considered more effective because they are more innovative and respectful of the environment (see also Chapter 5).

3.4.2 CEA x Preparedness: BoD Drill 1

3.4.2.1 Analysed strategies

The table below summarises objectives and preparedness options for the management of strong wind-related emergencies affecting the marble items in Michelangelo's Cloister, as well as for their documentation and monitoring.

BoD Drill 1			
Area	**Michelangelo Cloister**	**Item**	Marble items
Objectives	Efficient response for unstable marble items facing strong winds	**Timeframe**	short-term (< 1 year)
Primary hazards	Sudden-onset: strong winds	**Related hazards**	-
DRM Step	**Strategies**		
Documentation	**Option A**. Classic documentation		
	Option B. STORM platform		
Pre-impact measures	**Option A**. Evacuation of movable elements		
	Option B. Onsite protection of movable elements		

Cost analyses were performed for the Preparedness strategies listed above; effectiveness was assessed via expert discussion, and only the final consensus is presented. The results are summarised in the table below, where the lower C/E ratios correspond to the most cost-effective strategies.

3.4.2.2 Cost-effectiveness analysis of Preparedness – BoD Drill 1

Table 23: Cost-effectiveness analysis of Preparedness – BoD Drill 1

Site	BOD	**Area**	Garden of Cinquecento	**ITEM**	Micro-Asian sarcophagus, inv. 2000761; Front Cover of sarcophagus, inv. 2005047	
Hazard	Strong winds	**Lack of Coping & Adaptive Capacity**	High (4)	**Risk score**	Medium (3)	
STEP	**Action type**	**Products/ Equipment**	**Human Resources**	**Costs (C)**	**Effectiveness (E)**	**C/E ratio**
Drill documenta-tion management	Classic documentation: graphic/ photographic/ video/ audio	Camera, PC	1 archaeologist 1 conservator- restorer	3000,00 €	8	**375,00**
	STORM platform (dashboard + app)	PC + Android tablet with internet access	1 archaeologist 1 conservator-restorer	2000,00 €	8.5	**235,29**
Pre-impact activities						
Evacuation or onsite protection of movable elements (pre-impact)	**Option A:** Evacuation of movable elements	<u>Collection and cataloguing:</u> Camera, meters, PC <u>Packaging, transport and storage:</u> gloves, shock absorbing material, scotch tape, boxes, wheelbarrow, transport pallet, wooden panels	<u>Collection and cataloguing:</u> 1 archaeologist 1 conservator/ restorer <u>Packaging, transport and storage:</u> 1 conservator-restorer 3 handlers (outsourced)	3300,00 €	7,5	**440,00 €**
	Option B: Onsite protection of	<u>Collection and cataloguing</u>: Camera, meters, PC	<u>Collection and cataloguing:</u>	2000,00 €	8,5	**235,29 €**

movable elements	Packaging plastic sheeting protection, gloves, shock absorbing material, scotch tape	1 archaeologist 1 conservator-restorer Packaging: 3 conservator-restorers 1 workman			

3.4.2.3 Remarks

Resorting to the STORM platform+app for drill documentation was found to be more cost effective than classic documentation strategies such as video, audio and photo recording. The added effectiveness essentially resides in the potential for the dashboard to aggregate all associated records (image and audio) under the concerned area or item, making them easier to manage. The costs of resorting to the STORM platform+app are also lower, albeit some of those costs were covered within the project (e.g. web hosting costs).

The analysis of the choice between protecting movable – and yet heavy – items onsite and evacuating them showed onsite protection to be more cost effective, with lower costs and a higher effectiveness. Of course, evacuation should always be viewed as a last resort, since it may give rise to many new risks for the items' cultural significance. In the case of stone objects, such as the ones considered here, the logistics and risks involved in the evacuation would hardly compensate the benefits of such an option, except in the case of a hazard much more impactful than strong winds for which the site manager would have an early enough warning.

3.4.3 CEA x Preparedness: BoD Drill 2

3.4.3.1 Analysed strategies

As part of its second emergency drill, a scenario where a relatively low-intensity earthquake generates instability on the window glasses atop a few heavy sarchophagi prompts the timely safeguarding of the latter from the glasses threatening collapse. The table below presents the options considered for this temporary protection.

Drill 2			
Area	**Hall 1**	**Item**	Several ancient sarcophagi
Objectives	Onsite protection of heavy items	**Timeframe**	short-term (< 1 year)
Primary hazards	Sudden-onset: Earthquake	**Related hazards**	-
Step	**Strategies – Stabilisation of immovable items – Temporary cover**		
Preparedness: pre-impact measures	**Option A:** temporary protection with a scaffolding + surface protection with shock-absorbing materials		
	Option B: temporary protection with paper airbags + surface protection		

Cost analyses were performed for the Preparedness strategies listed above; effectiveness was assessed via expert discussion, and only the final consensus is presented. The results are summarised in the table below, where the lower C/E ratios correspond to the most cost-effective strategies.

3.4.3.2 Cost-effectiveness analysis of Preparedness – BoD Drill 2

Table 24: Cost-effectiveness analysis of Preparedness – BoD Drill 2

Site	**BoD**	**Area**	**Hall I**	**ITEM**	Ancient pillar of the building. Several ancient sarcophagi (inv. 112328; 112444; 115173; 115712; 124711)	
Hazard	**Earthquake**		**Lack of Coping & Adaptive Capacity**	High (4)	**Risk score**	**Medium (3)**
STEP	**Action type**	**Products/ Equipment**	**Human Resources**	**Costs (C)**	**Effectiveness (E)**	**C/E ratio**
Pre-impact (pre-collapse) activities						
Stabilisation of immovable elements	**Option A: temporary protection with a scaffolding + surface protection with shock-absorbing materials**	- Scaffolding with modular elements to protect items - Surface protection shock absorbing material, scotch tape, bubble wrap	2 Conservator-restorers 5 Workmen	8300,00 €	7,5	**1 106,67**
	Option B: temporary protection with paper airbags + surface protection	- Paper airbags, air compressor, ethafoam, belts, wooden panels - Surface protection with plastic wrap, tarpaulin	4 Conservator-restorers 1 Technician 1 Workman	2300,00 €	8,5	**270,59**

3.4.3.3 Remarks

Both options were deemed to have similar performance in terms of efficacy; however, in terms of effectiveness it was considered that:

- a temporary scaffolding protection requires many materials and workers in place during the emergency, and entails a lot of circulation, which may cause new risks for the integrity of the sarcophagi.
- conversely, the airbag + surface protection combination can be set in place much faster, using materials existing in the museum's warehouses; furthermore, it requires much less circulation of personnel and heavy objects.

Coupled with the fact that its costs are substantially lower, the paper airbag option was set as the new choice for these type of emergencies at the Baths of Diocletian.

3.5 Application at the Historical Centre of Rethymno

3.5.1 CEA x Prevention: Stone desalination

3.5.1.1 Analysed strategies

The table below summarises the objectives, timeframes and the (long-term) Prevention/ mitigation options that may be considered for the 5-year management of the salts threatening the conservation of the Lighthouse limestone, as well as for their documentation.

Salt control at the Venetian Port Lighthouse			
Area	**Venetian Port**	**Item**	Stone base of the building of the Lighthouse
Long-term Objectives	Salt decay control	**Timeframe**	5 years
Primary hazards	Slow-onset: salinisation	**Related hazards**	Slow-onset: Wetting-drying cycles
DRM Step	**Strategies**		
Documentation	**Option A**. Photography		
	Option B. Conservation condition mapping		
Mitigation	**Option A**. Desalination with paper pulp poultices		
	Option B. Desalination with sepiolite poultices		

Cost and effectiveness analyses were performed for the strategies listed above; effectiveness was assessed via expert discussion, and only the final consensus is presented. The results are summarised in the table below, where the lower C/E ratios correspond to the most cost-effective strategies.

3.5.1.2 Cost-effectiveness analysis of Prevention

Table 25: Cost-effectiveness analysis of Prevention: salt decay control

Site	Historical Centre of Rethymno	Area	Venetian Port	ITEM	Stone base of the building of the Lighthouse	Timeframe	5 years
Hazard	Salinisation			**Susceptibility**	Medium (3)	**Risk score**	High (4)
STEP	**Options**	**Products/ Equipment**	**Human Resources**	**Initial costs (Ci)**	**Discounted future costs (Cf)**	**Average estimated effectiveness (E)**	**C/E = (Ci+Cf)/E**
Documentation	Photography	Photographic camera, memory card	1 archaeologist, 1 conservator	848,00 €	1 104,05 €	9,67	**201,94 €**
	Conservation condition mapping	Map printing	1 archaeologist, 1 conservator, 1 specialist drawer	349,00 €	1 553,69 €	9	**211,41 €**
Susceptibility management activities							
Conservation /Maintenance	Desalination by white paper tissue pulp poultices and deionised water	portable conductivity meter, white tissue paper pulp for poultices, deionised water in containers, beakers for preparing solutions, plastic boxes for transfer, 5 meters high scaffolding	2 conservators, 1 technician	2 948,70 €	2 747,17 €	10	**569,59**

Site	Historical Centre of Rethymno	**Area**	Venetian Port	**ITEM**	Stone base of the building of the Lighthouse	**Timeframe**	5 years
Hazard	Salinisation			**Susceptibility**	Medium (3)	**Risk score**	High (4)
STEP	**Options**	**Products/ Equipment**	**Human Resources**	**Initial costs (Ci)**	**Discounted future costs (Cf)**	**Average estimated effectiveness (E)**	**C/E = (Ci+Cf)/E**
	Desalination by sepiolite poultices and deionised water	As above – but with sepiolite instead of white paper tissue	2 conservators, 1 technician	2 935,90 €	2 734,47 €	9,33	**607,54**

3.5.1.3 Remarks

The most cost-effective strategy for the safeguard of the stones of the base of the Lighthouse is desalination with deionised water and white paper tissue pulp poultices because the removal of paper poultices after use is easier and does not leave any residue on the porous stone. A more in-depth discussion of this topic may be found in Chapter 5.

On the other hand, for documentation, the experts considered that photography can picture efflorescence better and more directly than mapping.

3.5.2 CEA x Preparedness: HCR Drill 1

3.5.2.1 Analysed strategies

The following tables refer to the first sudden hazard STORM drill performed in Rethymno, and concern the options considered for the quick response to an intense rainfall event.

Intense rainfall at the St Lukas bastion in Fortezza Fortress			
Area	**St Lukas bastion in Fortezza Fortress**	**Item**	Cod 01 Wall, part of the façade of the double gun hole in St. Lucas bastion in Fortezza Fortress
Objectives	Emergency stabilisation of the wall	**Timeframe**	< 1 year
Primary hazards	Sudden-onset: intense rainfall	**Related hazards**	Sudden-onset: landslides; Slow-onset: wetting-drying shocks; biological colonisation
DRM Step	**Strategies**		
Documentation	**Option A**. Video		
	Option B. Photogrammetry		
Response	**Option A**. Stabilisation with temporary shoring / scaffolding		
	Option B. Stabilisation via (mortar) pointing		

Cost and effectiveness analyses were performed for the strategies listed above; effectiveness was assessed via expert discussion, and only the final consensus is presented. The results are summarised in the table below, where the lower C/E ratios correspond to the most cost-effective strategies.

3.5.2.2 Cost-effectiveness analysis of Preparedness

Table 26: Cost-effectiveness analysis of Preparedness: HCR Drill 1

Site	Historical Centre of Rethymno and the Fortezza fortress	Area	St Lukas bastion in Fortezza Fortress	ITEM	Cod 01 Wall, part of the façade of the double gun hole in St. Lucas bastion in Fortezza Fortress	
Hazard	Intense rainfall		**Susceptibility**	Low (2)	**Risk score**	Medium (3)
STEP	**Action type**	**Products/ Equipment**	**Human Resources**	**Costs (C)**	**Effectiveness (E)**	**C/E ratio**
Drill documenta-tion	**Option A:** Video documentation	Video recording and editing equipment (subcontracted)	1 archaeologist 1 video editor	315,00 €	10	**31,5**
	Option B: Photogrammetry	Cameras, software, PC	1 specialist in photogrammetry	475,00 €	9,33	**50,90**
Post-impact activities						
In-situ stabilisation	**Option A:** Temporary shoring	scaffolding	3 technicians	4 206,00 €	10	**420,60**
	Option B: structure stabilisation	structural support with pointing mortars	3 technicians	4 685,00 €	9,33	**501,96 €**

3.5.2.3 Remarks

For documentation, the use of video is preferred because it is readily available, it is easy to use and it does not cause any interference on the monument; photogrammetry, albeit very low in intrusiveness, it does require the use of targets and, besides, it requires more expertise and time.

For the in-situ stabilisation of the structure, the most cost-effective strategy was determined to be temporary shoring using a scaffolding structure, which secures the monument directly – as opposed to mortar pointing, which will take more time to execute.

3.6 Final remarks

The application of the STORM CEA methodology to the several case studies presented above allowed several important conclusions:

3.6.1 Scope

Although the CEA was originally developed for conservation-restoration methods, it was deemed transposable to heritage DRM applications, essentially because conservation-restoration methods can be regarded as heritage risk control measures. Nevertheless, besides *structural measures* (which can be generally considered as measures interfering with the heritage fabric), DRM also includes *non-structural measures* (non-interfering with heritage fabric, e.g. training or documentation activities), and the STORM CEA should be able to tackle the analysis of the latter as well. This ability should of course be sought at the effectiveness level.

The application of the STORM CEA to non-structural measures (documentation and monitoring) showed that the practical consequence of the effectiveness analyses was to place heritage significance at the core of the discussion: all analysed measures were rated, first and foremost, considering their *contribution* to the conservation of the archaeological structures. This *contribution*, particularly in the case of non-structural measures, goes slightly beyond the concept of 'non-harmfulness', and it could be argued that a better designation for the 'material' and 'immaterial' effectiveness parameters is possible.

Still, it seems that all chosen parameters, as well as their rating guidelines, satisfactorily covered the main concerns that should be addressed when planning an intervention upon heritage items.

3.6.2 Effectiveness assessments/Expert discussion

The expert discussion was tackled differently by the STORM pilot sites: in Tróia, the assessments were given separately; in Rome and in Rethymno, the discussion was conducted live, and the final ratings presented correspond to the values agreed by all the involved professionals. In practice, this means that, for Rome and Rethymno, there is no way of knowing the extent of the discussion, or the degree of disagreement before a final consensus was reached. While the reaching of a consensus is a desirable result, perhaps resorting to anonymous iterative methods such as the Delphi technique would help eliminate eventual skews in the analysis generated e.g. by dominant personalities. This technique would eliminate the need for the uncertainty reporting, although it would be a much lengthier process.

The sites nevertheless agreed on the relevance of the parameters for guiding the discussion/assessments.

3.6.3 Sensitivity

When costs are very similar, as it happened for the Tróia window shoring decision, the result will entirely rely on the effectiveness assessments, and these should be carefully reviewed whenever the decision falls within the uncertainty interval. In these situations, giving weights to one of the effectiveness parameters (e.g. immaterial effectiveness) may help clarifying the chosen solution.

3.6.4 Easiness and usefulness

Although CEAs are routinely performed in anyone's daily life, the codification of the assessment parameters – both costs and effectiveness –, as well as the formalisation of the analytical process, was noted to create some implementation difficulties at site level. Some arguably more foreign concepts, e.g. cost discounting, may have been at the basis of an uneasiness in building the CEAs, but, more than that, it is argued here that this uneasiness is rooted at the accrued responsibility felt when formalising a decision dictating the future of (common) heritage assets.

For the same reason – i.e., because it was found that, despite its complexities, the STORM CEA supports a critical analysis of decisions, as well as their reporting – the sites agreed that it was a useful decision-support methodology.

3.6.5 Limitations

A previous application of this methodology (see *D1.3 Cost-effective conservation-restoration methods*) suggested that an acceptability threshold should be defined for the effectiveness results, below which those options would not be chosen in any circumstance. The CEAs described above did not allow to confirm or deny such a proposal (mostly because no values below suggested thresholds were chosen by any of the sites), and further applications are necessary. On the other hand, assigning different weights to the different parameters (or to the different experts) was not deemed necessary in the developed CEAs, and it would be interesting to test this type of option.

In general, it is considered that the STORM CEA is a helpful tool for decision support and reporting and may make a qualitative difference in the planning process. Even so, it would benefit from (1) more case-study applications; (2) future (post option implementation) re-visiting of the analyses described here; to fine-tune the effectiveness assessments.

4 Achieved efficacy of quick damage assessment methods

4.1 Objective of the tables

In the STORM process flow, after the collection of knowledge data on the platform, the "Preparedness phase" takes place. This is a phase during which a multidisciplinary team works on the planning of an emergency, simulating all the possible events and damages that can affect an area or a specific item. Furthermore, the actions necessary to control and mitigate the effects of hazard from those more limited to those of extended proportions are designed and planned. In this phase it is planned to carry out drills in the field that take into account and execute the indications of the emergency plan registered on the platform and available through a mobile app in the field. The first aid therefore finds its practical application during the exercises and the final objective in a real emergency. The exercises as well as being a method for acquiring practical experience, improve the awareness of the actions to be performed, the efficacy of the choice of materials, and the equipment provided, and the organized procedures. At the end of the exercise one or more debriefing meetings allow an evaluation of the procedure and its efficacy, the weak points that will emerge may evolve through specific identified suggestions and improvements.

To perform a procedure fine tuning, two drills have been planned.

The evaluation of effectiveness takes into account the speed with which the damage analysis is performed during an emergency, the quality of preparedness and the adequate response implemented by the first aid team.

In the tables below, through a narrative text the synthetic reports of the drills performed in the 5 pilot sites are reported. The purpose of these drills is explained in more detail in document *D9.2 Experiment Journal*. The salient points for the evaluation of efficacy of the drills performed is based on the level of adherence to the requirements requested and formulated in deliverable D1.4:

1. *conservation of historical material,*
2. *eco-compatibility of intervention,*
3. *local traditions and use of techniques,*
4. *execution techniques,*
5. *state of conservation,*
6. *previous interventions,*
7. *specific location.*

4.1.1 Table field specifications

After the general information related to the site, area and items involved reported to the beginning of the table, information related to the intensity of the hazard and risk score simulated (through the Risk assessment tool) are reported.

The fields below show the most salient summary data:

- **Actors involved**

  Reports the number and the figures of reference and the respective roles in the performance of the drill and reflect the organization system that comes into action when the task is activated, in case of emergency.

- **Quick assessment method**

  It is related to the methodological process put into practice by each individual site and takes into account the local political needs. The STORM process is integrated into the traditional local intervention procedures, almost always carried out by special bodies, aimed primarily at safeguarding the civilian population and secondarily at securing the cultural heritage.

- **Damage assessment**

  Brief but detailed description of damages occurred during the disaster, providing a clear identification of the materials involved and type of damage identified.

- **Use of the platform**

  The use of the platform is an essential part of the process, the field describes the specific use that was made during the drill.

The second part is strictly related to the evaluation of the efficacy of the individual interventions divided into:

- **Pre-hazard actions**:

  Those measures that can be adopted in the event of an alarm and in advance of the event.

- **Securing**:

  The phase that is activated if the event involves the population and there are obvious dangers even for experienced rescuers.

- **First Aid:**

  Those intervention measures that are activated by means of direct or indirect actions aimed at stabilizing or reducing the risks to the cultural heritage after a small or large event. They are performed by specialized personnel to perform specific conservation / restoration operations and properly trained and starts when the securing phase is finished and the *red zone* opened.

- **Planned full recovery**

  For full recovery it is defined the phase of total restoration of the work, that is carried out when the crisis period is definitively concluded or when it is possible to intervene with times and methods appropriate to the full return of the material values and suitable conditions for conservation. This field summarizes the fundamental operational phases to which the damaged items will be subjected.

4.2 First round of exercises

In the following tables a summary of actions with emphasis on procedures efficacy is provided.

4.2.1 QDA Achieved efficacy BATHS OF DIOCLETIAN Exercise 1

<table>
<tr><td>Site</td><td>Baths of Diocletian</td><td>Area</td><td>Garden of Cinquecento</td><td>Item</td><td>Micro-asian sarcophagus, inv. 2000761; Front Cover of sarcophagus, inv. 2005047</td></tr>
<tr><td>Hazard</td><td>Strong wind</td><td>Intensity</td><td>Extremely High</td><td>Risk score</td><td>3</td></tr>
<tr><td>Actors involved</td><td colspan="5">1 archaeologist; 2 restorers; 2 architects</td></tr>
<tr><td>Quick assessment methods</td><td colspan="5">Methodology used to identify damage and diagnostic investigations:
The visual inspection on the site has detected the extent of the damage to objects of historical interest; to avoid the risk of further damage it was decide to remove improper materials and to separate them form the ancient ones in a systematic way (through the method of the grid). The in site inspection was enough to evaluate that the staff convened was able to collect and remove the significant fragments, and to transport them with proper means to a suitable shelter.</td></tr>
<tr><td>Damage assessed</td><td colspan="5">The cover of the marble sarcophagus was hit and slammed down by the branch of a tree torn by the wind in the blow: the object broke into numerous pieces, and was covered by debris and material transported from the air as: earth,, leaves, water and parts of masonry. The ancient object had already been restored and the metal pin used in the previous restoration was visible. It was necessary to transport the debris in the temporary storage, waiting for the final restauration to avoid metal oxidation, loss of little fragments and corrosion.</td></tr>
<tr><td>Use of Platform</td><td colspan="5">Use of the platform for finding collected data and use of the app on field with a mobile.</td></tr>
<tr><td>Phase</td><td colspan="3">Description</td><td colspan="2">Efficacy</td></tr>
</table>

Pre-Hazard actions	n/a	n/a
Securing	It wasn't necessary because there was no risk for people.	
First Aid	The intervention took place in the following phases: - collect the necessary equipment for the intervention; - a grid was set up with a green coloured rope held in tension by nails; pen and paper were available to catalogue the fragments during the operation; it was necessary to make photographic documentation of the intervention area; - one restorer and one archaeologist performed the removal of deposits and foreign debris, dusting of ancient fragments, to distinguish original elements. It was necessary to review the image of the object, collected in the database before the event, to help the restorers in the first selection of the original fragments; - numbering and collection of the fragments in separated boxes, available in a dedicated area; - transport in temporary dedicated and planned storage with a wheelbarrow; - the team leader through the mobile describes the intervention and gives the recommendations and the deadline for future full recovery intervention.	**Thanks to the speed in the convocation of the emergency team**, the availability of information on the mobile platform, useful to verify the severity of the damage occurred, **the intervention has been optimized, to avoid the loss of the element of historical and artistic importance.** No materials or chemicals have been used that could cause damage to the environment or to the artefact. Useful implementation of the techniques and method of the grid usually used for the collection and documentation system in archaeological excavations. The original execution techniques were respected, it wasn't necessary the use of materials for consolidation but the transport to the storage already organized in the site was the most effective and rapid solution for the specific damage occurred. The presence of previous interventions was considered during the salvage, avoiding the application of water-based substances. It was also evaluated the need to move the artefact to a dry place; the presence of metal pins already used in previous restorations have been highlighted for future intervention.
Planned full recovery	Cleaning of the surface, re-composition, consolidation and gluing of the fragments, reintegration of the missing parts.	On hold of intervention. The plan was prepared according to the defined recovery principal

		including new prevention actions The time frame is in line with the overall recovery strategy

Figure 10 - BOD DRILL 1

4.2.2 QDA Achieved efficacy ROMAN RUINS OF TROIA Exercise 1

Site	Roman Ruins of Tróia	Area	(D5.1) RT-1b: Workshop 21	Item	(D3.1) RRT_03 - Two portions of masonry still erected forming the south corner of Workshop 21

Hazard	Coastal Erosion + Intense rainfall + Strong winds + High Tide + Landslide	Intensity	Extremely High P1hr > 10 mm from the rain gauge Wind speed > 70km/h through the Anemometer > 3,8 from the Tide Gauge confirmed by Acoustic sensor	Risk score	5

Actors involved	TRO (4 persons), SMPC (4 p.), NCRS (5p.), ENG(3p.), KP(1p.), INOV(1p.), National Civil Protection (ANPC) (1p.), Regional Civil Protection (MG-SMPC) (4p.), Alentejo Regional Directorate of Culture (DRCA) (1p.), Institute for the Conservation of Nature and Forests (ICNF) (1p.), Hydrographic Authority (APA) (1p.), Maritime Authority (2p.), Maritime Police (4p.), Portuguese Navy (Marinha) (4p.), National Republican Guard (GNR) (3p.), Grândola Firefighters (BMG) (6p.), Carpenters (MG) (4p.), Workmen (15p.).
Quick assessment methods	The wall was already kept under control by frequent visual inspections. The precariousness had already required previous safety measures to prevent the decohesion and detachment of individual stone elements. The alert system has activated a pre-hazard assessment procedure, to prevent the probability of a collapse of structures deemed particularly precarious.
Damage assessed	Risk of wall collapse is evaluated as extremely high with possible catastrophic impact, due to high tide associated to strong winds and intense rainfall. It was known that most aggressive hazard for the site of Tróia is the tide and river currents and sea waves combined with sea-level rise, provoking severe coastal erosion affecting the Roman structures located on the shoreline. The effect of tide currents and dune pressure is maximized by intense rainfall, strong winds and high tide, especially when there is a coincidence of these three factors. Workshop 21 is located in the shoreline of the estuary of Sado River and is one of the areas exposed to all these hazards and the possibility of their coincidence.

Use of Platform	Transposition of description, first aid and preparedness forms for site, area, and item fundamentals information. The platform emitted an alarm in the Situational Awareness section due to extreme conditions transmitted by the weather station (P1hr > 10 mm from the rain gauge; wind speed > 70km/h through the anemometer; > 3,8 from the tide gauge and confirmed by the acoustic sensor). The site manager checked the sensors data in the Sensory Map/Visual Analytics to confirm the extreme weather conditions. The task was dispatched to the Team Leader, the Conservator Nuno Proença. The Conservator Nuno Proença checked Quick Damage Assessment Recommender. All data was being shared in the platform so that all actors could participate in the decision process. The Risk assessment and management tool With the App mobile was used during the drill for the debriefing.	
Phase	Description	Efficacy
Pre-Hazard actions	To prevent the collapse of the window, frame the shoring of window arch on the southeast two actions were developed: 1. Conservators consolidated the masonry with the filling in of the hollows with lime mortar and protected the surfaces to be shored with UV resistant hydro-repellent tissue and extruded polystyrene foam sheets (XPS); 2. Carpenters of the Municipality of Grândola shored the window arch with wooden bars, cut and carved on site. Shock-absorbing material compatible with the ancient masonry was placed between the wooden structure and the original surface. The sandbag barrier was installed in several steps:	The conservation of this wall guaranteed by a consistent shoring of the windows frame (one of the few preserved of the Roman construction). Moreover, the wall aside was protected by a sandbags structure, from the historical point of view it was extremely necessary because this is the only fish-salting workshop wall preserved up to the top their original height, also the only case of a window preserved in a fish-salting workshop in Tróia. The materials used for the shoring are wood and shock adsorbent materials cut and shaped during the quick assessment, the sand used to screen the impact of the waves, was taken from appropriate neighbouring areas, transported with mechanical and manual systems, maintaining the principle of non-alterability of the hydro-geological balance of the natural park, the others materials used for this barrier are recycling. From the eco-compatibility point of view and for the respect of local traditions and use of techniques.

	1. Five operators of the civil protection service install a pipe for the transfer of the sand from the hill to the seashore where the archaeological area is located. 2. Three of them fill the bags in resistant tissue to protect the base of the southeast wall from the high tide. 3. A u-shaped barrier has been erected by the adjacent vat walls (especially the one parallel to the southeast wall) from the wave impact. 4. The sand bags are stacked, protected by a geotextile tissue and further wrapped in a metal net (galvanized iron) to improve the impact resistance of the waves.	Shoring with wood by carpenters from the region and local dune sand used in the sandbags (bags in plastic). The window frame is tightly held by the shoring, no element loss. Tides are not reaching the wall; the goal was achieved. No secondary damage created by First Aid. Materials were compatible with the execution techniques, and the original material as actual shape have been respected. The not permanent character of intervention takes in account the site located in a natural park trying not to interfere with the shape of the costal skyline.
Securing	n/a	n/a
First Aid	n/a	n/a
Planned full recovery	The full recovery will be achieved with the consolidation of the wall structure through the use of injections and sealing with natural lime mortars the definitive structural consolidation of the window arch and with the installation of a permanent barrier to protect the walls from the tides.	Sandbag barrier was completed in March 2019. The plan was prepared according to the defined recovery principal including new prevention actions The time frame is in line with the overall recovery strategy

Figure 12 - TROIA Drill 1

4.2.3 QDA Achieved efficacy MELLOR Exercise 1

Site	Mellor	Area	MAT-02: Mellor Mill	Item	Drive shaft- Item 6.1
Hazard	Intense Rainfall	Intensity	Very High	Risk score	4
Actors involved	1 volunteer; 2 archaeologists; 1 site manager; 1 team leader; 1 county archaeologist; 1 technical adviser.				
Quick assessment methods	Heavy and consistent rain noticed through the weather station data reported in the STORM dashboard and local data. Damage to some of the handmade bricks in the draft shaft area was observed, as was a landslip close to the main pathway into the site. The landslip demonstrated the potential of secondary hazards. The first assessment was conducted using visual inspections, and the dashboard app.				
Damage assessed	Drive shaft 6.1 is in flooding, the drainage system has stopped filling with debris and plants that prevent the exit of the water. Once water is allowed to drain the driveshaft slowly empties leaving the damaged item. The brick walls had begun to crumble and break. Bricks were dislodged and had fallen onto the base of the drive shaft. These bricks may block drainage pathways, causing further hazards, if they were not removed.				
Use of Platform	Having seen the alert system on the STORM dashboard and checked the weather graphs within the dashboard. Use of the first aid mobile phone application to alert staff members and to record the processes undertaken.				
Phase	Description		Efficacy		
Pre-Hazard actions	n/a		n/a		

Securing	The site is cleared of the public. Cordoned off to ensure the safety of staff and the general public. The area of the landslip is cordoned off and the flooded area is sealed.	n/a
First Aid	Drive shaft 6.1 is in flooding, the drainage system has stopped filling with debris and plants that prevent the exit of the water, following the plan of action of the first aid, the drains are released through drainage rods. During the preparedness phase the availability of the majority of the equipment was available to first responder, however some equipment and PPE was not available, and as a result new storage arrangement was made. The first aid operation was to clear the blockages in the mill to allow the water to drain. A volunteer group cleared the blocked drains under archaeological supervision, removing tree branches. Wall is made safe using sandbags to ensure that the wall is shored up until restorers can be contacted to perform long term fixes, like re-mortaring the wall and hard capping.	Throughout the exercise the scenario was filmed and recorded by the STORM mobile application via an android tablet, which is a dedicated device for the first responder. Despite the narrow valley location of the Mellor Mill site, a wi-fi connection with the tablet computer was possible, if a little slow. The ability to bring up data on the Mellor site, including the conservation plan and past surveys for comparison with the damaged area **using the STORM Dashboard app demonstrated the great advantage of having the real-time hazard management system available** to the Mellor Archaeological Trust. The procedure adopted follows the practice already in use on the site in the maintenance operations of biological and environmental control that are periodically carried out. It should be noted that the procedure highlighted the ability to coordinate and the confidence of the actors involved with the materials and the state of preservation of the structures. Each actor within the First Aid team was aware of their responsibilities and act accordingly. The actions have also taken into account the specific location and natural environment in which the site and the items is allocated, avoiding the use, within the allowed limits of biocidal products or serious actions that weigh from the hydrogeological point of view.
Planned full recovery	Archaeologists assess the state of the item and decide whether sections of the wall need to be taken for further analysis and how the remaining section of wall can be restored. Assessment of the bricks included analysing the	Still on going.

	brick for treatments to make the brickwork more water resistant. The samples were despatched to Spain for testing. This was to test multiple coats of different products could be applied to protect ceramic (handmade bricks) in humidity exposed environments.	

Figure 13 - MELLOR Drill 1

4.2.4 QDA Achieved efficacy EPHESUS Exercise 1

Site	Great Theatre of Ephesus	Area	Visitor entrance, Cavea	Item	Entrance wall code 01
Hazard	Earthquake	Intensity	Magnitude > 6.5	Risk score	5
Actors involved	Director of Ephesus Museum Director of Survey and Monuments, Izmir Bogazici University (BU) Local rescue organizations				
Quick assessment methods	An integrated methodology which takes into account both real-time SHM data and an analytical approach was implemented. It is based on analysing the vibration data provided from the structure. Data was acquired through high cost, low noise and very precise force balance accelerometers. The simulation involved the collapse of some heavy stone blocks from the masonry and the involvement of visitors to the archaeological site, the emergency was activated in coordination with first responders by the local rescue organization, assisted by the presence of archaeologists and specialists for handling large stone blocks.				
Damage assessed	Based on the selected analytical procedure, the structural damage to the wall has been defined and calculated in four levels. D1 corresponds to no damage; D2 is the onset of damage (at 0.2 g); D3 is restorable damage (0.3g) and D4 corresponds to failure or collapse (0.4g). In reality there was no damage, hence damage estimate was based on computer simulations due to a synthetic earthquake. The simulation: The earthquake caused the detachment and collapse of numerous blocks of stone that constitute the upper part of the wall structure. The collapse from above has caused numerous fractures to the blocks themselves and has damaged the stones of the base parts. Some blocks have injured visitors.				
Use of Platform	When the earthquake signal was detected by the SHM system, the measured peak acceleration was compared to the structure-specific damage thresholds that were calculated analytically.				

	Alarm signal was automatically sent to the site manager trough the platform Awareness System. As soon as the alarm signal was received by the field manager, response measures were taken, and evacuation was initiated according to the Turkish existing emergency protocol.	
Phase	Description	Efficacy
Pre-Hazard actions	n/a	n/a
Securing	Site manger takes necessary action to secure the site, provides for the evacuation of people still present on the site and delimits the area forbidding access to outsiders not involved in the security of the area. Involves the first aid actions to save trapped people under debris and valuable and broken items by the SAR group (group of experts acting in emergency).	Site manager takes immediate action to coordinate the work for conservation of historical material. This action was so immediate that mobile lines were still active. Experiences on past earthquakes reveal that internet lines become engaged, 15-20 minutes after such events. Therefore, this action can also be considered as an indirect and innovative measure to provide resilient communication. Humans and valuable items were saved as planned. Successfully completed.

First Aid	An early warning alarm signal has been produced within seconds after the occurrence of the earthquake and automatically sent to the platform; the Site manager advice the Team leader that activates the task with SMS message. Team leader convened by the Site manager activates the task by consulting the specifications indicated in the preparedness phase, access routes for the arrival of the equipment and means for lifting and moving the large and heavy stone elements. In the preparedness phase were previewed the transport of manual gantry tripod equipment already available on the site. The bags for transport of non-heavy elements; labels for numbering.	Not extraneous or not compatible elements with the ancient material were employed. The tools already prepared on site and the use of consolidated practice in the management of the earthquake emergency permitted that emergency has been resolved in very fast period as for people involved as for the moving of the ancient stone. The Stone were transported manually and with use of safety bags.
Planned full recovery	Extension of the ongoing restoration works. Consolidation of stone cracks; relocation of the element with adequate coupling pins and reinforcement structures; Cleaning; bonding of little parts with compatible materials with the original; integration of the missing part; grouting joint and infill of lacunae.	On hold of intervention, the plan was prepared according to the defined recovery principal including new prevention actions. The time frame is in line with the overall recovery strategy

Figure 14 - EPHESUS Drill 1

4.2.5 QDA Achieved efficacy EFARETH Exercise 1

Site	Historical Centre of Rethymno and the Fortezza Fortress	Area	Bastion of Saint Lucas– Identification code 111	Item	Cod 01 Wall, part of the façade of the double gun hole in St. Lucas bastion in Fortezza Fortress
Hazard	Intense Rainfall	Intensity	Medium	Risk score	3
Actors involved	EFARETH First Aid team (civil engineer, technicians, municipality heavy duty vehicle operator, conservators, archaeologist).				
Quick assessment methods	Risk Assessment and Management Tool: The tool was used prior to the drill in order to assess the severity of the hazard and the risk score of the ITEM. Sensory Map: The sensory map gave information on the sensors available in the area. Situational Awareness: The area affected by intense rainfall was visible on the map. Quick damage Assessment Recommender: The preparedness actions were followed during the drill as they were viewed through the platform. Crowdsourcing for crisis management (task dispatcher): The site manager was able to assign the task to the archaeologist in charge of the specific monument in short time after the event.				
Damage assessed	1st step included the health and safety check and damage assessment of the collapsed wall by the site manager, archaeologist, civil engineer, conservators and technicians and the architect of the municipality of Rethymno. A large portion of the wall structure has collapsed. A possible cause of event is believed to be the retention of water from the intense rainfall within the excavation dig of the Hellenistic period below the Venetian wall. The earth fills that the wall is built on softened from the excess rain water given that the wall does not have any kind of foundation. The wall salvage area is near by the collapsed area but free from other constructions and with no risk to sustain water in the case of an intense rainfall. The operator transfers the rumble stone and debris there.				
Use of Platform	The platform was used throughout the drill for ensuring the preparedness actions are carried out correctly. The in situ actions were recorded in the platform for the debriefing action after the drill.				

Phase	Description	Efficacy
Pre-Hazard actions	n/a	n/a
Securing	Given the Health and Safety risk, the fire fighters inspect the area first and provide access to the First Aid EFARETH team. Access restriction by the Police, on the Katehaki street and Fortezza fortress. Health and Safety assessment by the Fire fighter. Simulations of rescuing injured people was performed by the National Emergency Aid Centre, Hellenic Red Cross actors. The "victims" will be performed by actors' volunteers and dummies. Ensures the appropriate construction of scaffolding in terms of structural stability.	Performed by the Municipality of Rethymno, the coordination with the internal group was increased thanks to the emergency planning and the exchange of information with the site's technical team. The organization has been facilitated by the use of the platform and the use of the mobile app on the field.
First Aid	The First Aid EFARETH team is taking action. The team leader with archaeologist, civil engineer, conservator and technician, inspect the damage and coordinate the damage documentation and recording. During the scaffolding preparation, the municipality heavy duty vehicle prepares the ground for easy access, the fallen stones within the excavated area directly below the wall are handpicked and removed manually, collecting the fallen rumble stones and transporting them in secure location. The rectangular shaped stones are placed separately but within the designated area in order to be placed back in the original location. This will be done after cross reference with	The decisions made in that point relevant to the temporary structural support of the wall and the secure transfer of fallen stones should ensure the minimizing of further loss of the ancient structure. The collected stones will be then used for the restoration of the wall. The first aid team of EFARETH had access to utilities in effective time to reach the area directly after the event and secure its condition. Specific clothing and equipment, hand tools, were reusable, consolidation materials (polymers, gauze, mortar) labelling materials (markers, drawing paper were used. First aid conservation of semi-detached stone material have been performed according with the conservation standards and required in quick condition of intervention. The availability of resources is considered

	the archive documentation and past orthophotography of the wall before the collapse. The First Aid Team gathers the appropriate tools and the necessary materials from the storage facilities of the Ephorate and starts the work recording at the same time all the actions. Removal of the falling stones followed by the selection of the best preserved ones in order to use them again for the reconstruction of the wall. Video and drone recording supported by the IT team was done prior to the removal. Construction of a scaffolding of the remaining part of the wall to provide structural stability, done by the specialized technicians. The technicians, after securing the vaulted gun holes below the wall, proceed with scaffolding on the external part of the wall. The scaffolding consists of wooden planks and stainless steel rods positioned in angle as to support the wall properly. During the removal of fallen stones at the top of the stone pile, two iron cannon balls were found within the earth fill. The designer documents the finds by using the excavation grid. The cannon balls were corroded and there were risks of material loss. Paraloid B72 7-20% w/v in acetone was used to consolidate the iron corrosion products in place. The balls were then wrapped in acid free tissue and placed in Ethafoam cushion and in plastic boxes for transfer support. The finds were transferred to the conservation laboratory for further conservation by the EFARETH conservators.	successful for the organisation in the site. Thanks to the preparedness phase, the First Aid team had all the available means in each step to effectively carry out the individual tasks (means: EFARETH pick-up 4X4 truck and jeep, hand tools, electrical power generator, water tanks, camera, wooden planks or related materials for structural support). Furthermore, through the platform the preferential access routes plan for special vehicles were highlighted and used.In the emergency planning, the involvement of private external companies from Misiria storage of Efareth was also planned, ready to intervene as for the supply and installation of the shoring on the façade, this facilitated and accelerated the quality of the first aid

	Then starts the removal of the falling stones followed by the selection of the best preserved ones in order to use them again for the reconstruction of the wall. With precaution the excavation grid has been used to mark the exact original area that each stone was removed from. The stones have been labelled and documented. The drill ends by setting the third part of the scaffolding at the south part of the wall.	
Planned full recovery	The full restoration plan for the double hall cannon wall includes the following steps: - Reconstruction project. - Gap filling on the preserved walls with stones similar to the ones in the masonry. - Grouting with appropriate lime mortar on the masonry of the arches of the cannon halls. - Gap filling/restoration of the masonry that collapsed with appropriate stones (the ones collected in situ and belong to the original masonry). The rumble stones will be cleaned mechanically from damaged mortar.	Ongoing process. The plan was prepared according to the defined recovery principal including new prevention actions. The time frame is in line with the overall recovery strategy

Figure 15 - EFARETH Drill 1

4.3 Second round of exercises

4.3.1 QDA Achieved efficacy BATHS OF DIOCLETIAN Exercise 2

Site	Baths of Diocletian	**Area**	All 1	**Item**	Ancient pillar of the buildings. Ancient sarcophagus stored in the Hall: (inv. 112328; 112444; 115173; 115712; 124711)
Hazard	Earthquake	**Intensity**	medium	**Risk score**	5
Actors involved	6 fire-fighters (CNVVF); 1 archaeologist; 1 conservator/ restorer (SSCOL); 2 restorers volunteers; 6 handlers (outsources); Site manager (SSCOL).				
Quick assessment method	An alarm signal informs that the guard thresholds have been exceeded due to a slight earthquake. First recognition by the internal BoD guardians in the Hall. The site manager alerts the CNVVF and activates the task by convening the team leader and the intervention team. A small group of Firefighters carries out a first inspection and decides to perform of a new 3D scanning with an integrated multi-dimensional tool; as there are three previous point clouds included, it is possible to value the movements of the building and to understand the risks. The Fire official takes a new point cloud to evaluate residual safety levels and decide they are sufficient to allow the first aid team to enter for the intervention. Two actions are undertaken simultaneously on two areas: in the so-called red zone the CNVVF asses the protection from the window frame which is at risks of falling down; in another area outside the red zone the expert first aiders are proceeding to protect the artwork.				
Damage assessed	Some shards of glass and small fragments of brick have fallen to the ground and on the archaeological remains preserved there. They are visible: in the Right Window the detachment of iron frame, the glass of central window is broken. Small pieces of mortar, expulsion of two brick and two fissures are worrying as to require an immediate risk assessment. Numerous sarcophagus of marble with high relief, sculptured with scenes of battle mainly from the Roman period, are preserved in this area of the ancient Roman baths. Some of them are in the direction of a possible further breaking of the windows and are exposed to the risk of being hit by fragments of masonry, glass and iron elements.				

Use of Platform	BoD Director is alerted by the platform. The Team leader called by the BoD Director convene the team for the first aid the Team leader gives instruction with the help of the information uploaded. Accessing preparedness with the app it is possible to know which is the priority for the intervention to the exhibited works, indications concerning the weight of the constituent material and the Response, which resources are necessary and the means available to carry out an intervention on site. Record of images and diary dictation are done of the field.	
Phase	Description	Efficacy
Pre-Hazard actions	n/a	n/a
Securing	A small group of Firefighters take care of the securing after the 3D Laser scanner relief (this method is able to value the movements of the building and to understand that the area is safe). Three different scans allowed to monitor the structural behaviour of the ancient building before in peacetime, the images compared with the new scan after the earthquake allows to verify significant changes in the structure. After the evaluation: the firefighters set up the protection of some sarcophagus closer to the window. In coordination with the Team Leader, they receive from him the information of where to take the equipment in *Innocenti tubes* and wooden boards prepared in a dedicated area. The group of firefighters begin to build the protective structure; then delimitate the area to the access and give permission to do the first aid in the items in another area near there.	Rapid intervention guaranteed by the existence of a storage place for equipment for sheltering and emergency intervention.

First Aid	The team leader provides instructions to the team; after evaluating the level of danger he decides not to move the works. Among the options offered by Preparedness on the app there is the possibility of bringing a trans-pallet from the warehouse and moving some items. The risk of damage can also be mitigated by leaving the works on place and by protecting them with absorbent bump material. The resources on the app show the availability of: a cylinder for transportable compressed air on site, airbag inflatable cushions (*Cocoon Packaging system*), ratchet straps and equipment for a first aid in the event of fracture or detachment of parts. The team organizes the intervention: two operators take the material stored in a dedicated area, while they begin to inflate the cushions; two of them also carry other materials such as Ethafoam. During the operation some photos are taken, and the intervention diary is written in real time on the mobile app.	The inflatable cushions are composed of an inner polyethylene bag (40gr / m² approx.) covered externally with one or more layers of water-resistant Kraft paper (80gr / m² approx.), this ensures the robustness of the inflatable cushion even when subjected to strong stresses. They are born for the packaging and transport of fragile products of various kinds, a light, safe and very economical protective system, and they are reusable after deflation. They reduce, when emptied of the air, the problem of storage space, as they are very thin and light to carry; the polyethylene film is internal and the quantity is such as to be considered environmentally friendly. The Preparedness provides for the use of silent transportable cylinders that can be used in conditions of absence of electricity.
Planned full recovery	Brushing of the surface.	To be done.

Figure 16 - BATHS OF DIOCLETIAN Drill 2

4.3.2 QDA Achieved efficacy TROIA Exercise 2

<table>
<tr><td>Site</td><td>Roman Ruins of Tróia</td><td>Area</td><td colspan="3">BAS – Basilica (ref. D5.1: RRT-07 Basilica)</td><td>Item</td><td>RRT-BAS-m – Basilica - wall m with frescoes paintings</td></tr>
<tr><td>Hazard</td><td colspan="2">Local wind (draft); salinization; humidity cycle changes/ wetting-drying cycles; intense rainfall.</td><td>Intensity</td><td>Very High (5)</td><td colspan="2">Risk score</td><td>5</td></tr>
<tr><td>Actors involved</td><td colspan="7">TRO (3), NCRS (3), INOV (1)</td></tr>
<tr><td>Quick assessment methods</td><td colspan="7">High humidity followed by strong winds cause sudden changes on the moisture levels of the masonry (wetting-drying cycles); the salt-laden wall paintings undergo a fast salt crystallization, leading to imminent detachment, peeling, flaking and loss of the paint layer. An intervention to immediately stabilize/consolidate the most fragile painted areas was deemed urgent and necessary.</td></tr>
<tr><td>Damage assessed</td><td colspan="7">The platform emitted an alarm in the Situational Awareness section due to extreme conditions transmitted by the Arduino Environmental Sensor Network.
The site manager checked the sensors data in the Sensory Map/Visual Analytics to confirm the extreme weather conditions.
The task was dispatched to the Team Leader Conservator Nuno Proença. The application indicated the location of wall m.
Once on-site, he checked the Quick Damage Assessment Recommender.
The photo, video, audio and text recording of the performed intervention was fully handled by the platform.</td></tr>
<tr><td>Phase</td><td colspan="4">Description</td><td colspan="3">Efficacy</td></tr>
<tr><td>Pre-Hazard actions</td><td colspan="4">n/a</td><td colspan="3">n/a</td></tr>
</table>

Securing	n/a	n/a
First Aid	The access to the wall area was limited using emergency tape, the area was secured to restrict access from all those not involved in the heritage first aid actions. To face the fragility and potential loss of wall painting, an immediate intervention was decided for stabilizing and reinforcing the artefact. The decision fell on the application of the temporary consolidant. Cyclododecane in spray. It was sprayed to the most fragile painted surface interested by powdering flaking of the fresco paintings. The whole procedure was thoroughly documented via STORM platform and app; photocamera; and video camera.	One of the best preserved monuments of the archaeological site of Tróia is the Paleochristian Basilica, a church built at the end of the 4th century or the beginning of the 5th century. The damaged wall still bears many parts of fresco-painted surfaces. The chosen product and application method were adequate and the best practices in conservation followed, preserved a most famous post classical era (5th century AD) frescoes, incredibly preserved though located in an area with a high microclimatic risk for their conservation. The frescoes in this wall are among the most fragile and damaged of all the Basilica wall paintings. The used consolidant is of low toxicity, and sublimates without residue on the original materials; it is considered of low environmental impact. Roman execution techniques were respected, this product is temporary but highly effective for the very thin painted layers. The frescoes were protected without further damage for the originality of the materials and techniques. The painting is sufficiently stabilized and will hold until a more effective conservation intervention can take place, the undertaken first aid actions do not prevent nor will interfere with a more effective and detailed conservation intervention. Edging repairs in some intonaco areas, performed in the ~1980s, did not show signs of decay and were not affected by the First Aid intervention. This first aid solution is transferable to other fragile heritage surfaces facing similar threats. Given the characteristics of low

		toxicity, easy and quick application, low environmental impact sublimation without leaving residues, it can also be extended to other surfaces, without any impact on the natural environment in which they are stored.
Planned full recovery	Starting from the environmental control, it is necessary to program as soon as possible a more effective conservation action to guarantee the preservation of the structure and the frescoes decorated surface. The intervention previewed is structural consolidation with injection of grout, fixing flakes and fragments of painting layers, micro-fillings and grouting, salt reduction, cleaning and protection are to be considered.	Already in programming.

Figure 17 - TROIA Drill 2

4.3.3 QDA Achieved efficacy MELLOR Exercise 2

<table>
<tr><td>Site</td><td>Mellor</td><td>Area</td><td colspan="2">Area 1 Old Vicarage</td><td>Item</td><td>Ditch wall (Graveyard) South-facing Bridge Support
Geological Plating Below Bridge</td></tr>
<tr><td>Hazard</td><td>High winds and Electrical Storms</td><td>Intensity</td><td colspan="2">Very High (Intolerable)</td><td>Risk score</td><td>5</td></tr>
<tr><td>Actors involved</td><td colspan="6">5 Volunteers (A collection of Trustees and Friends of the Trust) who are in a group created for “STORM First Responders”
3 Professional Archaeologists (2 providing advice, 1 surveying damage)
2 Site Management Employees
1 Team leader (non-STORM related for realism)
1 Joiner/Carpenter</td></tr>
<tr><td>Quick assessment methods</td><td colspan="6">The first responder in this drill was a volunteer first responder who is NOT involved in the STORM project as heavily as the main employees. This was done to provide realism – does the APP work in a real situation when the user is a non-expert and does not know what to expect from the hazard and event. All volunteers have received training in the APP and Platform as detailed in D9.2.
Quick assessment was performed using the application. The predefined form was used, and a diary entry was made with a photograph of the damage recorded.
The hazard (strong winds) had damaged a tree and bring a large branch down on top of the archaeology. This tree had damaged the supporting metal mesh. So, a detachment was reported via the STORM app. Further visual inspections were undertaken around the item and area to assess secondary hazards. None was found.</td></tr>
<tr><td>Damage assessed</td><td colspan="6">Damage to the supporting mesh meant the earthworks were no longer supported and risk of sudden collapse causing further damage to the archaeology.</td></tr>
</table>

Use of Platform	The platform was used to receive the alert and the event was dispatched to a volunteers STORM app, so that they could follow the predefined policy on how to respond to the event. Laser scan data was uploaded to the platform form USAL and downloaded by the MAT site manager who then send to a local joiner/carpenter so that they could cut wooden supports to the exact size of the ditch – saving time for the site manager or joiner who would have had to measure up the ditch before cutting the wood to size. The first responder was a volunteer who has little involvement with this site of the project. This was a great test as he had only training in how the app worked but did not know what hazard to expect or what steps to follow. The clear and concise nature of the instruction meant he knew what to do, where to find equipment and what to tell the site manager and volunteer group. We had great feedback from the app user on its intuitiveness.	
Phase	Description	Efficacy
Pre-Hazard actions	n/a	n/a
Securing	The site is cleared of the public. The site is cordoned off to ensure the safety of staff and the general public using hazard tape and warning signs.	This is in line with local procedures because the area in question is open to the public so the need to cordon off the site was reiterated to the land owner and permission granted.
First Aid	The tree was cut into small manageable pieces and then moved from the archaeology area. Expert arrived with all the tools necessary to do intervention. Weeds were removed from the mesh so that it could be taken away without causing further damage to the archaeology. Mesh was removed revealing the damaged earthworks. Using the dashboard as a collaborative tool, detailed plans of the item could be sent to suppliers so that wood could be cut to size off site and further prevent.	The works were conducted in a way where no further damage could be caused to the archaeology. Experts were at hand to advise. Weeding was useful in general as it improves the state of conservation of the item and is in line with previous interventions. Local tradesmen were used to improve the environmentally friendly and thick local approach of this work. Having the wood prepared offsite and to exact measurements ensured the archaeology surrounding the item could remain as untouched

	Use of the STORM app for reporting in the diary and taking photos and videos throughout the first aid process ensured non-experts could respond within the STORM Mellor policies and practises, preventing damage to the archaeology in the installation process.	as possible by the installation of the temporary shoring. Wood was used for its eco-compatibility although a return to the metal mesh is necessary for its long-term durability and cost effectiveness.
Planned full recovery	Short term a joiner provided and installed wooden shoring to keep the earthworks in place.	Over the coming weeks, a new mesh will be provided and reinstalled as this has provided 10+ years of stability to the cross section item.

Figure 18 - MELLOR Drill2

4.3.4 QDA Achieved efficacy EPHESUS Exercise 2

Site	Ephesus	**Area**	Theatre	**Item**	Wall
Hazard	Earthquake	**Intensity**	high	**Risk score**	4
Actors involved	Director of Ephesus Museum Director of Survey and Monuments, Izmir Bogazici University (BU) Local rescue organizations				
Quick assessment methods	Director of the Ephesus Museum receive the awareness, verifies sensor data on the situational awareness area of the platform and decides to contact conservator-restorers and dispatched to the team leader to open the task. Through the use of Ecobox (as alternative communication channel in case of lack of line) the first responders are alerted by Jandarmate and intervened. Restorers performed visual inspection at the stairs entrance wall of the theatre and documented the situation.				
Damage assessed	The Roman wall built in the inner part with smaller unorganized stones connected with mortar (Opus Caementicium), the surface coating is constituted by rectangular stones from marble it is an important part of the structure in the main façade. A stone facade at the entrance wall of the theatre has been displaced. A small portion of the cracked marble has fallen down. The remaining portion of the façade has become vulnerable against aftershock (ACE4). During the event the façade displaced about 10 cm towards North direction and is in risk of collapse.				
Use of the Platform	Platform is actively used during the exercise. Planned action is retrieved and situation is documented. The STORM app is used for the first aid linked with platform to collect the data. Through the app, any further displacements of the building were verified directly on the field by photographic comparison.				

Phase	Description	Efficacy
Pre-Hazard actions	n/a	n/a
Securing	n/a	n/a
First Aid	Temporary strengthening of the damaged sections started with construction of a scaffolding to secure, to stop the façade from collapse from the rest of the wall. The model of this system of shoring it is that one projected and recommended as per the recent Turkish Guidelines Risk Management of Historical structures. The shoring system was designed to function as a supporting wall, all components of the shoring were to be removed when the shoring is no longer needed. The shoring plans was completely identified according to the site constraints and the shoring system. During the shoring phase, light and strong materials, which were supplied near the site and which could easily be brought to the field, were used. A fallen marble stone is stabilized by "Ethafoam" (Poliethylen foam), covered by plastic, moved into a dedicated box to a storage in the site.	The Roman wall constructed in the main façade with big rectangular stones from marble and inner part with smaller unorganized stones connected with mortar, it is an important part of the structure. The moving of the stone it was catalogued in view of the relocation in future. A construction of a scaffolding was built to secure, to stop the façade from further collapse from the rest of the wall.
Planned full recovery	Moving of 25 stones of the upper part of the wall. Injection will be done with eco-compatible mortar. Relocation of stones at the same position.	

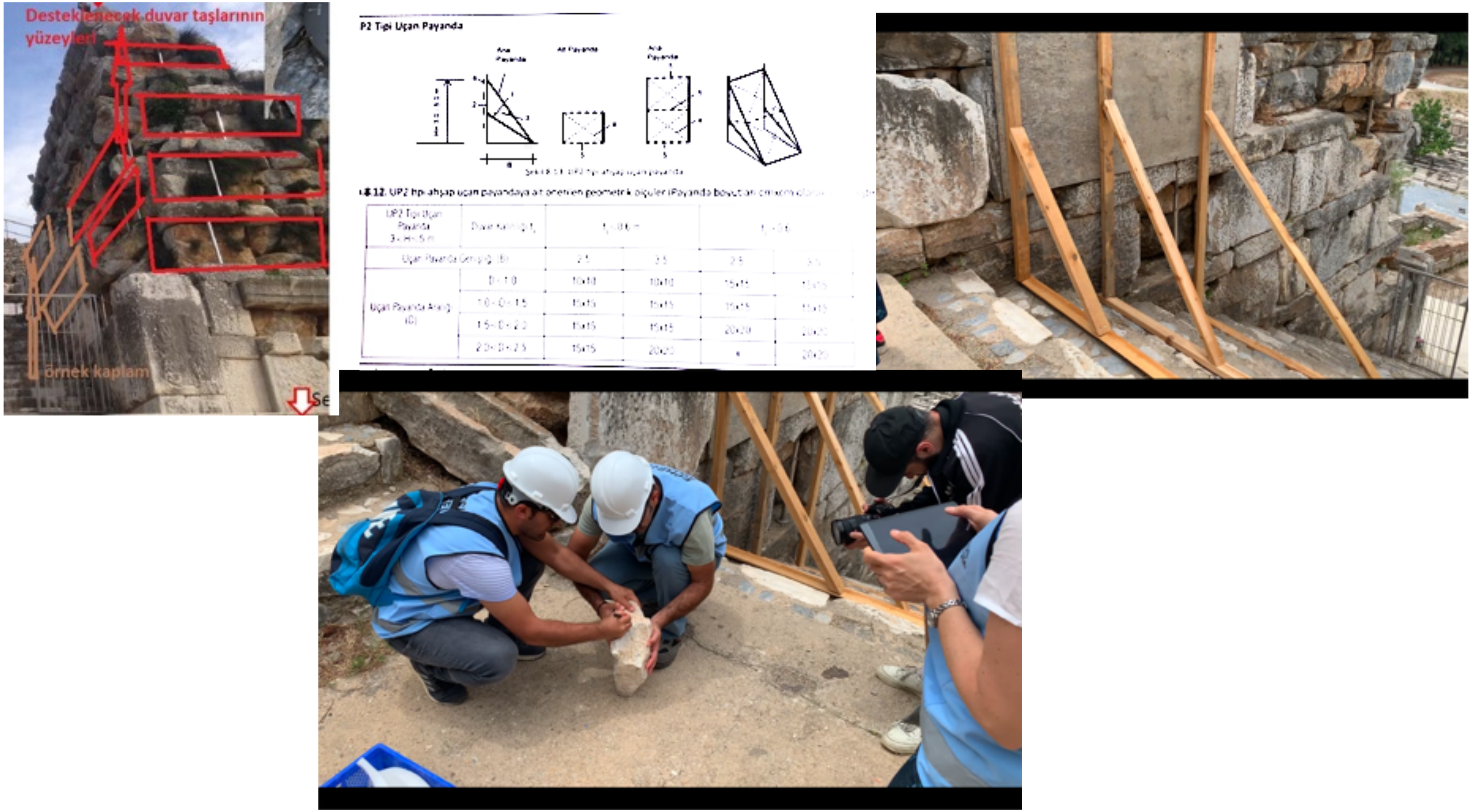


Figure 20 - Ephesus first aid interventions

4.3.5 QDA Achieved efficacy EFARETH Exercise 2

<table>
<tr><td>Site</td><td>Historical Centre of Rethymno and the Fortezza Fortress</td><td>Area</td><td>Fortification wall and watchtower on the corner of St. Paul's bastion</td><td>Item</td><td>1. Watchtower FFW.40
2. Fortification wall with pre-existing crack
3. One sculptured stone and one inscription of marble</td></tr>
<tr><td>Hazard</td><td>Earthquake</td><td>Intensity</td><td>Medium</td><td>Risk score</td><td>2</td></tr>
<tr><td>Actors involved</td><td colspan="5">Site Manager.
Municipality of Rethymno; departments of Civil Protection, Police, Fire fighters, Coast Guard, National Emergency Aid Centre, Hellenic Red Cross, and Volunteers of Civil Protection of Rethymno.
Team Leader archaeologist responsible of the specific monument of EFARETH site.
1 Civil engineer, 1 conservator and 2 technicians perform the first aid to the items.</td></tr>
<tr><td>Quick assessment methods</td><td colspan="5">The method was used to assess the area affected by the earthquake.
Quick damage Assessment Recommender.
The preparedness first aid actions were followed during the drill through the platform.
Crowdsourcing for crisis management (task dispatcher).
The site manager assigned the task to the archaeologist in charge through the method.
The Team leader (archaeologist responsible of the specific monument of EFARETH site) communicates with the local authorities (External actors) for the restriction of public access and the securing of the area around the collapsed part of the bastion.
The responsible archaeologist, civil engineer, conservators and technicians perform the first aid to the items.</td></tr>
<tr><td>Damage assessed</td><td colspan="5">The earthquake caused the collapse of the already semi-detached east side of the watchtower wall and the expansion of the crack running vertical on the surface of the fortification wall underneath.</td></tr>
</table>

Use of the Platform	Risk Assessment and Management Tool. Sensory Map. The map gave information on the sensors used for data collection prior to the event. The platform was used throughout the exercise. The first aid actions were both described to the actors and documented through the diary.	
Phase	Description	Efficacy
Pre-Hazard actions	n/a	n/a
Securing	During the STORM Drill, the first aid exercise was also carried out for people involved in the earthquake event. Simulations of rescuing injured people were performed by the National Emergency Aid Centre, Hellenic Red Cross actors. The "victims" were be performed by actors – volunteers and dummies. Access restriction performed by the Police, on the Melissinou and Katehaki street and by the Coast Guard on the street that leads from the Kefalogiannidon street to the Fortress. The EFARETH guardians restricted the access at the Fortress. Health and Safety assessment by the Fire fighters. Given the Health and Safety risk, the fire fighters inspect the area first and provide access to the First Aid EFARETH team.	n/a
First Aid	When the area was secured and the victims safely removed, the First Aid EFARETH team took action. The site manager together with the responsible archaeologist, civil engineer, conservator and technician inspected the damage and coordinated the documentation and recording, the	The collection/secure transfer or storage of fallen material was carried with minimum use of vehicles and by using reusable boxes. The scaffolding is made by wooden planks and stainless

	structural support of the fortification wall and the safe transport of the fallen material. The sculpted stone and the inscription that was found in the collapsed masonry were transferred in reusable boxes and placed over Ethafoam cut in shape to ensure minimum motion. Construction of scaffolding of metal tubes and wooden planks (technicians-restorers, conservator, archaeologist) for temporary structural support of the masonry.	steel rods. The materials are eco-friendly and reusable.
Planned full recovery	Two studies need to be prepared by specialists and approved by the Central Archaeological Council, Hellenic Ministry of Culture and Sports. The soil infills of the bastion require stabilization. Restoration study of the watchtower and the part of the collapsed fortification wall. Full architectural documentation/design. The project can consider the re-use of the rectangular stones that were collected from the collapsed part are in good condition. Reconstruction with compatible material (Natural Lime) cleaning and consolidation of areas adjacent to the collapse; use of natural lime for injection and anchoring systems compatible with the ancient structure.	The plan was prepared according to the defined recovery principal including new prevention actions. The time frame is in line with the overall recovery strategy

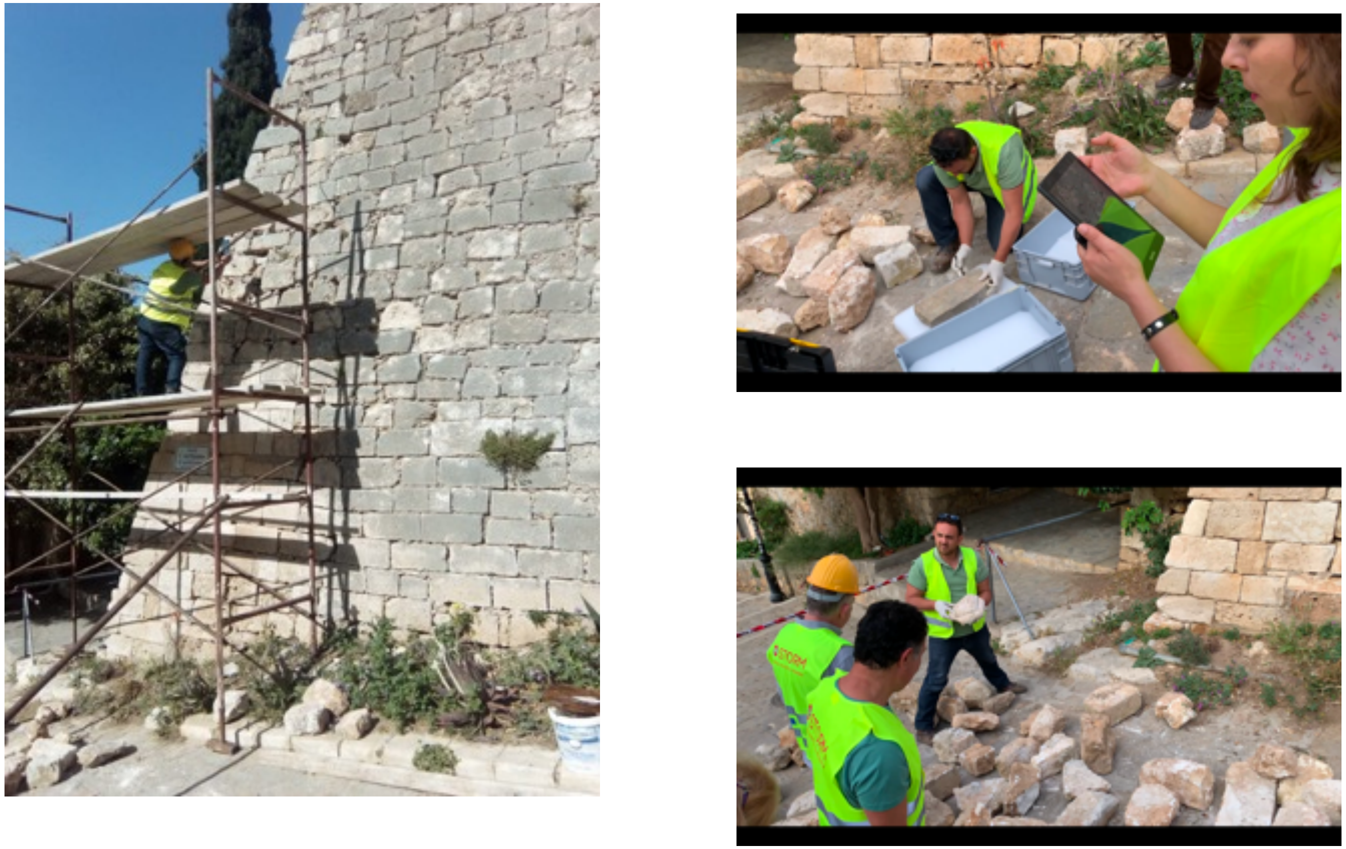


Figure 21 - EFARETH Drill 2

4.4 Summary of results

Hereinafter a table proposing a "by process" summary of results is provided to give an overall view of experiences achieved:

Process	Constraints	Storm added value
Damage assessment	Existing constraints are represented by most of information available is in a not structured way and not in a digital format.	STORM platform proposes a structured way to store and manage emergency needed data directly on field before, during and after the disaster.
Data collection	The collection of information useful in case of emergency, also when performed by non-specialized personnel.	Through the platform information related to state of conservation before the damage as the preexisting interventions or historical data, are made available in real time. This information takes into account an assessment carried out in peace time by specialized personnel (also revising information provided by non-professional people), that analyses all the possible implications due to damage caused by extreme or sudden climatic events.
Preparedness	Inability to react promptly and effectively or preventively, due to the lack of planning and availability of specialized and trained human resources, necessary means and equipment, no planning of evacuation routes, or adequate shelter systems.	STORM makes the concept of preparedness its own by inserting the forecasting of events into the emergency plan and assessing its severity, organizing teams trained to face the emergency to make the resolution quicker and more effective, minimizing any secondary damage or total loss of the asset. Providing instructions made available on mobile apps in the field, to personnel trained with effective materials, equipment and information.
Pre-Hazard	Absence of a prediction of the severity of a hazard and of the possible impact on specific materials or areas affected, generates the impossibility to activate in time the organization of the emergency.	The environmental monitoring system through the use of sensors and the creation of sending alarms targeted to specific situations allows to mitigate the impact on the imminence of a hazard, minimising some specific damage on materials or structures that could be involved, but also creating temporary systems or environmental climate control with direct or indirect and extremely localized protection.
Securing	Difficulties in managing information and lack of communication systems between the teams responsible for securing the population involved. Furthermore, there are difficulties in	Improvement of coordination between the teams dedicated to the safety of the CH, synergistic effect of knowledge and sharing of information gathered in the Preparedness such as preferential access and evacuation routes, type of buildings and presence of

	coordinating with cultural heritage protection experts, who in serious emergency situations, are unable to promptly assist or provide the necessary information, due they are outside the involved area.	facilities that can be facilities for interventions on both citizens and cultural heritage. The use of the information available on the platform, also through the app in the field, can allow the fast use of information.
First Aid	Lack of knowledge of conservative practices by first responders, often voluntary personnel, or civil protection. Lack of management, in crisis situations, of first aid operations for the stabilization of the cultural assets involved, unavailability of adequate and commensurate equipment. Poor knowledge of the type of materials, their risks and characteristics of the items, as well as the specific location and value of the CH. Absence of programming leads to the use of inadequate materials incompatible both with the conservation of the art work and with the environment already attacked.	The system developed in STORM foresees a phase of study and planning of the emergency plan and the organization of teams with one or more Team leaders leading multi-professional groups. In the process the staff is already trained in peace time to perform first aid operations, knows the peculiarities of the site, improving the coordination capacity. The time needed for first aid is improved by the presence of a "preparedness" phase and the choice of materials or methods useful for the intervention are optimized, because they are planned. Advantages in terms of the quality of the materials that can be supplied and the cost / benefit effectiveness, optimization of spaces and economic resources, minimum environmental impact and use of local resources. Real-time knowledge through the app, connected with data on the platform, is to the advantage of the historical-artistic recovery of the works involved.
Planning recovery	Difficulty in planning of definitive conservation interventions due to lack of information related to first intervention done.	Through the platform it is possible to record in real time the data of the first aid intervention carried out and the quantification of damages, also the data relating to the transport and removal of cultural heritage damaged for reasons of lack of space or conservation reasons, in adequate buildings, they are registered and accompany the work to its temporary destination in organised warehouses. These data are stored via the platform.

4.5 Conclusions

First Aid constitutes a field of experimentation of STORM processes. During the drills, real exercises in the field, the project has demonstrated the quick acquisition by the pilot teams of a greater awareness on the management capacity in case of emergency.

Between the first and the second drill rounds, the involved actors have shown increased ability of coordination of the teams, improving the synergistic work between the different actors involved. The demonstration of this could be observed through an evident improvement of the reaction time during the exercise.

Although the results evaluation of pilots' drills found several common points to be compared, In general, the results of the drills were hard to be compare due to differences in scenarios and cases studied, both for climatic reasons and degrees of exposure but also due to the emergency protocols often different from site to site. Those difference offered more hints for a broader evaluation of events and of the response system implemented.

Furthermore, STORM introduced a challenging way to support relationships between site managers and emergency forces where both conservation protocols and emergency procedures could work in synergy also providing inputs for an evolution of existing regulations.

With regard to the principles of eco-compatibility, in the choice of materials and equipment used, it was in most cases held in high regard, and better expressed in the choice of the protection system with inflatable cushions for the indirect protection of the items (placed at the risk of being invested from collapse of structures), proposed in the Baths of Diocletian site; such as the execution of a temporary barrier set up in a few hours in synergy with the local authority, using for the intervention the local shoreline sand to build a physical barrier to waves along the Sado shore in Tróia.

The interventions have always kept in mind the respect of the original materials and the existence of any previous interventions, preferring the use of indirect stabilization systems and/or transportation of the movable items towards adequate storage, according with the conservation rules and best practice, as often was suggested in the preparedness forms of the STORM platform.

In general, the two rounds experiments satisfied the expected results on average, as far as the items selected are concerned, all have taken into account the priorities and historical-artistic values of the goods involved, and the choice of interventions has greatly favoured the in-situ stabilisation system.

5 Prevention/Slow-Hazard - Pilot results evaluation

This section is dedicated to the slow-hazard prevention and mitigation activities, developed through the experiences carried out during the experimental phases of the five pilot sites involved in the project. The goal was to verify and make more effective the actions to prevent the degradation of cultural heritage through innovative materials and methodologies, based on the results obtained from the evaluations of non-invasive and non-destructive methods for survey and diagnosis (widely discussed in D1.2), and conservation-restoration methods.

5.1 Slow Hazard, prevention and mitigation

Climate change and extreme events represent nowadays a considerable challenge for the preservation of cultural heritage. These conditions can affect the biological, chemical, and physical mechanisms leading to degradation of the cultural assets. In this perspective, cultural heritage adaption to climate change impact includes risk assessment strategies, that involves a large number of processes/actions common to both slow-disasters and sudden-disasters[20]. About this, Barclay Jones[21] defined two deterioration mechanisms that threaten cultural heritage: the factors that slowly deteriorate cultural heritage materially, and the incidents that rapidly and catastrophically destroy cultural heritage in a very short time period. The slow deterioration of objects over a long-time period is generally caused by, for example, environmental, storage material or place of storage issues. Rapid and catastrophic damage in cultural heritage could instead be caused by, for example, floods, fires, sabotage, natural disasters, terror attacks or acts of war. Regarding this, a detailed description is reported in D1.3[22].

With the intention of safeguarding our tangible cultural heritage, the actions and measures of conservation, in addition to involving materials and structures, have to take into account past, current and future deterioration. Conservation and prevention (in particular this last one), become instruments to avoid or minimize future risks and degradation.

Conservation prevents or retards cultural heritage’s deterioration by controlling the environment and the object’s structures to maintain them as unchanged as possible, with the help of prevention and restoration.

Prevention is, instead, a system based on a series of methods that include all the processes in the field of conservation, such as the study of the cultural asset and its hazards through monitoring activity, restoration, and maintenance, the study of the climate for its regulation (indoors) or adaptation (outdoor), learn from prior traditions and experiences in collection care (fig. 22).

---

20 D5.1 Risk Assessment and Management Methodology

21 Jones, B. G. (1997). Economic Consequences of Earthquakes: Preparing for the Unexpected.

22 D1.3 Cost-effective conservation and restoration methods

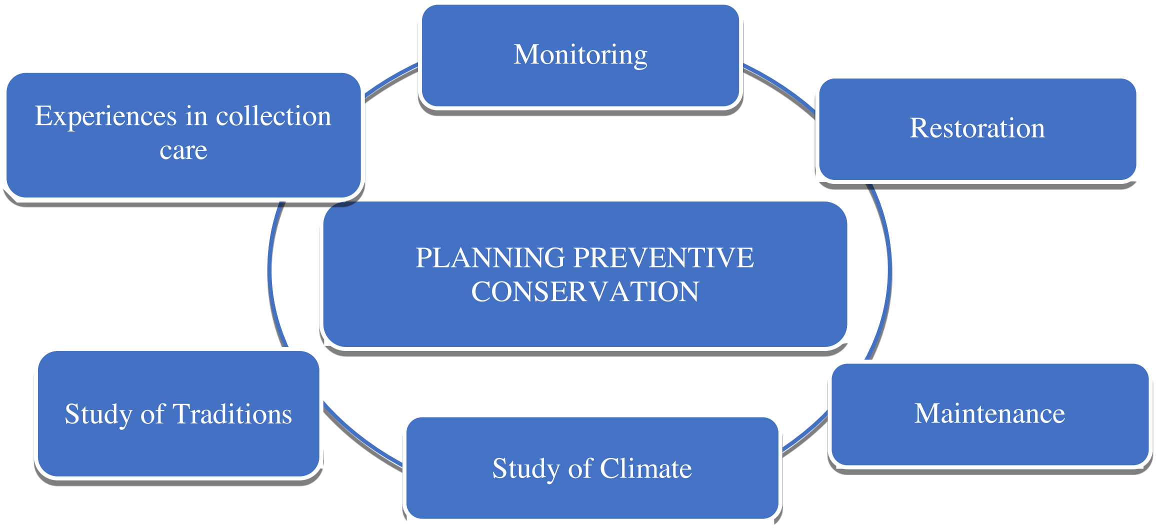


Figure 22 Main phases related to prevention method for cultural assets

Starting from the idea that prevention is not always feasible since it is not possible to completely avoid all the potential risks, in some cases, it will be more correct to speak of mitigation.

5.1.1 Process evaluation

The evaluation of prevention methods, therefore, have to respond to the above descriptions, which starting from the hazard identification, includes all the carried-out activities. In D5.2 document[23] those aimed at prevention and mitigation are identified, which concern monitoring interventions (of the hazard), reduction of exposure to risk and of the susceptibility of materials through restoration and conservation, monitoring and maintenance of the cultural property.

For the management of slow-hazard in the pilot sites, the processes related to the prevention, adaptation and full recovery, have been addressed through monitoring and conservation/restoration activities performed in the experimental scenarios already reported in D9.1, were the sites involved are characterized by different geographical positions, different materials and construction techniques, which can interact with the surrounding environment giving rise to natural or anthropogenic hazards.

5.1.2 Knowledge base

The experimental scenarios of slow hazards have been carried out through a reasoned installation of sensors, intervention techniques and in-situ detection of on-going phenomena, in order to give early warnings of risk and validate non-destructive methods and monitoring systems. These processes made it possible to monitor the degradation forms present both before and after restoration interventions, and to assess their effectiveness and durability over time. The following table reports a descriptive section regarding the Slow-Hazard experimental scenarios at the five STORM pilot sites.

[23] D5.2 STORM Risk management tool

Table: Slow-Hazard experimental scenarios

EXPERIMENTAL SCENARIO	INVOLVED ACTORS	TIMESCALE
MAT_EXP8: Process experimentation - Freeze thaw	MAT, USAL, Volunteers	M32
BOD_EXP1: Process experimentation - Rising humidity, vibration, biodegradation	SSCOL, ENG, TUSCIA, ZAMG	M29-M35
BOD_EXP7: Process experimentation - Biological degradation	SSCOL, TUSCIA, ENG	M28-M32
HCR_EXP8: Process experimentation - Salinisation	EFARETH personnel (conservators, civil engineers, archaeologists), KP, FORTH, ENG	M28-M32
RRT-EXP01: Monitoring of shoreline structures – tidal and wave action, coastal erosion	TRO, INOV, UWA, ENG	M01-M36
RRT-EXP02: Biocolonisation monitoring of the Basilica frescoes	TRO, INOV, NCRS, TUSCIA	M15-M36
RRT-EXP03 + RRT-EXP04: Weather monitoring	TRO, ZAMG	M22-M36
ACE_EXP3: Process experimentation: Prolonged Dry Period / Heat wave	Directorate of Ephesus Museum Directorate of Survey and Monuments, Izmir Municipality of Selcuk, Bogazici University Local rescue organizations	M31-M32

For a better understanding, a brief description of each treated slow-hazard is given.

5.1.2.1 Bath of Diocletian (1) – Rising humidity (Humidity cycle changes/ relative humidity shocks)

Threats to the chemical and physical stability of archaeological sites are potentially impacted by changes in humidity cycles, which in turn depend on the parameters that most influence the water balance and humidity of outdoor materials such as: extreme precipitations events, a saturation of soils, water loading on roofs and other architectural elements. Additionally, dry summers look likely to increase the impact of humidity cycles (via salt crystallization) and potentially lead to the drying out of building materials and soils. The extreme changes that occur in humidity cycles can trigger a great deal of damage such as physical changes to porous building materials and finishes due to rising damp splitting, cracking, flaking, dusting of materials and surfaces, corrosion of metals[24]. The relevant presence of this hazard in Baths of Diocletian has led to different forms of degradation such as crack

[24] Verges-Belmin, V. (2008). Illustrated glossary on stone deterioration patterns. ICOMOS.

& deformation, detachment, erosion, moist area, salts efflorescence of materials and decorative elements (references in D5.3 and D9.1).

5.1.2.2 Bath of Diocletian (2) – Vibration

(Development pressure as defined in STORM Classification of Hazards and Climate Change-related Events)

Heritage buildings may be subject to damage due to road and rail traffic vibrations, earthquakes, vibrations induced by temperature variations, ground and wind conditions. Since in this case it is very difficult to use preventive actions, a monitoring activity is necessary in order to mitigate the damage. Common measures to reduce road and rail traffic are possible, but very expensive, then they can be used when the vibration level can be considered high enough to induce structural and non-structural damage. For this reason, critical levels of vibrations should be determined for particular section of the structure.

5.1.2.3 Bath of Diocletian (3) – Biological degradation

Biodegradation can be considered as an undesirable changing of both organic and inorganic materials that affect our cultural heritage. In particular, regarding stone and building materials (mortars, plasters, bricks and so on), the microorganism growth (bacteria, archaea, fungi, moss and lichens), and their metabolic activity can lead a biodeterioration phenomenon controlled by several factors, such as i.e. chemical composition, porosity, fabric of the object, its exposure environment, maintenance or conservative interventions done. These degradations forms can lead to the irreversible loss of value and/or information[25]. To avoid or at least slow down the damages, in outdoor environments the control is carried out essentially by direct methods. Those are largely represented by biocide treatments with broad-spectrum chemicals or herbicides (as already reported in D1.3, Biocide treatments). Recently, some methodologies and new substances have been the subject of research and experimentation due to the remarkable biocompatibility and ecological function. About this, in Bath of Diocletian, some experiments were carried out in the framework of STORM for the treatment of bio-deteriogens through the use of innovative, eco-friendly substances based on natural or bacterial products. These testing had the aim of identifying, among the eco- friendly technologies, the most effective ones for the treatment of biological growth giving an effective mitigation effect[26].

5.1.2.4 Efareth - Salinisation

Structures made of porous materials, such as stones, brick, mortars, concrete and so on, easily absorb water into the fabrics. Most frequent are rising damp (where ground moisture is drawn into the porosity by capillary action), falling damp (e.g., leaking roofs, etc.), and penetrating damp (vie dew deposition or ingress by wind pressure). The problem is that soluble salts contained in groundwater and soluble compounds from the materials are carried with the rising moisture to the surface of the porous materials, to the external atmosphere. But also salt weathering and the wind that brings salt from the sea are serious problems that affect especially the Cultural Heritage assets close to the sea. In this last situation, prevention is very hard, due to factors that cannot be controlled. This is also the case of Efareth pilot site, where salinization is the slow-hazard simulated experimentation for stone weathering due to excessive salt accumulation after prolonged heat period (salt crystallization) was made. The methodologies used to obtain necessary data for conservation and risk

[25] STORM Project. Constituent materials of the Cultural Heritage assets and Hazards

[26] Htt://www.storm-project.eu/ Slow hazard prevention procedures started to be experimented at Dioclethian Baths

prevention/mitigation are photogrammetric and laser scanning surveys (as reported in the related questionnaire 5.1.3.4), through which it was possible to evaluate the changes and the degree of damage by comparing the initial 3D photogrammetric reconstruction models with those later.

5.1.2.5 Ephesus - Heat waves

Heat waves are climatic events that are by nature unpredictable, short term and uncomfortable. Here is no common definition of a heat wave although it is generally understood to be a “prolonged period of excessive heat” which is usually associated with atmosphere-related heat stress. Regarding this, recent studies about climate change models have demonstrated that there is a tendency to an increase in the frequency and intensity of extreme natural hazards such as storms, floods, wildfires, and droughts, heat waves[27]. In order to prevent or at least mitigate the potential damage of this hazard toward buildings and archaeological elements, the STORM experimental campaign in Ephesus has concerned the study of the durability of stones due to excessive temperature change during a prolonged heat period. The limits for the temperature change damages were evaluated by an automated control of temperature changes with the help of a meteorological weather station.

5.1.2.6 Mellor - Freeze-Thaw cycles

When water goes from the liquid to the solid phase it increases in volume by about 9%. If this expansion occurs within a porous solid, or in a structural crack, this can cause damaging stress. If this stress is repeated, the solid may become weaker and eventually delaminate and spall. Freeze-thaw damage may not be a risk in materials with coarse pore structure such as sandstone or where there is severe salt contamination e.g. in coastal regions[28]. In Mellor site, some damages are also the result of slow-hazards such as the gradual degradation of masonry/earth works as a result of freeze-thaw action. The stabilisation methods have included the maintenance of the ditch and erecting of steel mesh walls at either end of the ditch to retain the infill. In terms of general maintenance, the ditch is cleaned and cleared of vegetation on regular occasions throughout the year. At either end of the exposed ditch, there are metal mesh sheets, these retain the infill preventing collapse. Thanks to STORM surveying and monitoring the trust is able to intercept damage, before the hazard evolves into a bigger issue, carrying out the maintenance in good time and ensuring the upkeep of the ditch. Hard capping and other measures directly evolving from WP5 were included in the works carried out at the Mill site.

5.1.2.7 Tróia (1) – Coastal erosion and tidal and wave action

Coastal erosion is a consequence of tide currents and sea waves and sea-level rise, and its most evident impact in the site of Tróia is the removal of sand from the shoreline of the river estuary, leaving the once buried foundations of buildings at sight and at the reach of the tides. This hazard also aggravates the impact of the tide and river currents on the Roman structures causing wetting-drying cycles on construction elements which soften mortars and soft stones and cause the fracture and collapse of archaeological structures. Along the shoreline of the Sado River estuary, all Roman structures, spread

---

[27] World Meteorological Organization (WMO), United Nations International Strategy for Disaster Reduction (UN/ISDR) and other international partners, 2009. Fact sheet #1. Climate information for reducing disaster risk www.wmo.int/wcc3 September 2009. Accessed on January 30, 2010.

[28] Brimblecombe, P., Grossi, C. M., & Harris, I. (2010). Climate change critical to cultural heritage. In Survival and sustainability (pp. 195-205). Springer, Berlin, Heidelberg.

along 2 km, are exposed to these hazards, as well as to human presence, currently without surveillance.

The degradation process of structures may be assessed by regular photogrammetric surveys. Two case studies were chosen for testing, the well of workshop 23 and the wall with a window of workshop 21. On the other hand, two other methods were tested to help surveillance across this long archaeological area: the building of a game for implicit crowdsensing, and the installation of an acoustic sensor in one of the most sensitive points, the wall with a window in Workshop 21, sending the recording of sounds to the STORM platform in real time.

5.1.2.8 Tróia (2) - Biodegradation

The seasonal presence of biodeterioration agents on some of the Basilica frescoes, particularly after very humid seasons, has led to the recurring appearance of green stains on the wall paintings. This causes discolouration and the potential disaggregation of the surface finishes. The biological colonisation on the painted N-E wall of the Basilica was treated with a biocide a few years ago, and, within the scope of STORM, was monthly assessed with an induced fluorescence sensor.

5.1.2.9 Tróia (3) – Damage alerts for the shoreline structures

5.1.2.9 Many of the natural hazards affecting the Tróia structures are hydro-meteorological in nature, and a weather station is therefore a valuable tool both for the monitoring of such hazards and for the triggering of warnings when extreme events are underway. In the early stages of the project, and considering the risk assessment results, alert thresholds were set for such warnings that, after the analysis of the weather station data collected in Tróia, could be fine-tuned to its specific context.

5.1.3 Slow hazards and prevention

Through the hazard evaluation completed in D5.1, it was possible to determine those to be involved in the further risk assessment procedure and define a prevention project[29], consisting of a detailed list of actions finalized not only to the identification of main risks for the cultural heritage but also defining a maintenance plan and mitigation of natural hazards. The list included actions such as:

1. Reducing hazards and threats - depending on the hazard, there are different ways to reduce the hazard and threats to cultural heritage sites.
2. Monitor the hazards (as illustrated in STORM D1.1, STORM Consortium 2017a, STORM D1.4, STORM Consortium 2017c summarized in Section 2.1.2).
3. Reducing the exposure of elements-at-risk.
4. Reducing the susceptibility.
5. Regular monitoring and maintenance of the site.

Though the slow-hazards don't cause immediate damages, continuous monitoring and well-considered maintenance have a fundamental importance in order to improve the stability of the cultural heritage objects and structures.

[29] D5.3 STORM Risk management guideline

For the evaluation of the results obtained from the preventive actions used in the two rounds of drills, a questionnaire for each pilot site was introduced. The table summarizes data for the identification of the cultural asset and its hazards, information related to the damages, methodologies for preventing or monitor the damages and the obtained results (some information was already reported in D.9.1 and D1.3).

The data collected in the questionnaire has been used to realize a score tables (with reference to D5.2) used for the evaluation of slow-hazard prevention experiments.

5.1.3.1 Bath of Diocletian (1) - Rising humidity

<table>
<tr><td colspan="10">PREVENTION / SLOW HAZARD (condition report of the cultural asset - treatment, monitoring and prevention/mitigation)</td></tr>
<tr><td>Site</td><td>Baths of Diocletian</td><td>Area</td><td colspan="3">Hall I of the Baths of Diocletian</td><td colspan="2">Item</td><td colspan="2">S-W pillar of the Hall I</td></tr>
<tr><td>Actors involved</td><td colspan="9">SSCOL, TUSCIA, ENG</td></tr>
<tr><td>Hazard</td><td colspan="9">Rising humidity</td></tr>
<tr><td>Intensity</td><td colspan="9">Medium</td></tr>
<tr><td>Data collected (insert the date)</td><td colspan="2">10/2017 – 04/2019</td><td colspan="7">Weather station monitoring</td></tr>
<tr><td>Environment</td><td>Urban</td><td colspan="8">Roman building (outdoor)</td></tr>
<tr><td>Item’s material</td><td>Bricks</td><td>Concrete</td><td>Lime plaster</td><td colspan="6"></td></tr>
<tr><td rowspan="2">Damage assessed</td><td rowspan="2">Alteration
Decay
Degradation
Deterioration
Weathering</td><td colspan="2">Crack & Deformation</td><td>Detachment</td><td colspan="2">Features by material loss</td><td colspan="2">Discoloration & Deposit</td><td>Biological Colonization</td></tr>
<tr><td colspan="2">Disconnection between/within structural elements, hair cracks, fractures</td><td>Blistering</td><td colspan="2">Erosion, missing parts</td><td colspan="2">Moist area, salts efflorescence’s</td><td>Biogrowth (algae, black patina)</td></tr>
<tr><td>Parameter to investigate</td><td>Air temperature</td><td>Relative humidity</td><td colspan="7">Cracks/fissures movements</td></tr>
<tr><td rowspan="2">Investigation methods</td><td colspan="3">Off-line monitoring sensors</td><td colspan="6">Real-time monitoring sensors</td></tr>
<tr><td colspan="3">n/a</td><td colspan="6">Fibre optic (FBG) sensor</td></tr>
<tr><td>Phases</td><td colspan="3">Description</td><td colspan="6">Results</td></tr>
</table>

1st phase (10/2017 – 04/2019) Monitoring	*Data collection - Temperature and Humidity:* The useful parameters to monitor the capillary rise are the temperature and the rising humidity. Fiber Bragg Grating (FBG) sensors have been used to obtain and collect data on variations in rising humidity. Temperature was collected by Arduino sensor	*Temperature and Humidity:* The recorded data, once processed and observed in scatter plots (XY), shows a sinusoidal tendency in which the percentage of humidity goes from 0 to 100. This representation allows to count the number of fluctuations that occur in the investigated period.
2nd phase (10/2017 – 04/2019) Monitoring or prevention/mitigation actions	A series of software components, installed on monitoring computers have been developed, written in the Python programming language, for sending the data already processed on the STORM platform.	The data continuously reach the STORM platform and can be correctly displayed. Only in the case of humidity values must first be processed by an employee because they need different indexes for each month. Moisture data will be uploaded to the platform as an offline file.

5.1.3.2 Bath of Diocletian (2) - Vibration

PREVENTION / SLOW HAZARD (condition report of the cultural asset - treatment, monitoring and prevention/mitigation)						
Site	Baths of Diocletian	**Area**	Hall I of the Baths of Diocletian		**Item**	S-W pillar of the Hall I
Actors involved	SSCOL, TUSCIA, ENG					
Hazard	Vibration					
Intensity	Medium					
Data collected (insert the date)	10/2017 – 04/2019		Weather station monitoring			
Environment	Urban	Roman building (outdoor)				
Item's material	Bricks	Concrete	Lime plaster			

<table>
<tr><td rowspan="2">Damage assessed</td><td rowspan="2">Alteration
Decay
Degradation
Deterioration
Weathering</td><td colspan="2">Crack & Deformation</td><td>Detachment</td><td>Features by material loss</td><td>Discoloration & Deposit</td><td>Biological Colonization</td></tr>
<tr><td colspan="2">Disconnection between/within structural elements, hair cracks, fractures</td><td>Flaking</td><td>Erosion, missing parts</td><td>n/a</td><td>n/a</td></tr>
<tr><td>Parameter to investigate</td><td>Air temperature</td><td>Relative humidity</td><td colspan="5">Cracks/fissures movements</td></tr>
<tr><td rowspan="2">Investigation methods</td><td colspan="3">Off-line monitoring sensors</td><td colspan="4">Real-time monitoring sensors</td></tr>
<tr><td colspan="3">n/a</td><td colspan="4">Fibre optic (FBG) sensor</td></tr>
<tr><td>Phases</td><td colspan="3">Description</td><td colspan="4">Results</td></tr>
<tr><td>1st phase (10/2017 – 04/2019)
Monitoring</td><td colspan="3">Data collection - Temperature and Humidity: The useful parameters to monitor the capillary rise are the temperature and the rising humidity. Fiber Bragg Grating (FBG) sensors have been used to obtain and collect data on variations in rising humidity. Temperature was collected by Arduino sensor.
Data collection - Vibration: The parameters useful for monitoring vibrations are the expansion / contraction movements of the lesions and the movement of a sensor in the three spatial dimensions (XYZ). Fiber Bragg Grating (FBG) sensors were used to obtain and collect data for expansion and contraction movements.</td><td colspan="4">Temperature and Humidity: The recorded data, once processed and observed in scatter plots (XY), shows a sinusoidal tendency in which the percentage of humidity goes from 0 to 100. This representation allows to count the number of fluctuations that occur in the investigated period.
FBG Vibration: The recorded data show a classic sinusoidal trend in which expansions and contractions follow the changes in temperature and humidity between day and night. It is also possible to observe sudden variations due to the movements of the masonry.
Arduino: These data are also processed and observed in scatter plots (XY). They show the movements in the three spatial axes, and the rotation angles of the sensor.</td></tr>
</table>

2nd phase date Monitoring or prevention/mitigation actions	A series of software components, installed on monitoring computers have been developed, written in the Python programming language, for sending the data already processed on the STORM platform.	The data continuously reach the STORM platform and can be correctly displayed. Only in the case of humidity values must first be processed by an employee because they need different indexes for each month. Moisture data will be uploaded to the platform as an offline file.

5.1.3.3 Bath of Diocletian (3) - Biological degradation

PREVENTION / SLOW HAZARD (condition report of the cultural asset - treatment, monitoring and prevention/mitigation)								
Site	Baths of Diocletian	**Area**	Michelangelo's cloister			**Item**	Cippus, trabeation fragment	
Actors involved	SSCOL, TUSCIA, ENG							
Hazard	Biological degradation							
Intensity	High							
Data collected	Oct-nov/2019	**Air temperature**	Mean temp. Test 1: 20 °C	**RH**	N/A	**Precipitation**	Test 1: 2,86	
Environment	Urban	Garden						
Item's material	Stone, Marble							
Damage assessed	***Alteration Decay Degradation Deterioration Weathering***	***Crack & Deformation***	***Detachment***		***Features induced by material loss***	***Discoloration & Deposit***	***Biological Colonization***	
		n/a	n/a		Erosion	Staining, Moisture	Bacteria, fungi, algae	
Parameter to investigate	Air temperature	Relative humidity	Rainfall	Identification and characterisation of microorganisms				

Investigation methods	***Off-line monitoring***		***Real-time monitoring sensors***
	Photographic and microphotographic documentation. Bioluminometer measurements	Biological sampling	Weather stations
Phases	**Description**		**Results**
1st phase (10/2017 – 04/2019) Monitoring	Experimentation of innovative ecofriendly biocide based on natural or bacterial products. ***Test 1) Cippus*** - 11 areas, treated with different biocides: - Bio Z: bio-emulsifier - Liq: 3% liquorice leaf extract - NapalCap: mucilage of Opuntia (prickly pear) - SME1.11: bacteria (Arthrobacter oxydans) in gel - Mix 10bis 1.3% essential oil of Cinnamomum zeylanicum, Corydothymys capitatus and Eugenia caryophillatas - Benzalkonium chloride 1% - Reference control (deionized H_2O) ***Test 2) Trabeation fragment*** - 12 areas, treated with different biocides: - Alcoholic extract of liquorice leaves (3%) - SME1.11: bacteria (Arthrobacter oxydans) in gel - Reference control (deionized H_2O) - Mix 10bis 1.3% essential oil of Cinnamomum zeylanicum, Corydothymys capitatus and Eugenia caryophillatas		Test 1) Cippus- The best result seems to have been obtained with the SME1.11 (bacterial strain) applied through a Vanzan NF-C gel compress, on average the alcoholic extract of liquorice leaves applied by means of a Vanzan gel compress has also proved to be effective. In general, the compresses applied with the gel (Vanzan NF-C) have been more effective than those applied with cellulose pulp. Test 2) Trabeation fragment- The tests from one to seven days of contact, did not show, at a macroscopic observation, significant results. the effects of all the products seem to be comparable with each other. The low result of the biotreatments carried out could be due to the different environmental conditions related to the two experimental phases. A verification of environmental parameters (temperature and precipitation) was carried out using the weather data station. The results highlight during the second phase of the experimentation, lower temperatures on average about 10 ° C than the first, as well as rainfall, which instead they are much more abundant.

2nd phase (23-27/05/2019) Monitoring or prevention/mitigation actions	Whole cleaning of marble surfaces with the best biocide resulting from the tests.	Monitoring the efficacy of biocide treatments through a photographic camera, digital microscope and bio-luminometer measurements for an estimate of the bio-deteriogens present. The photo and micro-photographic documentation were elaborate with the Adobe Photoshop software to achieve small areas to be analysed with the Image Analysis. With the evaluation of RGB colour space related to the bioluminometer results, we had monitored the chromatic variations over time.

5.1.3.4 Efareth - Salinisation

PREVENTION / SLOW HAZARD (condition report of the cultural asset - treatment, monitoring and prevention/mitigation)						
Site	Historical Centre of Rethymno	**Area**	Venetian Port	**Item**	Stone building of the Lighthouse	
Actors involved	EFARETH, KP, FORTH, ENG					
Hazard	Salinization					
Intensity	Very high					
Data collected	**Air temperature**	18-3-19 (+/-3 days) and 2-5-19 (+/-3 days)	**High Speed-Wind**	18-3-19 (+/-3 days) and 2-5-19 (+/-3 days)	**Precipitation**	18-3-19 (+/-3 days) and 2-5-19 (+/-3 days)
Environment	Urban outdoors	Exposed to marine environment				
Item's material	Limestone	Lime-based mortar	Cement mortar from past interventions			

Damage assessed	***Alteration*** ***Decay*** ***Degradation*** ***Deterioration*** ***Weathering***	***Crack & Deformation***	***Detachment***	***Features induced by material loss***	***Discoloration***	***Biological Colonization***
		Cracks	Detachments, Flaking	Corrosion	Salts crystallization	n/a
Parameter to investigate	Comparing degree of change and damage		Conductivity			
Investigation methods ***Scanning surveys March 2017-2018***	**Off-line monitoring**			**Real-time monitoring sensors**		
	Photogrammetry, Laser scan, Photography camera, conductivity meter			Weather stations	Accelerographs	
Phases	**Description**			**Results**		
1st phase (March 2017- October 2018) Monitoring or	Evaluation of Damage Assessment (degree of damage) through visual comparisons of 3D photogrammetric reconstruction models. In particular, use the first 3D reconstruction model to assess state of preservation at the beginning of monitoring. Compare initial 3D monitoring			The process of desalination was conducted by pultices of sepiolite. Each poultice was left on the surface for 20 minutes. Time of application was tested for 10, 20 and 30 minutes. The process was successful in stabilizing the conductivity		

conservation/restoration actions	with subsequent ones and assess degree of change and damage. Specifically: Apply poultices of sepiolite or white tissue paper soaked in solutions of different conductivity by the following order: Tap water poultices 90% Tap water/ 10% w/w deionised water poultices 70% Tap water/ 30% w/w deionised water poultices 50% Tap water/ 50% w/w deionised water poultices 30% Tap water/ 70% w/w deionised water poultices 10% Tap water/ 90% w/w deionised water poultices Deionised water poultices Measuring conductivity of the solution before and after application and record measurements. Perform testing on the time of poultices application for maximum salt removal. Assess appearance of stone after conductivity is stabilized in low percentages.	in low percentages. Two outcomes derived from the process: 1. Sepiolite left particles in the pores and their removal was difficult. The sepiolite will be replaced by white tissue paper. 2. Best time for poultice application is 30 minutes.
2nd phase **(May 2018-2019) Monitoring or prevention/mitigation actions**	The monitoring of the condition of limestone includes in situ inspections after consulting the weather data on instances where weather fluctuations are high. Mitigation actions include desalination with improved application steps, as defined in 1st phase, in regular intervals.	It is estimated that regular desalination on the porous limestone will prevent the excess building-up of salt crystallization.

5.1.3.5 Ephesus - Heat wave

PREVENTION / SLOW HAZARD (condition report of the cultural asset - treatment, monitoring and prevention/mitigation)						
Site	Ancient City of Ephesus	**Area**	Main Entrance of the Theatre		**Item**	Visitor entrance wall, Cavea
Actors involved	Directorate of Ephesus Museum, Directorate of Survey and Monuments, Izmir Municipality of Selcuk, Bogazici University (BU, Local rescue organizations)					
Hazard	Prolonged Dry Period / Heat wave					
Intensity	Very high					
Data collected	**Dec 2018-May 2019**					
Environment	2 kms southeast of Selcuk district and 8 kms to the coast					
Item's material	Stone, Marble, Brick, Mortar					
Damage assessed	***Alteration Decay Degradation Deterioration Weathering***	***Crack & Deformation***	***Detachment***	***Features induced by material loss***	***Discoloration & Deposit***	***Biological Colonization***
		Cracks, shifting of the wall	Disintegration and loss of bonding material between stone blocks	Erosion, mechanical damage	Loss of the original colour of the stone	n/a
Parameter to investigate	Temperature change					
Investigation methods	***Off-line monitoring***		***Real-time monitoring sensors***			

	n/a	Weather station
Phases	**Description**	**Results**
1st phase date Monitoring - Lab experiments - December 2018	Drill1: Definition of the prolonged dry period (PDP) and calculation of the site-specific PDP for Ephesus.	PDP has been defined as the "number of consecutive dry days without precipitation" (less than 2mm per day). After analysing the climate data, the site-specific PDP value for Ephesus was calculated as 152. Innovation: N/A. Analysis performed by ZAMG.
2nd phase May 2019 Monitoring or prevention/mitigation actions	Drill 2: During a regular site survey the site manager identifies discoloration, deterioration and cracks on the surfaces of some stones. He decides to take immediate action to reduce the effects of climatic conditions on the structure due to long term exposure of stones to direct sunlight.	PDP has been defined as the "number of consecutive dry days without precipitation" (less than 2mm per day). After analysing the climate data, the site-specific PDP value for Ephesus was calculated as 152. Innovation: N/A. Analysis performed by ZAMG.

5.1.3.6 Mellor (1) - Freeze-Thaw cycles

PREVENTION / SLOW HAZARD (condition report of the cultural asset - treatment, monitoring and prevention/mitigation)					
Site	Mellor Heritage Project	**Area**	Mellor Archaeological site: Mill remains	**Item**	Walls not yet consolidate of the mill
Actors involved	MAT, USAL, Volunteers				
Hazard	Freeze thaw action				
Intensity	Catastrophic				

Data collected	***Winter 2017 - Spring 2018; Summer 2018 - Winter 2019***		Weather station monitoring			
Environment	Heathland vegetation	Close to the river				
Item's material	Stones, Lime mortar, Wood, Bricks, Metals					
Damage assessed	***Alteration*** ***Dacay*** ***Degradation*** ***Deterioration*** ***Weathering***	***Crack & Deformation***	***Detachment***	***Features induced by material loss***	***Discoloration***	***Biological Colonization***
		Recent excavation: Little examples of deformation	n/a	Brick work has become brittle and begun to crumble away from the structures	n/a	n/a
Parameter to investigate	Soil temperature-moisture	Atmospheric pressure	Wind direction-speed			
Investigation methods	**Off-line monitoring sensors**			**Real-time monitoring sensors**		
	Photogrammetry	Laser Scans		Weather Station		
Phases	**Description**			**Results**		
1st phase Dec 2018 – May 2019 Monitoring	Simulation of decided recovery actions. Fine tune simulation based on simulation results.			Suggested STORM surveying and diagnosis methods helped the site determine the area most at risk from damage and those that were deteriorating most rapidly. Results from these scans fed directly back into the planning of intervention methods.		
2nd phase Monitoring or	Mill site: is undergoing landscaping because of another heritage project which is ongoing. For the time being, the			Landscaping works were undertaken with suggestions from the STORM WP5 included in the planning. Hard capping and other		

prevention/mitigation actions	temporary fences have been installed to direct the public around the information boards and a platform overlooking the Wheel Pit is in place.	measures directly evolving from WP5 were included in the works carried out at the Mill site.

5.1.3.7 Mellor (2) Freeze-Thaw cycles

PREVENTION / SLOW HAZARD (condition report of the cultural asset - treatment, monitoring and prevention/mitigation)					
Site	Mellor Heritage Project	**Area**	Area 1: Old Vicarage Site	**Item**	1.1 Ditch Section 1.2 Ditch wall (Graveyard) 1.3 South-facing Bridge Support 1.4 Geological Plating Below Bridge 1.5 Ditch Information Board
Actors involved	MAT, USAL, Volunteers				
Hazard	Freeze thaw action				
Intensity	Catastrophic				
Data collected	***Winter 2017 - Spring 2018; Summer 2018 - Winter 2019***		Weather station monitoring		
Environment	Heathland vegetation	Outdoor	Exposed Hilltop	Open to the public	
Item's material	Sandstone	Overlaying deposits of boulder clay	Topsoil and subsoil	Material contained within ditch fills includes: Roman and Iron Age pottery, Roman copper alloy brooches, Lead and Glass fragments	

Damage assessed	*Alteration* *Dacay* *Degradation* *Deterioration* *Weathering*	*Crack & Deformation*	*Detachment*	*Features induced by material loss*	*Discoloration*	*Biological Colonization*
		Recent excavation: Little examples of deformation	Stone walls of the ditch have detached due to their formation	n/a	n/a	n/a
Parameter to investigate	Soil temperature-moisture	Atmospheric pressure	Wind direction-speed			
Investigation methods	**Off-line monitoring**			**Real-time monitoring sensors**		
	Photogrammetry	Laser Scans		Weather Station		
Phases	**Description**			**Results**		
1st phase **October 2018** **Monitoring or conservation/restoration actions**	The stabilisation methods include the maintenance of the ditch and erecting of steel mesh walls at either end of the ditch to retain the infill. In terms of general maintenance, the ditch is cleaned and cleared of vegetation on regular occasions throughout the year. At either end of the exposed ditch, there are metal mesh sheets, these retain the infill preventing collapse.			Thanks to STORM surveying and monitoring the trust is able to intercept damage e.g., to the ditch cross section, before the hazard evolves into a bigger issue.		
2nd phase - **May 2019** **Monitoring or prevention/mitigation actions**	Simulation of decided recovery actions. Fine tune simulation based on simulation results.			Assessing the variety of factors being measured in the ditch area, the trust can ensure that volunteers carry out maintenance in good time and ensuring the upkeep of the ditch.		

5.1.3.8 Tróia (1) – Monitoring of the shoreline structures

PREVENTION / SLOW HAZARD (condition report of the cultural asset - treatment, monitoring and prevention/mitigation)							
Site	Roman Ruins of Tróia	**Area**	(D5.1) RRT-1b: Workshops on the shoreline		**Item**	(D3.1) RRT-01 – Wall with window in Workshop 21 (D3.1) RRT-03 – Well of Workshop 23 (D5.1) Other areas of RRT-1b	
Actors involved	Site manager and team TRO: 4; UNIWA: 5; INOV: 3						
Hazard	Tidal and wave action		Coastal erosion		Intense rainfall		
Intensity	Very high		Very high		Very high		
Data collected	**Photogrammetric data**	Monthly M01-M36	**Crowdsensing data**	M36	**Acoustic data**	Continuous M32-M36	
Environment	Coastal area: shoreline of the estuary of Sado						
Item's material	Stone masonry, occasional ceramic elements						
Damage assessed	***Alteration Decay Degradation Deterioration Weathering***	***Crack & Deformation***	***Detachment***	***Features induced by material loss***	***Discoloration & Deposit***	***Biological Colonization***	
		Fractures Deformation	Different detachment processes in some masonry blocks	Erosion Missing parts			
Parameter to investigate	Mass loss; deformation; missing parts			Vandalism; extreme event alerts			
Investigation methods	***Off-line monitoring***			***Real-time monitoring sensors***			
	Photogrammetry			Acoustic sensor	Gamification		

Phases	Description	Results
1st phase Dec 2018 – May 2019 Monitoring	The first phase of RRT EXP1 consisted of the photogrammetric survey of the two selected items. The first phase of RRT EXP3 consisted of the construction of a game inviting people to record the evidence in specific points of the Roman ruins of the shoreline and thus contributing to assess their state of conservation. The first phase of RRT EXP4 consisted of the building and installation of an acoustic sensor (WASN) hidden in Workshop 21 and transmitting data via Wi. Fi to the Storm platform.	Accurate survey of archaeological of selected items and recording of their state of preservation in different moments along three years. Long testing of the game regarding the GPS location of the points to monitor. The WASN was installed in January 2019.
2nd phase Monitoring or prevention/mitigation actions	The second phase of RRT EXP1 consisted of the processing of models and orthophotos and comparison among them. The second phase of RRT EXP3 consisted of the experimentation of the game. The second phase of RRT EXP4 consisted of the collecting of data recorded by the acoustic sensor.	The processing of models and analysis of the decay rate of the two items showed no visible damage in the period of 3 years, contrary to the opinion of the site team that believed that both the wall and the well had suffered the loss of elements. Photogrammetry proves to be more accurate than the human eye and mind of the technicians that regularly visit and inspect the structures. Digital conservation was ensured. Short period of experimentation but volunteers experimented and sent pictures documenting the state of preservation. The WASN has achieved to successfully record sound samples and forward them to the STORM platform. During the time period of sound samples recording and classification, no events of extreme weather phenomena were captured. However, there have been reported events of human presence.

5.1.3.9 Tróia (2) – Biological degradation

PREVENTION / SLOW HAZARD (condition report of the cultural asset - treatment, monitoring and prevention/mitigation)						
Site	Roman Ruins of Tróia	**Area**	BAS – Basilica (ref. D5.1: RRT-07 Basilica)	**Item**	RRT-BAS-a – Basilica wall a (ref D3.1: RRT-02: Northeast painted wall)	
Actors involved	TRO, INOV, NCRS, ENG					
Hazard	Biological colonisation					
Intensity	Very High					
Data collected	SFS sensor	**Fluorescence spectra**	Once a month since Aug 2017			
Environment	Coastal area, walls under a shelter					
Item's material	Painted plaster - fresco technique					
Damage assessed	***Alteration*** ***Decay*** ***Degradation*** ***Weathering***	***Crack & Deformation***	***Detachment***	***Features induced by material loss***	***Discoloration & Deposit***	***Biological Colonisation***
	Deterioration					Biofilms formed on the face of the painted walls

Parameter to investigate	Bio-growth	high humidity	pluviosity			
Investigation methods	**Off-line monitoring sensors** Induced Fluorescence Sensor			**Real-time monitoring sensors** Weather station		
Phases	Description			Results		
1st phase Monitoring or conservation/ restoration actions	Monthly assessments of microorganism presence with the specially developed Spectral Fluorescence Signature (SFS) sensor, based on the spectroscopic analysis of the fluorescence emission from chlorophyll and characteristic proteins (of algae, fungi, bacteria, moss and lichen biofilms) induced by a wide-spectrum Xe flashlamp.			The data collected confirmed the early detection of chlorophyll and protein showing the need for an early treatment.		
2nd phase Monitoring or prevention/ mitigation actions	Define bio-colonisation threat levels by comparing different sensor data. More specifically, ascertain concerning environmental conditions by measuring + high humidity + pluviosity from environmental sensors (incl. weather station) jointly with chlorophyll / protein assessment carried out with the SFS sensor. Result reporting uploaded to the STORM platform periodically.			The amount of biofilm detected, and the weather conditions follow general expected patterns but is not always directly correlated, which emphasizes the utility of the sensor.		

5.1.3.10 Tróia (3) – Weather monitoring

PREVENTION / SLOW HAZARD (condition report of the cultural asset - treatment, monitoring and prevention/mitigation)						
Site	Roman Ruins of Tróia	**Area**	All		**Item**	All
Actors involved	TRO, INOV, NCRS, ENG, TUSCIA					
Hazard	Intense Rainfall	Rain	Thunderstorms	Strong winds	Wind-generated waves	Humidity cycle changes
Intensity	High	High	High	High	Very high	High
Data collected	**Weather station monitoring (M22-M36)**	Temperature	Humidity and Dew point	Wind and gust	Precipitation – rate and accumulated	Atmospheric pressure
Environment	Coastal area, temperate climate					
Item's material	Essentially stone masonry					
Damage assessed	***Alteration***	***Crack & Deformation***	***Detachment***	***Features induced by material loss***	***Discoloration & Deposit***	***Biological Colonisation***
	Decay					
	Degradation					
	Weathering					
	Deterioration	(weathering)	(weathering)	(weathering)	-	(weathering)
Parameter to investigate	Temperature	Humidity	Wind speed and direction	Precipitation rate		

		Accumulated precipitation
Investigation methods	**Off-line monitoring sensors** n/a	**Real-time monitoring sensors** Weather station
Phases	**Description**	**Results**
1st phase **Monitoring or conservation/ restoration actions**	Deployment of the weather station and starting of data collection.	Warning thresholds for meteorological phenomena were set based on hazard assessments conducted in D5.1.
2nd phase **Monitoring or prevention/ mitigation actions**	Comparison of collected data with predictive analysis conducted for the Risk Assessment (D5.1)	Identification of extreme events in terms of frequency and characterising parameters. Reviewing and slight adjustment of the warning thresholds.

5.1.4 Overall view

The results obtained from the experimental work are briefly summarized in table 26.

Table 27 results of experimental scenarios activity

SLOW HAZARD	Investigation methods and actions involved	Results
MELLOR Freeze thaw (1,2)	Photogrammetry, Laser Scans, Weather Station Quick Assessment forms, Situation Awareness, Crowdsensing mobile app, Knowledge Sharing Framework, Risk Assessment map and tool, Sensory Map, Visual Analytics	Monitor the deterioration of masonry/earth works that are at risk from freeze-thaw.Reduction in time that will be needed to respond to hazard occurring.
BOD Rising humidity, Vibration	Optical fiber (FBG) sensors, environmental sensors, weather station monitoring to dectect the danger signals. Risk analysis in order to evaluate actions for both preparedness and rapid intervention.	Improvement of the effectiveness of prevention and recovery plans and evaluation of the for the materials and artefacts.
BOD Biodegradation	Cleaning and Monitoring activity by photographic and microphotographic documentation, Bioluminometer measurements, Biological sampling/ Weather stations	Experimentation of innovative eco-friendly biocide, with good performance of bacterial and natural products
EFARETH Salinisation	Monitoring activity and desalination on stones of the base exhibiting salt efflorescence with 3D photogrammetric reconstruction models and weather station monitoring. Risk Assessment and Management, Event Manager, Surveillance and Monitoring (Situation Awareness), Collaborative and knowledge sharing platform	Evaluation of Damage Assessment (degree of damage) through visual comparisons of 3D photogrammetric reconstruction models
TROIA Biodegradation	Monthly assessments of microorganism presence through Spectral Fluorescence Signature (SFS) sensor	The data collected confirmed the early detection of chlorophyll and protein showing the need for an early treatment, underlined the utility of the sensor

SLOW HAZARD	Investigation methods and actions involved	Results
TROIA Tidal and wave action, coastal erosion Weather monitoring	Monitoring of the shoreline structures through photogrammetric survey of the selected items. Alerts via acoustic sensors and gamification. Weather station monitoring for T/RH and pluviosity and for defining parameters for coastal flood on the STORM Platform (Heavy Rains, High Tide).	Accurate survey of archaeological selected items through the monitoring of conservation state evolution and alerts for extreme events that can cause damage and require intervention.
EPHESUS Prolonged Dry Period / Heat wave	Weather station monitoring, Automated Significance of Temperature Changes for definition of PDP (Prolonged Dry Period) for Ephesus	Evaluation of the temperature change limits for the damages

To process the obtained information, a table has been developed (see table 27) where the main variables, already defined in the questionnaire, are collected in two groups; a blue section in which hazard, damage and their intensities are reported as variables for the state of conservation and an orange section, where instead are reported the actions and methodologies employed for the prevention. These variables are given a score related to the parameters entered in the questionnaire. The grey rows report the sums of the scores related to the two groups.

The final indices are obtained by multiplying or dividing the results of the sums together.

Index 1 quantifies the actions involved for damages prevention, without discriminating between the state of conservation and the methods used for prevention; the greater its value, the greater the importance of the entire hazard/prevention system. It can reach a maximum value of 272 and can be divided into three subgroups: up to 90 (*low*), from 91 to 180 (*medium*), from 181 to 272 (*high*).

Index 2 tells us how much the prevention/monitoring part used in the intervention is predominant over the damage. In this case, values below 1 have a positive meaning as they emphasize the importance of the methodologies used, while values greater than 1 could indicate insufficient preventive action.

Index 3 is the inverse of index 2. It gives more importance to the hazard/damage section.

Table 28 Descriptive table for results processing

VARIABLES	SCORE	BOD			EFth	EPhs	MELLOR		TROIA	
Hazard		**Rising humidity**	**Bio-degrade**	**Vibration**	**Salinization**	**Dry-heat/ waves**	**Freeze thaw 1**	**Freeze thaw 2**	**Bio-degradation**	**Tidal/wave action, weather station**
Simulation	***1***				1	1	1	1		
Real	***2***	2	2	2					2	2
Hazard Intensity										
Low	***1***									
Medium	***2***			2						
High	***3***	3	3							
Very high	***4***				4	4	4	4	4	4
Damage Intensity (1)										
1-3 forms	***1***						4	4	4	4
4-6 forms	***2***	6	6	4	8	8				
7-9 forms	***3***									
Sum 1		11	11	8	14	14	10	10	10	10
Investigation methods										
Off line (1* each)	***1***		1		4	1	2	2	1	1

Weather station	***2***	2	2	2	2		2	2	2	
Real time (2* each)	***2***	3		3	3	3				2
Parameter to investigate										
Parameters	***N°***	3	3	3	2	1	3	3	3	1
Actions										
Monitoring	***1***	1	1	1	1	1	1	1	1	1
Conservation/Restoration	***2***		2		2	2		2		
Innovation	***3***		3						3	3
Sum 2		9	12	9	14	8	8	10	10	8
(sum1*sum2)	**Index 1**	**99**	**165**	**72**	**195**	**104**	**72**	**90**	**100**	**100**
(sum1/sum2)	**Index 2**	**1,2**	**0,7**	**0,9**	**0,9**	**1,6**	**1,1**	**0,9**	**1,0**	**1,0**
(sum2/sum1)	**Index 3**	**0,8**	**1,4**	**1,1**	**1,2**	**0,6**	**0,9**	**1,1**	**1,0**	**1,0**
(1) n° degradations forms * hazard Intensity										

5.1.5 Results

Index 1 shows two values considered low: BoD vibration, Mellor freeze-thaw 1; six values are considered medium: BoD biodegrade and rising humidity, Ephesus, Tróia biodegradation and Tidal/wave action. Only Efareth shows a high value.

Index 2, related to the predominant prevention/monitoring part over the damage, reports values very close to 1 or equal to 1 for most pilot sites, indicating an equilibrium state. The sites with the most distant values (positive or negative) are BoD biodegrade and Ephesus. This is the same for index 3. In both cases, only Ephesus shows high disagreement values, giving more importance to the hazard/damage section.

The results obtained from the three indices allow us to quantify the value of the actions undertaken and underline in which area (state of conservation or methods used for prevention) enhance the actions of each individual pilot site, to obtain the maximum results. For example, in the case of Ephesus, it may be necessary to implement the diagnostic phase.

In accordance with the previously defined prevention processes, all the pilot sites have used monitoring both for the analysis of the hazard and for the regular maintenance of the cultural asset and for about 50% were carried out conservation/restoration interventions aimed at reducing the susceptibility to degradation. The low number of innovative materials/methods used in the prevention of slow hazard highlights the need to improve the quality of the system also through the use of STORM platform, where the great number of applications developed has made it possible to index and archive the data obtained from the different monitoring methods.

In conclusion, this section highlighted the complexity of the topic and the need to continue working to improve preventive conservation measures both through risk reduction strategies and the improvement of the methodologies used.

6 Pilot results evaluation

This chapter objective is to summarise the work done in view of achievement evaluation. To reach that objective the three main point of views addressed in the project: **Technologies, Services, Processes** have been analysed having clear the interdependencies of them.

The overall idea has been to design indicators able to evaluate each aspect Pilot partners have dealt with about the drills they have conducted during the project. The analysis based on this section is supported with quantitative and qualitative data gathered among the partners on each single pilot.

In particular, for the STORM evaluation a mixed methods approach has been followed. The mixed methods approach involves the use of both quantitative and qualitative methods in a single study; since each of these has its own strengths and limitations, combining them together to more fully answer complex research questions seems to be a good solution. The mixed methods are used more often than it appears, and that, where there is a trace of it, details on the processes and the methodology followed is often missing, as well as the conscious justification of theirs use. Beyond the theoretical-practical disquisitions, the introduction of mixed methods certainly represents a significant opportunity for reflection linked to the awareness of the methodological choice needed today more than ever to achieve quality results communicable and shareable.

The choice to use mixed methods can be justified by the need to advance confirmatory and exploratory hypotheses or questions, times respectively to demonstrate the theoretical link between different aspects of the same phenomenon and to explain the nature of the underlying process; secondly, there is a need to obtain better inferences by using different data sources to increase the validity of the data, or even the consideration of the opportunity to reach a higher level of understanding (insight) of phenomena, which may be lacking with the use of a single research method, also offering the possibility of designing a new phase in progress for further investigation of the phenomenon.

The STORM platform and all the associated technologies, services and processes add value on managing the three main phases related to the impact of climate change on cultural assets, covering a comprehensive approach with ex-ante planning and prevention, management and actions, and response activities, namely:

- Risk Assessment: identification, assessment and monitoring of disaster risks, improving prevention, preparedness and real-time monitoring;
- Situation Awareness: improving awareness and management of disasters;
- Quick Assessment: improving response and recovery activities. There is evidence to suggest that cultural heritage suffers not just from disasters but also from inadequate and uncoordinated post-disaster recovery efforts, inadequate response and contingency plans, and limited knowledge and capacity.

The STORM pilot sites have defined experimental scenarios and simulation activities with the aim to validate the project proposed solutions in relation to those phases. STORM introduces a comprehensive approach that supports end users with transversal services as data analytics and knowledge sharing during all these phases.

The three sections provide items closely tied to specific objectives and related project objectives in order to create a coherent and well-balanced questionnaire with proper links to the STORM proposal. All Pilot partners have had a tailored questionnaire where they have had to fill in some common items and then site-specific ones finalized to the in-depth analysis of their drills. For this reason, five questionnaires have been submitted to the five STORM pilot sites in order to collect each specific evaluation and analysis. It is thus possible to build a more complex overview and learn more about the consequences and reactions of sites subjected to stress due to damage caused by natural events. Actually, the different kind of natural hazards need a case-by-case analysis that can however provide a rich informative base useful for prevention and for first aid.

At the end, a harmonised evaluation going further the single pilot evaluation has been provided.

A brief summary and explanation of main **KPIs** used in the overall project achievements evaluation is the following:

- **Technologies**: The KPIs used to evaluate technologies are provided by technological experts and are focused on the specific technology that needs to be evaluated. They are pretty technological indicators defined following both a quantitative and qualitative approach.
- **Services**: Services' related KPI are specific outputs for the heritage site preservation and divulgation; they increase its degree of knowledge, the attention to a conservative scientific approach in the ordinary monitoring and management operations. They are represented by technical structural health monitoring bulletins, restoration and diagnostic reports.
- **Processes**: The processes related KPIs have a general return on the cultural heritage positive interactions with different stakeholders, from the civil society to the tourism subjects and heritage authorities. They consist of operational procedures for a safe usability of the heritage site, decision support tools for its own managing authority, as well as best-practice management handbooks for other heritage institutions.

In the following tables the three views are addressed against defined KPI, providing the single pilot evaluation and (under the KPI brief description) the overall score compared with target.

PILOT RESULTS EVALUATION INDICATORS

Technology Evaluation

The following table allows to evaluate the technologies tested in the STORM pilot sites according to some specific KPIs. The first column presents the specific technological macro-category, namely Real-time monitoring on-line sources and Surveying and diagnosis off-line sources, while in the second column the specific technology is reported along with the responsible. The technology is linked to the specific objective in the third column. The fourth column in turn links the specific objective in the general ones of the project in order to provide a clear and unambiguous reading for the drafting of the final report. The fifth column has to be completed by the partners indicating the means of verification through experiments. This latter can be identified in the number of integrated multidimensional tools, in the number of tested and validated methodologies and services, according to the type of technology and the specific objective or in general explaining how the specific technology has been implemented in the site. The sixth column provides the KPIs identified by each technological responsible. The last column gives the partners the possibility to add a comment and provide further information for the project evaluation.

Technolo	Specific	Obj	Related project Objs	Means of verification through experiments	KPIs	Evaluation
Real-time monitoring on-line	Fibre Bragg Grating	Data collecting and	OBJ1 – OBJ2	BOD: Installation of FBG sensors in Hall I and Michelangelo's Cloister. Data collection and analysis. Data sent to the platform.	Rationalise the conservation and restoration activities by evaluating the results of analysis of the insights from the item's material monitoring, also by giving an appropriate score to each material, depending on the risk vulnerability for each material and how it may affect the artefacts conservation. Analysis of the structural health of the site to address quick interventions and long-term conservation strategies.	BOD: Despite some problems have been encountered and solved, monitoring through FBG sensors proved to be efficient and useful in monitoring the chosen parameters, because of their minimal aesthetic impact and the possibility to collect data with a high acquisition frequency.
	Senso	Data	OBJ1 – OBJ2	BOD:	Rationalise the conservation and restoration activities by evaluating the results of analysis of the insights from the	BOD:

			Installation of sensors with Arduino controller. Data collection and analysis. Data sent to the platform.	item's material monitoring, also by giving an appropriate score to each material, depending on the risk vulnerability for each material and how it may affect the artefacts conservation. Analysis of the structural health of the site to address quick interventions and long-term conservation strategies.	Even if some problems have been encountered, they were solved and sensors with Arduino controller proved to be quite efficient in monitoring the chosen parameters, also being very cheap and easy to be installed.
			TROIA: Installation of three nodes in the Basilica with sensors providing real-time local data on temperature, relative humidity, light intensity, presence of water in the ground, rain, speed and wind direction.	Monitoring of local conditions in three sensitive points. Detection of abrupt changes in the humidity affecting the frescoes. Support to the automatic alarming, linked with the weather conditions.	**TROIA:** Despite the relatively short time of testing and some difficulties with the correct functioning of the anemometer, the sensors proved to be a cost-effective method for the monitoring of the environmental conditions of the wall paintings of the basilica.
Wireless Acoustic Sensor	The WASN was used in order to	OBJ1 – OBJ2	BOD: Detection of extreme weather events.	a) No. of redundant microphone sensors. b) No. of sound samples used for neural training. c) No. of wireless network protocols. d) No. of wired communications protocols. e) No. of data fusion techniques for classification. f) No. of sound samples collected and classified on the field.	BOD: **a)** 4 **b)** 11544 **c)** 6 **d)** 6 **e)** 8 **f)** 6649
			TROIA: Detection of extreme weather events and abnormal human behavior.		TROIA: **a)** 4 **b)** 11544 **c)** 6 **d)** 6 **e)** 8 **f)** 436
			MELLOR: Detection of abnormal human behaviour.		MELLOR: **a)** 4 **b)** 11544 **c)** 6 **d)** 6 **e)** 8 **f)** 164

Accelerometer	Data collecting and processing for threat identification	OBJ1 – OBJ2	EFARETH: Seismic model of the Lighthouse. Installation of two accelerographs at the foot and the top of the Lighthouse. The accelerographs of CMG-5TDE type with 3-components – force-feedback sensor system, digitizer of 24bit@200sps, GPS for internal clock synchronization, internal USB memory stick of 16Gb for local archiving of records. The two instruments were installed with the same orientation (N0°) and at almost the same vertical trace. Installation of one more instrument of the same type at guards office in the Eastern gate of Fortezza fortress as a reference site (geological conditions refer to hard rock).	Continuous monitoring of ambient noise and possible earthquakes during the 3 months of installation (since June 2017).	EFARETH: Continuous monitoring of ambient noise and possible earthquakes during the 3 months of installation. Numerical simulation with 3D finite elements (ABAQUS). The seismic model of the Lighthouse of the Venetian port is in progress by the NOA stakeholders of the pilot site of Rethymno. This model could be the reference point of the behaviour of the construction in earthquake events, so that EFARETH will be aware and prepared for any reinforcement of the structure or first aid actions.
			EPHESUS: 2 high cost (force balanced type and high precision accelerometers) and 2 low cost collocated accelerometers installed.		EPHESUS: Data provided by high cost accelerometers were used to calibrate the numerical model of the structure. The model was then used to estimate the response of the structure in future strong earthquakes.

Crack-meter	Data collecting and processing for threat identification	OBJ1 – OBJ2	EFARETH: Crack meters were installed at: Bastion of St. Paul, Bastion of St Elia, Bastion of St. Luke and Episcopal Mansion (Fortezza fortress). A statistical ARX model (Auto-Regressive model with eXogenous input) has been employed to analyse the influence of the environmental parameters. The successful application of the methodology at the four monitored cracks has provided important information about their state of damage, possible causes and early warnings in case of hazard.	Validation of the installed online sensors and evaluation of the data visualisation and situational monitoring services.	EFARETH: Over the evaluated period, it appears that the bastion of St. Elias is in a stable condition, while the bastion of St. Loukas and St. Paul are vulnerable to rainfalls. Moreover, the Episcopal Mansion showed a destabilization response during the rainfall period, which is possible to result in the activation of an overturning mechanism.
			EPHESUS: Mechanical crack meter. Real time measurements not applicable.		EPHESUS: No changes were observed in the installed crack meters
Environmental	Data collecting and	OBJ1 – OBJ2	BOD: An integrated solution: Environmental Sensor Network and Weather Station: • Two pre-assembled Plug & Sense based on WASPMOTE: Plug & Sense	Environmental data and damage correlation	BOD: The installed sensors have allowed to determine some climatic parameters such as humidity, temperature, rain and wind, the environmental parameters and atmospheric pollutants. The impact of atmospheric pollutants, which are the main cause of the deterioration of the surfaces of the buildings, depends on the type of

			Smart Agricolture PRO; Plug & Sense Smart Cities PRO • Three OEM-type WASPMOTE Libelium: Gases Sensor Node; Environmental Node; Acoustic Noise Node) • Router/Gateway MESHLIUM		material and the climatic factors. Analysing the relationship between the climatic parameters and environmental parameters it has been possible to determine how the climatic parameters influence the concentration of atmospheric pollutants in the air. Furthermore, some values such as acoustic noise and vibrations have allowed to assess how vehicle traffic influences the concentration of pollutants in the air. Moreover, a heterogeneous network able to detect different types of physical parameters has been effective as it has allowed to set alert thresholds and to implement rules for safeguarding the cultural heritage. The thresholds and rules have been relevant in order to face the action of atmospheric pollutants, due to the net loss of material, namely "erosion", which occurs especially in areas exposed to the rain, and "blackening", determined from the deposit of the carbonaceous particles on the surface of the monument and that occurs in the areas protected from the rain.
			MELLOR: 15 sensors installed across the archaeology (items) at the Mellor Vicarage sites (Area 1)		MELLOR: Data from the Environmental sensor network, despite some issues, proved vital to the site. It enabled the site to monitor in high resolution the temperature and humidity across the archaeology, both inside and outside of remains and items.
Weather Station	Data collecting	OBJ1 – OBJ2	BOD: An integrated solution: Environmental Sensor Network and Weather Station: • Two pre-assembled Plug & Sense based on	Environmental data and damage correlation	BOD: The installed sensors have allowed to determine some climatic parameters such as humidity, temperature, rain and wind, the environmental parameters and atmospheric pollutants. The impact of atmospheric pollutants, which are the main cause of the deterioration of the surfaces of the buildings, depends on the type of

WASPMOTE: Plug & Sense Smart Agricolture PRO; Plug & Sense Smart Cities PRO • Three OEM-type WASPMOTE Libelium: Gases Sensor Node; Environmental Node; Acoustic Noise Node) • Router/Gateway MESHLIUM		material and the climatic factors. Analysing the relationship between the climatic parameters and environmental parameters it has been possible to determine how the climatic parameters influence the concentration of atmospheric pollutants in the air. Furthermore, some values such as acoustic noise and vibrations have allowed to assess how vehicle traffic influences the concentration of pollutants in the air. Moreover, a heterogeneous network able to detect different types of physical parameters has been effective as it has allowed to set alert thresholds and to implement rules for safeguarding the cultural heritage. The thresholds and rules have been relevant in order to face the action of atmospheric pollutants, due to the net loss of material, namely "erosion", which occurs especially in areas exposed to the rain, and "blackening", determined from the deposit of the carbonaceous particles on the surface of the monument and that occurs in the areas protected from the rain.
TROIA: Weather station installed on a prominent point of the site monitoring the atmospheric conditions and sending real-time data to the platform.		TROIA: Very cost-effective solution to monitor the weather conditions, very effective and easy to maintain. Very good presentation of results and historical archive of data easy to consult. Support for the emission of alarms.
MELLOR: Three weather stations installed at each area of the pilot site. Necessary due to the unique micro-climatic conditions across the Mellor areas.		MELLOR: Data was easy to obtain and analyse both on and off-line. The 3g connection proved important as the Mellor site is unmanned and remote. The data was assessed in D9.2 and it was determined that the data was useful and comparable to the long-term climate data obtained from

			the UK met office, despite the inexpensive equipment used.
	EFARETH: Weather stations were installed at: • Counsellors building, Fortezza Fortress • Historical Centre of Rethymno: Arkadiou str. Ephorate of Antiquities of Rethymno. The raw data of the weather stations are being collected locally and simultaneously used in the crack meters monitoring methodology. Considering the fact that weather fluctuation has reversible effects at the structural integrity, it is of great importance to recognize the environmental and operational variation of the structure, and subsequently identify any separate structural change caused by damage. This has been achieved by employing a statistical ARX model (Auto-Regressive model with eXogenous input), calibrated for each case after several months.		EFARETH: Furthermore, the data are downloaded in graph forms and are assessed when necessary. They were used during February 2019 storms to view the rainwater precipitation in the area. The data were also sent to ZAMG to be interpreted. The use of weather stations is necessary for assessing the long-term hazards and the effects on the monuments of the site.

	Once this process has been completed it is possible to detect active damage on the examined structures and estimate possible causes for them.		
	EPHESUS: One DAVIS weather station installed in the site to measure humidity, wind speed, precipitation, temperature and UV. Real time data coming from these sensors.		EPHESUS: No direct damage correlation available but based on meteorological data provided by the meteorological station (2km to the site) our partner ZAMG was able to provide a site-specific value for prolonged dried periods for Ephesus site. This can be related to the damage in stone elements.

Surveying and diagnosis off-line sources	Induced Fluorescence spectroscopy – SFS sensors	Data collecting and processing for threat identification	OBJ2	TROIA: 1. Locally off-line stored raw data, representing SFSs (spectral fluorescence signatures) that are surfaces characterising the detected spectral density of the fluorescence emission as a function of the excitation and emission wavelengths. The data corresponds to periodic monthly measurements of induced biofilm fluorescence, from Aug-2017 to May-2019. 2. Evaluation reports provided to the STORM platform on the basis of recorded SFSs, characterising the biological infestation in terms of two parameters: M (0-4), the infestation magnitude and G (0-4) the infestation gravity.	1. Sensor portability and autonomy: weight of 6.6 kg, power consumption of ~30 W. 2. Low exploitation cost and eco friendliness: consumes only electric power [no reagents] and contains xenon lamp [not alkali metal or mercury vapour]. 3. Non-destructiveness and non-invasiveness: irradiation-pulse fluence of ~1 $\mu J/cm^2$, about 1000 times less than the safe threshold of ca. 1 mJ/cm^2. 4. Sensitivity: the sensor has demonstrated the ability of early detection of biological infestation, at the stage in which the biofilm is invisible to the naked eye.	TROIA: The induced fluorescence spectroscopy based on the pulsed lamp irradiation has proven to be an efficient innovative method, overpassing the traditional laser induced spectroscopy. The method versatility enabled the team to extend the technique to other applications, in particular: to the development and validation of bio-optical ecotoxicological tests in marine phototrophs and to the use of the induced fluorescence spectroscopy for phenotyping of higher plants.

Time-Lapse (4 – D) Electrical Resistivity Tomography - ERT	Data collecting and processing for threat identification	OBJ1 – OBJ2- OBJ3	EFARETH: Monitoring soil infill conditions and internal water flow on the fortification walls in order to define restoration – conservation actions where necessary and suggest preparedness actions to prevent potential collapse.	Resolution of the final images less than 0.3m	EFARETH: The 4-D ERT method was employed along individual lines, which were laid out in three different areas on the walls of Fortezza (Bastion of Saint Paul's, Louka's and Nicola's). The aim of the specific survey was to extract the stratigraphy of the sediments in the interior of the walls, to map the thickness of the walls, to locate sections of increased moisture and define paths of moisture flow though resistivity monitoring. The 2D and 4D ERT results were quite promising and fulfilled the initial expectations signifying the efficiency of the method in assessing the integrity of standing cultural monuments.

Ground Penetrating Radar - GPR	Data collecting and processing for threat identification	OBJ1 – OBJ2- OBJ3	BOD: Assess hidden structures and voids under the pavements in order to assess structural weaknesses to be compensated by provisional measures in the immediate aftermaths of an emergency so to prevent potential sudden collapse.	Resolution of the final images less than 0.1m	BOD: The test focused on the feasibility of using GPR in the course of the first phase of emergency management. Considering such point of view, the tool output still requires too specific expertise to be realistically available in that phase.
			EFARETH: Assess structural discontinuities like cracks and voids on the walls in order to define restoration – conservation actions where necessary and suggest preparedness actions to prevent potential collapse.		EFARETH: An important fact regarding GPR method is its site dependency, thus its performance can significantly vary from site to site, as well as the way that the data are collected, treated, processed and interpreted afterwards. The analysis of the GPR data revealed the wall thickness, the boundary between the two walls, as well as wall-air and wall-soil. No differences were observed to aid risk assessment, other than the higher water content. Overall, GPR can be employed as a complimentary method regarding risk assessment especially for monitoring historical buildings wall thickness.

Radar Interferometry -	Data collecting and	OBJ1 – OBJ2- OBJ3	BOD: Specific tests were carried out with the direct participation of several rescuers with different background. After the test those rescuers met to evaluate the feasibility of adopting such technology in the emergency management domain.	Rescuers feedbacks: 80% positive	BOD: The feedbacks were very positive under specific classes of scenarios. In particular, the technology was positively evaluated to measure the residual safety levels for rescuers soon after structural issues. The added value in protecting CH was considered as less interesting.
Terrestrial Laser Scanning - TLS	Data collecting and processing for threat identification and	OBJ1 – OBJ2- OBJ3	BOD: Numerous tests concerning TLS technology were carried out with the aim to evaluate the eventual added value when applied to emergencies impacting CH, with a specific focus on earthquakes.	Material degradation level: Overall accuracy of the detected changes in the range of 1-5cm	BOD: The tests successfully demonstrated that TLS can provide a clear added value to the emergency management when involving CH. Moreover, 3D point clouds collected for different reasons can find further use in this specific context for their value in documenting the status of the CH in a said time in the past, so as to allow for fast comparison of the newly collected point clouds vs. the previous ones.
			MELLOR: Monitor small (mm) changes to the items in Area 1 and Area 2.		MELLOR: The TLS, whilst being expensive to hire, provided the site with high detail data for assessing changes in volume to structures and items across the Mellor Mill and Old Vicarage area. Scans conducted every three months could be analysed to show changes over time and responses could be conducted to mitigate the damage.
			EFARETH: Assess and monitor the surface structural damages using comparative analysis to define preparedness actions to prevent		EFARETH: Laser scanning and photogrammetry are well-known and consolidated methods for the documentation of CH. The proposed approach demonstrates the possibility to use methods and procedures to obtain quantitative and

potential collapse and/or future damages		qualitative data of a given artefact. Such information, although still in need of manual (human driven) data analysis, can provide unique information for the state of monitored buildings and can as well strongly contribute to the identification of potential issues and relative solutions. In the specific case of monitored building of Fortezza Fortress, the TLS and photogrammetry approach was capable to identify point-cloud differences below one centimetre. Examples have been given also for the structural analysis of single point-cloud (numerical deformation of damaged wall surface) and for possible use of such dataset for other purpose (modelling for seismic analysis) or methods (calibration of geophysical measurements).
EPHESUS: The point cloud provided from laser scanning was used to develop the 3D model of the structure which was then used to develop the numerical model and estimate the response of the structure in future earthquakes.	Effectiveness in generating the 3D model	EPHESUS: The model was successfully generated and used in further simulations to estimate structural weaknesses of the wall.

Terrestrial Photogrammetry	Data collecting and processing for threat identification and damage	OBJ1 – OBJ2 – OBJ3	TROIA: Assessment and monitoring of two archaeological items through the comparison of six surveys during the period of three years to infer the decay rate and assess the needs of prevention and mitigation.	Structure damage and degradation level: overall accuracy of the detected changes in the range of 1-5cm	TROIA: Contrary to the perception of the site technicians, the two items monitored did not suffer major damage and did not lose any element or develop new cracks. Photogrammetry revealed to be a very accurate and useful monitoring method also ensuring digital conservation of archaeological structures seriously threatened by coastal erosion.
			MELLOR: Compare surveys to baseline, pre-storm, and multiple scans taken at 3-monthly intervals.		MELLOR: Scans could be analysed to study the volumetric and dimensional change to items and assets. As with TLS, but modern cameras provide less detail, but probably enough detail for this use case.
			EFARETH: Assess and monitor the surface structural damages using comparative analysis to define preparedness actions to prevent potential collapse and/or future damages.		EFARETH: As in TLS (see above).
Multispectral	Data collecting	OBJ1 – OBJ2 – OBJ3	MELLOR: Compare surveys to baseline, pre-storm, and multiple scans taken at 3-monthly intervals.	Structure damage and degradation level	MELLOR: As with Terrestrial Laser Scanning (see above).

	Reflectance	Data collecting and	OBJ1 – OBJ2 – OBJ3	MELLOR: Compare surveys multiple scans taken at 3-monthly intervals at Area 3 Shaw Cairn.	Vegetation density	MELLOR: NDVI has been very useful for monitoring minute changes to vegetation density that could not otherwise be detected using normal RGB photography. Ability to monitor and map underground archaeology was discovered.

The questionnaire filled in by the pilot site in the Technology section has reflected the specificity of the experiments and the specific needs of the pilot sites in order to analyse the evolution of damage in the archaeological site to achieve a better knowledge about innovative, cost-effective, non-invasive and non-destructive methods and processes, as well as applications for survey and diagnosis based on the study of materials properties, particular environmental conditions, and profile of the cultural assets.

Service Evaluation

The following table allows to evaluate the services tested in the STORM pilot sites according to some specific KPIs. The Service section is composed of both common and customized items per each Pilot partner and is the most detailed compared to the other two (Technology and Process) because of its intrinsic importance in the general objective of STORM to define and implement innovative supporting services for the mitigation of natural hazards and climate change, and the assessment/management of corresponding threats while minimizing their impact. The services that have been evaluated are the STORM Operative services, the STORM Collaborative services and . Each Pilot site has been observed in order to find peculiarities and useful records to be studied and adapted case-by-case. The STORM solutions have been defined in the context of a multidisciplinary team, in close cooperation with technical experts and cultural site managers, to go beyond the state of the art regarding the management of the impact of natural hazards on cultural sites. The analysis of the current practices and processes, as well as, a clear understanding of the user needs and the available technologies, have allowed the definition of a core of services, which has been evaluated in the STORM pilot sites.

Specifically, the first column presents the specific service that is linked to the objective reported in the second column. The third column in turn links the specific objective in the general ones of the project in order to provide a clear and unambiguous reading for the drafting of the final report. The fourth column has to be completed by the partners indicating the means of verification through experiments. This latter can be identified in the number of addressed mitigation/actions strategies manageable, in the number of compact/low-cost eco-friendly sensors introduced and tested, the number of sets available for stakeholders, the number of collaborative simulations activated, the number of simulations done, the number of tested and validated methodologies and services or any other means of verification filled in by the specific pilot sites. All Pilot partners are asked to fill and integrate the section “Means of verification through experiments” according to the information required and add comments to help assessing the effectiveness and details about each specific pilot. The fifth and the sixth columns provide respectively quantitative and qualitative data. In the fifth column partners are asked to self-evaluate their drill results according to a scale of values that includes four possible indicators ranging from 0 to 3. Each partner can assign a value that will result substantially in a positive or negative evaluation without the possibility of a median value. In this way it is possible to better define the evaluation indications and compare the results. According to the keys provided to the partners for the compiling, the indicators for *Degree of adaptation (DoA), Level of adherence to WP1 and WP5 guidelines and best practices (ADWP1WP5), Knowledge usability index (KUI)* and *Level of consolidation (LoC), Updated knowledge base topics (KBU)* correspond to the following evaluation values: 3 stands for very high; 2 stands for high; 1 stands for poor; 0 stands for none. For the sixth column indeed is referred to comments that contribute to add qualitative data and offer a broader range of information to be analysed in order to obtain an overall evaluation.

SERVICE	Objective	OBJ	Means of verification through experiments	KPIs	Evaluation
STORM Operative Services					
Risk Assessment & Management	Specific risk assessment and management procedures per each pilot site	OBJ2	BOD: Number of addressed mitigation/actions strategies manageable 2 (drill 1 and drill 2)	Degree of adaptation (DoA)	BOD: Proposed improvements: The risk assessment system is a well-done tool even if the data compilation is a bit long and complicated. It could be useful to simplify the compilation system avoiding always having to repeat all the fields for all the items in the same area. DoA=2.5
			TROIA: Number of addressed mitigation/actions strategies manageable		TROIA: Proposed improvements: The risk assessment tool was based on the work done in WP5. The formulas used to calculate it are not demonstrated in the dashboard, which can make it harder for

			2 (drill 1 and 2)		other sites outside the STORM project to comprehend. DoA=3
			MELLOR: Number of addressed mitigation/actions strategies manageable		MELLOR: Procedures are in place that were not in place prior to STORM. DoA=2
			EFARETH: Number of addressed mitigation/actions strategies manageable		EFARETH: Risk management in all drills was highly satisfactory. DoA=3
			EPHESUS: Number of addressed mitigation/actions strategies manageable		EPHESUS: Generation of the early warning signal is used to decrease the post disaster loss by reducing the emergency response time. Immediate action plans were suggested considering both operational and structural aspects of risk mitigation strategies. DoA=2.8
Quick Assessment Recommender	Effective recommendations identified	OBJ2	BOD: Number of addressed mitigation/actions strategies manageable	Level of adherence to WP1 and WP5 guidelines and best	BOD: The suggestions received were useful and helpful to diminish the time of response and to improve the effectiveness of the interventions ADWP1WP5=2.7
			TROIA:		TROIA:

			First preparation of strategies for specific emergencies		The suggestions received were useful and helpful to diminish the time of response and be better prepared. ADWP1WP5=3
			MELLOR: Number of addressed mitigation/actions strategies manageable		MELLOR: Recommendations are in place that were not in place prior to STORM. ADWP1WP5=2
			EFARETH: Number of addressed mitigation/actions strategies manageable		EFARETH: High adherence to guidelines and best practices. ADWP1WP5=3
			EPHESUS: Number of addressed mitigation/actions strategies manageable		EPHESUS: Mainly operational aspects of risk mitigation were considered. ADWP1WP5=3 Structural aspects of mitigation strategies such as strengthening and retrofit have not been considered in order not to go beyond the scope of the project. ADWP1WP5=1.92
Situation Awareness (including Risk Map)	Reliable and prompt situational picture	OBJ1	BOD: Number of data sets available for stakeholders (open data)	Knowledge usability index (KUI)	BOD: Information available on the the site is considered useful KUI=2.7

		TROIA: Number of data sets available for stakeholders (open data) Clear panorama of the situation of a site	TROIA: Very useful in the specific case of Tróia, as it is a site with a large extension and not many human resources. KUI=3
		MELLOR: Number of data sets available for stakeholders (open data)	MELLOR: Useful information is now available to the site that otherwise wouldn't be. KUI=3
		EFARETH: Number of data sets available for stakeholders (open data)	EFARETH: Risk and hazard maps were developed based on seismicity of the region based on a GIS system. KUI=3
		EPHESUS: Number of data sets available for stakeholders (open data)	EPHESUS: Risk and hazard maps were developed based on seismicity of the region based on a GIS system. Site specific hazard analysis was performed for a specific area, hence, there is not much spatial variations in the earthquake hazard in the GIS approach. KUI=2.4.

Sensory Map	Web-GIS representation of deployed sensors	OBJ4	BOD: Number of simulations done weekly	Knowledge usability index (KUI)	BOD; The Sensory Map is easy to consult but the way to reach to the online measurement of the sensors is not very friendly. KUI=2.6
			TROIA: Access to the data of the sensors online		TROIA: Location of sensors and their data can help to efficiently monitor weather conditions on site. KUI=3
			MELLOR: Number of simulations done		MELLOR: Tested app proves that data from data can be useful especially when comparing to ongoing event. KUI=3
			EFARETH: Number of simulations done		EFARETH: Sensory map has been developed. Limited applications due to small amount of sensors used due to cost. Very good representation of sensors. KUI=2
			EPHESUS: Number of simulations done		EPHESUS: Sensory map has been developed. Applications were limited by small number of sensors. KUI=2

Visual Analytics	Graphical representation of historical sensor data	OBJ4	BOD: Number of simulations done weekly	Knowledge usability index (KUI)	BOD: The historical data are not yet visible. Need to be improved. KUI=2.2
			TROIA: Allows consulting previous data in case of doubt		TROIA: It was used by several teams throughout the project to check for unusual situations. KUI=3
			MELLOR: Number of simulations done		MELLOR: Tested app proves that data from data can be useful especially when comparing to ongoing event. KUI=3
			EFARETH: Number of simulations done		EFARETH: In addition to the field applications computer simulations were also performed and data processing has been made on the measured data in order to obtain meaningful information. KUI=2

			EPHESUS: Number of simulations done		EPHESUS: In addition to the field applications computer simulations were also performed and data processing has been made on the measured data in order to obtain meaningful information. We have recorded more than 64 real evets during the course of the project. Many computer simulations were also done. KUI=3.
Survey Reporting	Consolidated conservation status	OBJ2	BOD: Number of tested and validated methodologies and services (once a week)	Level of consolidation (LOC)	BOD: helped deciding/or not intervention. LOC: 3
			TROIA: Number of tested and validated methodologies and services Yearly and monthly case studies were surveyed.		TROIA: Allowed accurate monitoring of the evolution on the state of conservation and helped deciding/or not intervention. LOC: 3
			MELLOR: Number of tested and validated methodologies and services		MELLOR: Performed well in first round in aiding the site manager to the correct location and event. LOC: 3

			EFARETH: Number of tested and validated methodologies and services		EFARETH: High quality outcomes. LOC: 3
			EPHESUS: Number of tested and validated methodologies and services		EPHESUS: Mainly it has been carried out by the site management. Partially involved in the system as part of the structural analysis. Damage state 2 (D2) corresponds to the damage state for conservation. LOC: 2.2
STORM Collaborative Services					
Collaborative and Knowledge Sharing	Reliable and shared knowledge base	OBJ6	BOD: Number of collaborative simulations activated	Updated knowledge base topics (KBU)	BOD: Data collected in the process mining service have been useful during the drill execution Knowledge base in terms of pictures collected in the platform has supported the team work KBU=3
			TROIA: Data accessible to different stakeholders.		TROIA: Organization of document library could be improved, but in general several teams were able to use the commonly shared information. KBU=3

			MELLOR: Number of collaborative simulations activated		MELLOR: Not tested in first round. During Second round: Using the collaborative aspect of the STORM service, detailed measured drawings could be passed between USAL and MAT and then onto the supplier of shoring material. Much quicker than previously would have been. KBU=3
			EFARETH: Number of collaborative simulations activated		EFARETH: Data collected in the process mining service have been useful during the drill execution Knowledge base in terms of pictures collected in the platform has supported the team work KBU=3
			EPHESUS: Number of collaborative simulations activated		EPHESUS: Data collected in the process mining service have been useful during the drill execution Knowledge base in terms of pictures collected in the platform has supported the team work KBU=3

Real time monitoring, Diagnosis and First Aid Services					
Explicit Mobile crowdsensing	Detection of subtle clues or early signs of threats and damages affecting a CH asset	OBJ2, OBJ4	BOD: First crowdsensing campaign was focused on getting feedbacks about the user experience of mobile app. Next campaigns were focused to verify context-specific content and cross-validation effectiveness.	Quantitative KPIs: DDR/ Participants Ratio > 5 Qualitative KPIs: Damage Detection Report (DDR) Accuracy Damage Detection Report (DDR)	BOD: Quantitative KPI BOD DDR/Participants = 5.28 Qualitative KPIs Damage Detection Report Accuracy is mainly dependant on how easy is to unambiguously recognize clues of the specific damages. Damage Detection Report Reliability is mainly dependant on user's skills/expertise. Feedbacks coming from pilot execution has helped to improve the app, fixing some requirements sometimes too restrictive (i.e. checking GPS coordinates) and suggesting a more complex asset model to improve accuracy.

			EFARETH: First crowdsensing campaign was focused on getting feedbacks about the user experience of mobile app. Next campaigns were focused to verify context-specific content and cross-validation effectiveness.	Reliability	EFARETH: Quantitative KPI EFARETH DDR/Participants = 5.28 Qualitative KPIs Damage Detection Report Accuracy is mainly dependant on how easy is to unambiguously recognize clues of the specific damages. Damage Detection Report Reliability is mainly dependant on user’s skills/expertise. Feedbacks coming from pilot execution has helped to improve the app, fixing some requirements sometimes too restrictive (i.e. checking GPS coordinates) and suggesting a more complex asset model to improve accuracy.

Social Crowdsensing	Detection of STORM events through the posting of a set of tweets simulating alerts about two situations in which strong wind causes structural failure (Test1) and a situation in which a fire event is caused by a thunder (Test2) at the Diocletian's Baths (all areas).	OBJ3	BOD: Two precise sets of tweets for simulating the dangerous situations have been defined ad-hoc for the two experimentations. The tweets have been posted from 2 different user profiles.	Specific KPIs: • Percentage of tweets retrieved • Percentage of correctly classified tweets • Percentage of recognised useful info	BOD: The tests performed demonstrated the ability of the TEE to detect the STORM events. Even if the number of recognized tweets compared to those sent by the users is less than 50%, the TEE detects the STORM events. • Percentage of tweets retrieved: Test1: 47.1% -Test2: 42.8% • Percentage of correctly classified tweets: Test1:100% - Test2: 100% • Percentage of recognised useful info: Test1:100% - Test2: 100% LOC: 2.5

Mobile Crowdsourcing	Mobile App to support users involved in QDA and FAID activities.		BOD, TROIA, MELLOR, EFARETH, EPHESUS: Quick Damage Assessment and FAID simulation on specific items. The mobile app supports team leaders in charge of specific FAID tasks during FAID execution, retrieving always updated, context-specific information needed to perform FAID in an effective way (Preparedness, Planned Actions, …) as well as providing to site manager updated information about the status of resources and items involved, storing images and video and a diary of all the action executed during FAID.	End users satisfaction level and usability index	BOD, TROIA, MELLOR, EFARETH, EPHESUS: Feedbacks coming from users during pilots executions helped to fix some bugs and some features (one of the most relevant was the assumption that an internet connection was continuously guaranteed, causing loss of data). The Mobile App was revised a couple of time, between pilot executions, in order to improve users experience, mainly during FAID operation.
Implicit Mobile Crowdsensing (gamification)	Using the STORM implicit crowdsensing application, volunteers and students from the University of West Attica collected and annotated images containing		TROIA: 1. The gamification mobile application was used 2. The gamification mobile application was tested by users 3. The game administrators designed different games	1. Score/Player ratio > 0.5 2. Number of users used the app > 30 3. Number of games >= 2	TROIA: 2. The total number of tester users was equal to 14 3. The number of designed games is equal to 3.

	at least one graffiti/tagging. The included images display structures, such as walls, pavements, benches and statues that are located in the municipality of Athens and its suburbs. The developed graffiti/tagging detector model was tested on 209 images displaying structures in the municipality of Athens and its suburbs.		MELLOR: 1. The gamification mobile application was used 2. The gamification mobile application was tested by users 3. The game administrators designed different games		MELLOR: Tested app proves that data from the app can be implicitly used to monitor footfall and erosion across the site. 1. The total number of users was equal to 6264/7700. 2. The total number of tester users was equal to 11. 3. The number of designed games is equal to 3.

For each service a detailed evaluation has been conducted. For the *Survey Reporting* service, each Pilot partner has been asked to refer to its consolidated conservation status and specify the number of tested and validated methodologies and services. It was needed in order to gather information about the current situation which is closely tied to the *Surveillance and monitoring*, on the one side, and to the *Collaborative and knowledge sharing* service, on the other side, aiming to provide a reliable and shared knowledge base to design and foresee also a risk map. The *Risk assessment and management tools* are crucial to identify specific procedures per each pilot site and analyse the degree of adaptation in each risk circumstance. These items become part of a common set of services that provides important data to draft an effective management procedure for specific risks. *Visual analytics* and *Sensory Map* are two services that allow representing historical sensor data and deployed sensors and have the aim of evaluating and consolidating the quality of the platform.

In addition, all Pilot site partners were asked to fill in some service evaluation referred of course to their specific experiment. For instance, the Real time monitoring, Diagnosis and First Aid Services evaluation has allowed to measure models to manage a situational picture based on the data/information collected from the field by physical and human sensors and evaluations.

Process Evaluation

The following table allows to evaluate the processes followed in the STORM pilot sites according to some specific KPIs. The Processes that have been evaluated are: Data Collection, Preparedness (including the use of thresholds, PRE-Forms), First Aid, On-Field First Aid, Debriefing and Update risk assessment. These processes have been followed using the *Process Mining Forms* and *STORM mobile application for First Aid*. Each Pilot site has been observed in order to find peculiarities and useful records to be studied and adapted case-by-case. The analysis of the current practices, as well as, a clear understanding of the user needs has allowed the definition of a set of processes, which have been evaluated in the STORM pilot sites.

Specifically, the first column presents the specific process that is linked to the objective reported in the second column. The third column in turn links the specific objective in the general ones of the project in order to provide a clear and unambiguous reading for the drafting of the final report. The fourth column has to be completed by the partners indicating the means of verification through experiments. This latter can be identified in the Number of collaborative simulations activated, Data uploading and updating performed, Number of integrated multi-dimensional tools, Thresholds defined based on national inputs, Number of cases addressed in the experiments, Performance of the implemented models for managing a situational picture, Number of compact/low cost eco-friendly sensors introduced and tested and other means according to the specific experience. All Pilot partners are asked to fill and integrate the section "Means of verification through experiments" according to the information required and add comments to help assessing the effectiveness and details about each specific pilot.

The fifth and the sixth columns provide respectively quantitative and qualitative data. In the fifth column partners are asked to self-evaluate their drill results according to a scale of values that includes four possible indicators ranging from 0 to 3. Each partner can assign a value that will result substantially in a positive or negative evaluation without the possibility of a median value. In this way it is possible to better define the evaluation indications and compare the results. According to the keys provided to the partners for the compiling, the indicators for *Knowledge usability index (KUI), Number of addressed mitigation/actions strategies manageable. (items*hazards) – NAS,* and *Number of cases addressed (sites + areas + items) and number of periodic updates (CN),* that correspond to the following evaluation values: 3 stands for very high; 2 stands for high; 1 stands for poor; 0 stands for none. The sixth column indeed is referred to comments that contribute to add qualitative data and offer a broader range of information to be analysed in order to obtain an overall evaluation.

PROCESS	Objective	OBJ	Means of verification through experiments	KPIs	Comments
Data collection	Reliable and shared knowledge available	OBJ6	BOD: Number of collaborative simulations activated	*Knowledge usability index (KUI)*	BOD: The collection of data done by archaeologist and restorers allowed to define and better understand the state of conservation of the Areas and the single Items. KUI=3
			TROIA: Number of collaborative simulations activated Data uploading and updating was performed		TROIA: The collection of data done by archaeologists and restorers allowed to define a better and common understanding of the state of conservation. KUI=2.5
			MELLOR: Number of collaborative simulations activated		MELLOR: Collection of data done by both MAT employees, experts from the university of Salford and other stakeholders. KUI=3
			EFARETH: Number of collaborative simulations activated		EFARETH: The collection of data done allowed to define a better and common understanding of the state of conservation. KUI=3
			EPHESUS:		EPHESUS:

			Number of collaborative simulations activated		QDA information became available. KUI=2.7
Preparedness (including the use of thresholds) **(PRE-Forms)**	Identification of main relevant parameters to monitor and esteem the related threshold values.	OBJ2	BOD: Number of integrated multi-dimensional tools	*Number of addressed mitigation/actions strategies manageable. (items*hazards) - NAS*	BOD: The compilation of the PRE-Form of the Areas and the individual Items led to a better understanding of the state of conservation and to identify possible equipment materials and methods to intervene both to mitigate the damage of a sudden hazard and to prevent a degradation due to the continuous action of the weathering or slow hazard. NAS:2.9
			TROIA: Thresholds defined based on national inputs		TROIA: Thresholds are not easily updated, but no necessity was found to do so. NAS:3
			MELLOR: Preparedness forms were filled in		MELLOR: Forms have some benefit, improvements should be made for second round. Second round highlighted the benefit to the site of the online forms. It helped the site manager better understand the state of the areas and items across the pilot site. NAS:2
			EFARETH: Preparedness forms were filled in with instructions-actions of interventions to be evaluated through Drill 1 and 2		EFARETH: The use of preparedness forms through the platform during the drills was proved highly useful.

					NAS:3
			EPHESUS: Number of integrated multi-dimensional tools		EPHESUS: Structure specific threshold values were successfully defined. NAS:2.5
First Aid	Provide professionals with sharp and sudden direction to react during emergencies.	OBJ2 – OBJ5 – OBJ6	BOD: Number of collaborative simulations activated Area: Garden of 500, 3 items 2 times (drill 1 and drill 2)	*Number of cases addressed (sites + areas + items) and number of periodic updates (CN)*	BOD: In case of First Aid, the platform and app are useful tool. It would be interesting to enrich them with more content and tools such as maps, photos, 3D relief, with the possibility of immediate consultation. CN=3
			TROIA: Number of collaborative simulations activated		TROIA: Excellent tool to help experts cope with situations. The App can help professionals and improve the participation of other people in First Aid response. CN=3
			MELLOR: Number of collaborative simulations activated		MELLOR: App clearly helps professionals and first responders to the item and area where an event is occurring and reduces the time they need to identify issues. The second-round drill involved a trained volunteer in using the app and being the “first responder”. Overall, he was impressed with the application and provided the following feedback: • Important that people who are likely to be using the app should have some time to practice with it before

experiencing it in a real life situation. It is intuitive but even 20 minutes practice would help.

• The reference image on the front page, though useful to have of course, took ages to download and needed to load every time you left the page and returned to it. It occurred to me that if the image size was smaller it would presumably load more quickly.

• The drop-down menu - to select the type of hazard - needs to be revised so that the options can be assimilated more quickly. So shorter 'snappier' entries. Otherwise too much to read!

• Photographs. Useful feature to have available to record key events, but the use of the camera is not as intuitive as it might be. It would ideally work like a smartphone camera and save all images automatically without the need for follow-up actions. This would be especially helpful in a fast-moving emergency when there would not be time to save each image separately. If this is not possible within the app, then the 'save' button in the top right hand corner needs to be much more obvious. Currently it is too small, and white letters on a black background - so not at all obvious as it merges with the image - so is not noticeable. Smartphone screen design would normally place this image in the centre of the image so that you can't move on to the next action without acting (so 'Save Image - Yes/No' placed centrally). If this is not possible then the Yes/No buttons need to be white with black lettering - and larger.

• The notes page was a really useful feature - where the detail of actions (or variations from pre-planned actions) can be recorded. Users should be encouraged

					to use this feature as fully as possible as I feel that it is in these notes that post-event analysis of actions will be reviewed. CN=3
			EFARETH: First aid actions were defined and were readily available during the drills		EFARETH: The first aid actions were adequate for the actors to effectively respond upon the emergency CN=3
			EPHESUS: Number of collaborative simulations activated		EPHESUS: Efficient response of rescue team was maintained based on near real time data. System developed only for a single item (structure) but can be extended upon request. CN=3
On field First Aid	Exhaustive measures identified	OBJ1 – OBJ5 - OBJ6	BOD: Number of cases addressed in the experiments DRILL 1, Area: Garden of 500, 3 items 2 times (drill 1 and drill 2)	*Number of cases addressed (sites + areas + items) and number of periodic updates (CN)*	*BOD:* *First Drill.* Measures suggested to first responder. Chosen method was selected with the help of on-site restorers CN=3
			TROIA: Number of cases addressed in the experiments		TROIA: Item RRT-03 and BAS-m were easily located by teams on drills. CN=3

			Useful to help locate hazardous areas to those less acquainted with the site		
			MELLOR: Number of cases addressed in the experiments		MELLOR: Second drill: multiple measures suggested to first responder. Chosen method was selected with the help of on-site archaeologists. CN=2.5
			EFARETH: Number of cases addressed in the experiments The drills were prepared in a way to involve actors from a range of scientific disciplines and expertise as well as local authorities		EFARETH: Excellent performance by all involved actors CN=3
			EPHESUS: Number of cases addressed in the experiments		EPHESUS: Humans and artefacts were saved properly by a good coordination between the SAR group and site responsible. CN=1.8. Limited number of items (only the wall and stones) were considered.
Debriefing	Exhaustive measures identified	OBJ3	BOD: After drills there were meetings to discuss measures and procedures that took place. Number of compact/low cost eco-friendly sensors introduced and tested	*Number of cases addressed (sites + areas + items) and*	BOD: CN=2.8

		TROIA: After drills there were meetings to discuss measures and procedures that took place.	TROIA: The conclusions on the drills help improving for further work. CN=3
		MELLOR: After drills there were meetings to discuss measures and procedures that took place.	MELLOR: Debriefing involving stakeholders, local councils, planning services, and archaeologists conducted after each exercise. Such debriefs were not conducted prior to the introduction of STORM. CN=3
		EFARETH: Debriefings were carried out after the drills with the involved actors in order to discuss the actions and evaluate the effectiveness.	EFARETH: The debriefings were extremely valuable and successful. The involved actors provided their evaluation from their own expertise. CN=3
		EPHESUS: After drills there were meetings to discuss measures and procedures that took place.	EPHESUS: Useful debriefing. CN=2.7.

Update risk assessment	Identify priority related to specific hazard	OBJ4	BOD: Performance of the implemented models for managing a situational picture	*Number of cases addressed (sites + areas + items) and number of periodic updates (CN)*	BOD: CN=2.9
			TROIA: Prioritized database of items		TROIA: Easy to update status of conservation work. CN=3
			MELLOR: Prioritization of areas and items, as well as risks.		MELLOR: App clearly helps professionals and first responders to the item and area where an event is occurring and reduces the time they need to prioritise issues. CN=3
			EFARETH: Prioritization of areas and items, as well as risks.		EFARETH: The application enables the update of risk assessment and provides the means for prioritization. CN=3
			EPHESUS: Number of compact/low cost eco-friendly sensors introduced and tested		EPHESUS: Priority is to maintain the structural stability during an earthquake. CN=2.8

The collection of data done by archaeologist and restorers allowed defining and better understand the state of conservation of the Areas and the single Items. In most of the pilot sites, data collection made reliable and shared information available with a high knowledge usability index rated 3. The identification of main relevant parameters to monitor and esteem the related threshold values was successfully defined (being rated 3) and efficient response of rescue team was maintained based on near real time data. The compilation of the PRE-Form of the Areas and the individual Items led to a better understanding of the state of conservation and to identify possible equipment materials and methods to intervene both to mitigate the damage of a sudden hazard and to prevent a degradation due to the continuous action of the weathering or slow hazard. In case of First Aid the platform could be a useful tool although it would be necessary to have more tools available such as maps, photos, 3D relief, with the possibility of immediate consultation.

Starting from macro processes defined in D9.1 chap. 1.4, here the aim is to go deeper focusing on specific processes that have been evaluated through results of exercises according to main KPI introduced in D9.1 and further ones that have been considered useful during the exercise preparation.

Coming from D9.1 here means of verification against project objectives are provided:

STORM OBJECTIVE	STORM SERVICES & SOLUTIONS	MEANS OF VERIFICATION THROUGH EXPERIMENTS	PILOT SITES INVOLVED
OBJ1: Select, evolve and integrate innovative environment assessment methodologies and services to effectively and accurately process, analyse and map environmental changes and/or natural hazards.	Ground-based sensors and non-destructive technologies for micro-climate, vibrational (anthropic urban and natural seismic activity) and 3D and multispectral imaging analysis of archaeological areas and structures.	Number of data sets available for stakeholders (open data). Number of tested and validated methodologies and services.	MELLOR, TROIA, RETHYMNO, EPHESUS, BOD
OBJ2: Define and implement an innovative methodology and a supporting service for the mitigation of natural hazards and climate change, and the assessment and management of corresponding threats while minimizing their impact.	Environmental data analysis with statistical approach. Identification of main relevant parameters to monitor and esteem the related threshold values. Editing of intervention schedules and prevention programmatic actions.	Number of addressed mitigation/actions strategies manageable. Number of integrated multi-dimensional tools.	MELLOR, TROIA, RETHYMNO, EPHESUS, BOD

OBJ3: Provide innovative, cost-effective, non-invasive and non-destructive methods and processes, as well as applications for survey and diagnosis based on the study of materials properties, particular environmental conditions, and profile of the cultural assets to be assessed.	Analysis procedures based on diagnostic campaign on archaeological structures. Development of scientific datasets reporting mechanical and physical features of materials and their main vulnerability aspects.	Number of compact/low cost eco-friendly sensors introduced and tested.	MELLOR, TROIA, RETHYMNO, EPHESUS, BOD
OBJ4: Define and implement models and services for generating and managing a situational picture based on the data/information collected from the field by physical and human sensors and evaluations (crowdsensing).	Evaluation of simulation tools open to multi-source integrations for a knowledge-based understanding of heritage materials behaviour in realistic risk scenarios.	Number of simulations done. Performance of the implemented models for managing a situational picture.	MELLOR, TROIA, RETHYMNO, BOD
OBJ5: Provide innovative methodologies, practices and software tools for a more reliable maintenance, quick restoration and long-term conservation of the Cultural Heritage assets, preserving their historic and cultural integrity.	Development of technical protocols to draft and enhance scientific conservative and emergency procedure.	Number of cases addressed in the experiments.	MELLOR, TROIA, RETHYMNO, EPHESUS, BOD

OBJ6: Define a collaboration and knowledge-sharing framework for the community of stakeholders to co-create, share and maintain improved practices, knowledge and experience on cost-effective and eco-innovative solutions for sustainable management and conservation of Cultural Heritage in Europe.	Periodic meetings of scientific experts and stakeholders to present achievements and encourage cooperation agreements to test upgraded solutions in site management and promote new aware fruition models of cultural heritage.	Number of collaborative simulations activated.	MELLOR, TROIA, RETHYMNO, EPHESUS, BOD
OBJ 7: Propose adaptations, changes in existing policies and validation of new knowledge in government processes.	Interaction and communication actions to involve authorities and end users in the writing of open-access documents for common preservation tasks.	Number of new suggested policies as result of the experimental scenarios.	MELLOR, TROIA, RETHYMNO, EPHESUS, BOD
OBJ 8: Cost analysis for the sites protection against natural hazards managed by the STORM data analytics tools.	Technical bulletins for transparent divulgation of project efforts.	Number of available open data set related to protection costs. Number of improved (in terms of cost efficiency) processes.	MELLOR, TROIA, RETHYMNO, EPHESUS, BOD

7 Overall lessons learnt

After three years of research is the time to sum up and analyse what has been learned, not only by the experiments carried out in the field, but also thanks to the continuous and constant confrontation between each team partner of the Project, who were able to make available to the others their knowledge and skills, dictated both by work experience and by the situation in the country were they are living.

Surely the lessons learned are various and are easily extrapolated after reading this document.

First of all we had the chance to learn the importance of the technical components and of the correct use of any developed technology; we also learned how technologies, that until now were used in other situations, with some modifications and updates, can also be applied for monitoring or protection of cultural heritage.

It was then possible to analyse the costs of each activity carried out, both before and during the project, in order to have a deeper knowledge of the methodologies to keep costs under control even when a Cultural Site needs to face emergencies; this is certainly possible thanks to an adequate planning of the long term interventions to be carried out in order to mitigate not only the damage to the cultural assets, but also the costs to face them.

Thanks to the organization of the 10 drills for sudden hazards it was possible to experience how the preparedness can be useful for an adequate and effective emergency intervention. In these situations, the platform proved to be very useful, allowing the professional figures dealing with the emergency to have all the necessary information real-time, thanks to all the documentation and data entry work done by the pilot sites to test the platform in real environments with real data. On the occasion of these activities it was also possible to notice how, reusing and adapting some materials which are already present in situ, it is possible to mitigate damage in emergency situations while decreasing the interventions costs.

During the experimental campaign it was also demonstrated and confirmed how a good and well-planned prevention is important for the optimal conservation of CH, experimenting new methodologies and treatments, extremely low cost and eco-compatible, which can be effective for slow hazard management.

All these lessons learnt were the basis of the STORM training courses held, in January and February[30], within the Storm Academy (described in D10.7) which was an excellent tool to disseminate and publicize the STORM Approach.

[30] The STORM Academy took place in ISA (Istituto Superiore Antincendi) and TUSCIA University, on the 24th, 25th, 28th, 29th of January and 7th, 8th, 11th, 12th, 21st, 22nd, 25th, 26th of February

8 Conclusions

The deliverable, as a conclusion of the evaluation process of the STORM Project started in D9.1, has reported the evaluation of all what has been experimented and developed in the three years of research, showing all the lessons learnt. Starting from the objectives used together with the KPIs, the main aim has been to evaluate the technologies provided in STORM, but also all the services developed, and the efficiency of the STORM approach tested during the drills organised in each Pilot Site, in order to prove the efficacy of the innovations developed within the Project. Each Chapter has had the aim of describing, assessing and evaluating the technologies and services developed and the activities carried out in the fields of action of STORM during the experimental campaigns in the five pilot sites.

In particular, *Chapter 2* has been dedicated to the technologies developed and experimented. Specifically, this chapter has provided an evaluation of non-invasive and non-destructive methods of surveying and diagnosis based on the feedback from experimentation, justifying the achievement of the target TRLs (Technology Readiness Levels) for the key technologies. The *on-line* and *off-line* methods of surveying, diagnosis and monitoring have been analysed for each site. Moreover, a technology evaluation to the explicit and implicit crowdsensing methods based on the advanced information processing has been conducted and the achieved readiness levels of the key technologies have been discussed.

In *Chapter 3* the cost effectiveness methodology has been analysed. In particular, the main objective behind the CEA developed in STORM is to support decision making in the Conservation of cultural assets. The steps for the application of the STORM CEA to risk treatment options targeting the preservation of archaeological structures have been described. The STORM CEA application for the Tróia site, where CEA was used to support the planning of experimental campaigns carried out concerning Prevention and Preparedness measures has been presented in order to show the CEA usefulness.

In *Chapter 4 and 5* practical experimental activities organized in the five Pilot Sites have been described and evaluated; in particular in *Chapter 4* drills were evaluated in order to test the efficacy of the activities performed during the ten drills and the technologies developed in the STORM research, in terms of adherence to some requirements defined in D1.4, while in *Chapter 5* prevention/slow hazard activities were evaluated in terms of efficacy, eco-compatibility and potential for risk reducing.

Finally, *Chapter 6* has provided a detailed evaluation of the STORM Technologies, Services and Processes tested in the pilot sites, offering an overall vision of the whole work done. The overall idea has been to design indicators able to evaluate each aspect Pilot partners have dealt with about the drills they have conducted during the project. The analysis has been supported with quantitative and qualitative data gathered among the partners on each single pilot and using specific KPI. All Pilot partners have had a tailored questionnaire where they have had to fill in some common items and then site-specific ones finalized to the in-depth analysis of their drills. At the end, a harmonised evaluation going further the single pilot evaluation has been provided.

The Project has proved to have achieved the TRL’s levels that were expected.

9 Appendices: CEA supporting tables

9.1 Appendix 1: Parameters and rating guidelines for Conservation effectiveness assessments

Analytical parameter	Rating guidelines [1-10]
M: Material non-harmfulness (short and long run)	
Physical-chemical aggressiveness	10: similar and/or low-aggressiveness products/methods 5: moderately aggressive products/ methods 1: aggressive/very dissimilar products/methods
I: Immaterial non-harmfulness (short and long run)	
Significance level: maintained/enhanced – reduced Perceptiveness of shape or function: maintained/enhanced – reduced Type of approach: preventive; curative; reconstruction Compliance with conservation guidelines Visibility of interferences or disturbances to fruition Percentage of original material remaining	10: actions do not harm or interfere with cultural fruition/ do not reduce the site's values/ do not imply the removal of any original material/ are fully reversible; 5: actions partially prevent the fruition and/or research of the site/ require/cause the loss of some values, original material or information/ are partially reversible/removable; 1: actions strongly interfere with the significance, integrity or fruition of the site/ require/cause the loss of original material/ are fully irreversible
O: Operator skills	
Training of involved operators/professionals in the concerned specialities	10: Team members with specific training and experience 5: Some team members without specific training or experience 1: No team members with specific training and experience
If pertinent for the site[31] – E: Environmental impact (eco-compatibility)	
Product origin (local production, etc); residue collection and disposal Toxicity (to humans or environment)	10: materials whole or partly sourced locally/ produced on the site; skilled operators available in the region; non-toxic products, e.g. essential oil-based biocides or consolidation via biomineralisation 1: using only imported products; very toxic products used, e.g. strong acids or solvents.
Confidence level (Uncertainty)	Estimated uncertainty of the rating, calculated as the standard deviation to the average rating values.

[31] Given that the issue of environmental sustainability is of fundamental importance across all activity sectors worldwide, a few parameters are suggested here for its appraisal in what pertains to conservation interventions. It should be noted, however, that these were not included in the effectiveness assessment because environmental sustainability is not considered a priority when making conservation decisions – heritage significance is the first and foremost priority. Accordingly, an environmental sustainability evaluation should only be considered when two equally compatible conservation solutions are possible, but one is eco-friendlier than the other.

9.2 Appendix 2: CEA at the Roman Ruins of Tróia

9.2.1 CEA x Prevention – Workshops 21-23

9.2.1.1 Cost analysis – Monitoring

	Photogrammetry	Costs				(Future)	
		un.	quantity	unit price	total (€)	repet/y	total (€)
Photogrammetry	**Initial Investment costs**						
	Human Resources						
	2 archaeologists 1 computer expert	lump	1	1 000,00	1 000,00		
	Equipment/Products						
	Camera; PC; software	lump	1	7 101,16			
	Total initial costs (€)				**8 101,16**		
	Future costs						
	Yearly surveys						
	2 archaeologists 1 computer expert	lump	1	1 000,00	1 000,00		
	Yearly costs						1 000,00
	Total future costs – discounted to 2019						**17 292,03 €**
	Total costs (initial + future discounted)				**25 393,19 €**		

	Beach sections (topographic analysis)	Costs				Future	
		un.	quantity	unit price	total (€)	repet/y	total (€)
Beach sections	**Initial Investment costs**						
	Service						
	1 topographer + 1 expert Equipment	lump	1	7 791,00	7 791,00		
	Total initial costs (€)				**7 791,00**		
	Future costs						
	Survey contracted every 5 years	lump	1	7,791.00	7,791.00	0,2	1 558,20 €
	Yearly totals (€)						1 558,20 €
	Total future costs – discounted to 2019						**26 944,45 €**
Total costs (initial + future discounted)					**34 735,45 €**		

Laser scanning		Costs				(Future)	
		un.	quantity	unit price	total (€)	repet/y	total (€)
Laser scanning	Initial Investment costs						
	Service					-	-
	2 technicians + equipment	lump	1	10 000,00	10 000,00	-	-
	Total initial costs (€)				10,000.00		
	Future costs						
	Survey contracted every 5 years	lump	1	10 000,00	10 000,00	0,2	2 000,00 €
	Yearly totals (€)						2 000,00 €
	Total future costs – discounted to 2019						34 584,07 €
Total costs (initial + future discounted)					44 584,07 €		

9.2.1.2 Effectiveness analysis – Monitoring

Parameter	Indicators	Assessment					Uncertainty
		Exp. 1	Exp. 2	Exp. 3	Exp. 4	Average	Std.dev.
Photogrammetry							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	9	9	9,5	0,5774
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	10	10	10	10	10	0
Operator skills	Training and experience of the involved operators/ professionals.	8	7	7	7	7,25	0,5
Average values						**8,9167**	**0,3591**
Total Effectiveness		**8,92 (+/- 0,3591)**					
Beach sections (topographic analysis)							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	10	10	10	0
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	0	0	3	2	1,25	1,5
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
Average values						**7,08(3)**	**0,5000**
Total Effectiveness		**7,08 (+/- 0,5000)**					
Laser scanning							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	10	10	10	0
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	10	10	6	7	8,25	2,0616
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
Average values						**9.41(6)**	**0,6872**

Total Effectiveness	**9,41 (+/- 0,6872)**

Comments

Environmental compatibility was considered not applicable to this particular action, since no particular disturbance of the environment is expected from the listed monitoring options. In terms of human resources, it is assumed that, for the subcontracting options, Troiaresort would hire duly trained professionals for the tasks, and therefore a value of 10 was assigned to this parameter for all options entailing subcontracting.

Unlike the other options, photogrammetry would be (and, in fact, is) executed by the site staff, in collaboration with photogrammetry consultants; seeing as the site staff experience is lower than average – albeit it is of course expected to rise in upcoming years – their operational skills were ranked slightly below. In terms of immaterial compatibility with the archaeological structures, the following aspects were generally highlighted by the reviewers:

- photogrammetry once a year allows for a more in-depth monitoring of the structures;

- beach section analysis do not allow for the clear monitoring of structures;

- laser scanning once every five years allows for a detailed monitoring of the structures, but the frequency is considered too low.

9.2.1.3 Cost analysis – Hazard impact management

	Geobags	**Costs**				**(Future)**	
		un.	quantity	unit price	total (€)	repet/y	total (€)
Geobags	**Initial Investment costs**						
	Planning and documentation						
	HR senior technician	h	33,75	13,00 €	438,75 €		
	HR team leader	h	27	7,00 €	189,00 €		
	Vehicles	km	200	0,18 €	36,00 €		
	Infrastructures & logistics						
	Vehicles	km	900	0,18 €	162,00 €		
	Heavy machinery	h	9	60,00 €	540,00 €		
	Transport truck	km	300	0,90 €	270,00 €		
	Module barrier construction						
	HR senior technician	h	63	13,00 €	819,00 €		
	HR team leader	h	42	7,00 €	294,00 €		
	HR technician	h	126	6,00 €	756,00 €		
	Geobags	bag	450	12,00 €	5 400,00 €		

	Reinf. metal fence	m	30	3,70 €	111,00 €		
	Geotextile	m	30	10,00 €	300,00 €		
	Total initial costs (€)				**9 315,75 €**		
	Future costs						
	Maintenance						
	Vehicles	km	100	0,18 €	18,00 €	every 5 years = 0.2	3,60 €
	HR – senior technician	h	18	13.00	104.00	every 5 years = 0.2	20,8 €
	Barrier replacement	lump	1	8 983,88 €	8 983,88 €	every 12 years = 0.08(3)	748,66 €
	Yearly costs						773,06 €
	Total future costs – discounted to 2019						**13 367,71 €**
	Total costs (initial + future discounted)				**22 683,46 €**		
	Beach renourishment/ reburial of structures	**Costs**				**Future**	
		un.	quantity	unit price	total (€)	repet/y	total (€)
Beach renourishment	**Initial Investment costs**						
	Planning and documentation	lump	1	15 354,00	15 354,00		
	Assessment work (beach section, sand quality and deposition)	lump	1	7 791,00	7 791,00		
	Beach renourishment						
	Workshop 21	m3	3120	16,50	51 404,00		
	Workshop 22	m3	2520	17,00	42 295,00		
	Workshop 23	m3	4320	16,00	68 036,00		
	Total initial costs (€)				**177 089,00 €**		
	Future costs						
	Photogrammetric survey	lump	1	1000	1000	1	1000
	Maintenance (half volume)						
	Workshop 21	m3	1560	16,50	25740	0,2	5140
	Workshop 22	m3	1260	17,00	21420	0,2	4284

Workshop 23	m3	2160	16,00	34560	0,2	6912
Yearly totals (€)						17,344.00
Total future costs – discounted to 2019						**299,913.03**
Total costs (initial + future discounted)				**477 002,03 €**		

Reef balls	Costs				(Future)	
	un.	quantity	unit price	total (€)	repet/y	total (€)
Initial Investment costs						
Pre / Post deployment survey	day	3	500,00	1500	-	-
Delivery	mile	4000	1,33	5320	-	-
Deployment and loading	lump	1	24 053,00	24053	-	-
Workshops 21-23	m	300	331,61	99 483,00	-	-
Total initial costs (€)			**130 356,00 €**			
Future costs						
Monitoring						
Bottom survey after 5 years	days	90	442,15	39,793.5	0	39793.5
Yearly totals (€)						-
Total future costs – discounted to 2019						**32 707,36 €**
Total costs (initial + future discounted)				**210 356,00 €**		

9.2.1.4 *Effectiveness analysis – Hazard impact management*

Parameter	Indicators	Assessment					Uncertainty
		Exp. 1	Exp. 2	Exp. 3	Exp. 4	Average	Std.dev.
Geobags barrier							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	7	8	7	8	7.5	0.5774
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	5	6	5	6	5.5	0.5774
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0

Parameter	Indicators	Assessment					Uncertainty
		Exp. 1	Exp. 2	Exp. 3	Exp. 4	Average	Std.dev.
(If pertinent) Environmental impact	- Product origin and disposal - Eco-compatibility: toxicity to humans or environment.	6	6	6	6	6	0
Average values						**7.25**	0.2887
Total Effectiveness		**7.25 (+/-0.2887)**					
Beach re-nourishment / reburying of the stone structures							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	9	10	9	10	9.5	0.5776
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	5	4	5	6	5	0.8165
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
(If pertinent) Environmental impact	- Product origin and disposal - Eco-compatibility: toxicity to humans or environment.	8	9	9	10	9	0.8165
Average values						**8.1667**	0.4646
Total Effectiveness		**8.17 (+/- 0.4647)**					
Installation of reef balls							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	9	10	8	10	9.25	0.9574
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	10	10	10	10	10	0
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
(If pertinent) Environmental impact	- Product origin and disposal - Eco-compatibility: toxicity to humans or environment.	8	9	9	9	8.75	0.5000
Average values						**9.75**	0.3191

Parameter	Indicators	Assessment					Uncertainty
		Exp. 1	Exp. 2	Exp. 3	Exp. 4	Average	Std.dev.
Total Effectiveness		**9.75 (+/- 0.3191)**					

Comments

The ‘Environmental impact’ was considered important as an effectiveness evaluator due to the fact that the Roman Ruins are located in a Natura 2000 Network site, meaning it is a protected landscape area.

The ‘Operator skills’ were assessed considering that professionals with adequate training would be hired to do the jobs, as it has been a longstanding tradition of the company managing the Roman Ruins.

The ‘Beach renourishment’ strategy was generally rated as poor in terms of immaterial non-harmfulness because, in practice, the amount of sand required entails the reburial of the structures, essentially impairing the fruition of the shoreline structures.

The ‘Geobags barrier’ was considered as slightly harmful in terms of materials, because of its relative proximity to the structures; and, for the same reason, immaterial non-harmfulness was considered even lower, since the barrier would disturb the natural setting, especially in the low tides.

The ‘Reef balls’ option was by far the preferred one, with high material and immaterial non-harmfulness: if chosen, the reef would not directly interfere – neither visually nor physically – with the archaeological structures. It is also a solution designed to be environmentally friendly, albeit the experts considered that the deployment could bring a slight environmental impact.

9.2.2 CEA x Prevention – Basilica frescoes

9.2.2.1 Cost analysis – Biocolonisation monitoring

	SFS spectroscopy	Costs				(Future)	
		un.	quantity	unit price	total (€)	repet/y	total (€)
SFS spectroscopy	**Initial Investment costs**						
	Service subcontracting						
	SFS spectroscopy analysis	days	4	530,00	2120,00		
	Total initial costs (€)				**2120,00**		
	Future costs						
	Regular survey						
	SFS spectroscopy analysis	days	1	530,00	530,00	4	2120,00
	Yearly costs						2120,00
	Total future costs – discounted to 2019						**36 659,11 €**

	Total costs (initial + future discounted)	**38 779,11 €**

		Costs				Future	
		un.	quantity	unit price	total (€)	repet/y	total (€)
Visual inspection	**Initial Investment costs**						
	Service subcontracting						
	Visual inspection by a conservator-restorer	days	2	250,00	500,00		
	Total initial costs (€)				**500,00**		
	Future costs						
	Yearly survey						
	Visual inspection by a conservator-restorer	lump	1	250,00	250,00	2	500,00
	Yearly totals (€)						500,00
	Total future costs – discounted to 2019						**8 646,02 €**
	Total costs (initial + future discounted)				**9 146,02 €**		

9.2.2.2 *Effectiveness analysis – Biocolonisation monitoring*

Parameter	Indicators	Assessment					Uncertainty
		Expert 1	Expert 2	Expert 3	Expert 4	Average	Std.dev.
SFS sensor							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	9	8	8	9	8,5	0,5774
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	10	10	10	9	9,75	0,5
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
Average values						**9,4167**	0,3591
Total Effectiveness (averaged averages)		**9,42** (+/- 0,3591)					
Visual observation							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	10	10	10	0

Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	6	7	7	7	6,75	0,5
Operator skills	Training and experience of the involved operators/ professionals.	10	9	9	10	9,5	0,5774
Average values						**8,75**	0,3591
Total Effectiveness (averaged averages)		**8,75** (+/- 0,3591)					

Comments

The SFS sensor allows a much earlier detection of the biocolonisation, allowing timely – neither excessive nor insufficient – biocidal treatments. Visual inspections, on the other hand, will only detect the presence of microorganisms when they are developed enough to be visible, and therefore biocidal treatments become remedial rather than preventive.

9.2.3 CEA x Preparedness – Workshop 21: wall with window

9.2.3.1 Cost analysis – Stabilisation of immovable elements

Stabilisation of immovable elements		Costs			
		un.	quantity	unit price	total (€)
Geobags barrier	**Planning and documentation**				
	Vehicles	km	200	0,18 €	36,00 €
	Human resources - senior technician	hour	15	13,00 €	195,00 €
	Human resources - team leader	hour	12	7,00 €	84,00 €
	Module barrier construction				
	Vehicles	km	300	0,18 €	54,00 €
	Heavy machinery	hour	3	60,00 €	180,00 €
	Transport truck	km	100	0,90 €	90,00 €
	Human resources - senior technician	hour	21	13,00 €	273,00 €
	Human resources - team leader	hour	14	7,00 €	98,00 €
	Human resources - technician	hour	42	6,00 €	252,00 €
	Materials – geobags	unit	150	12,00 €	1800,00 €
	Materials – reinforcement metal fence	m	10	3,70 €	37,00 €
	Materials – geotextile blanket	m	10	10,00 €	100,00 €
	Materials – others	lump	1	30,00 €	30,00 €
	Total costs (€)				**3229,00 €**
Jute/ raffi	**Planning and documentation**				
	Vehicles	km	200	0,18 €	36,00 €

Human resources - senior technician	hour	15	13,00 €	195,00 €
Human resources - team leader	hour	12	7,00 €	84,00 €
Module barrier construction				
Vehicles	km	300	0,18 €	54,00 €
Heavy machinery	hour	3	60,00 €	180,00 €
Transport truck	km	100	0,90 €	90,00 €
Human resources - senior technician	hour	21	13,00 €	273,00 €
Human resources - team leader	hour	14	7,00 €	98,00 €
Human resources - technician	hour	42	6,00 €	252,00 €
Materials – raffia bags	unit	350	0,28 €	98,00 €
Materials – jute bags	unit	350	0,57 €	199,50 €
Materials – reinforcement metal fence	m	10	3,70 €	37,00 €
Materials – geotextile blanket	m	10	10,00 €	100,00 €
Materials - others	lump	1	30,00 €	30,00 €
Total costs (€)				**1 726,50 €**

N.B.: The contemplated costs do not include the labour spent by STORM-allocated HR, including professionals from TRO, SMPC and NCRS.

9.2.3.2 Effectiveness analyses – Stabilisation of immovable elements

Parameter	Indicators	Assessment					Uncertainty
		Expert 1	Expert 2	Expert 3	Expert 4	Average	Std.dev.
Geobag barrier							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	7	8	7	8	7,5	0,5774
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	5	6	5	6	5.5	0,5774
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
(If pertinent) Environmental impact/eco-compatibility	- Product origin and disposal - Toxicity (to humans or environment.	6	6	6	6	6	0
Average values						**7,25**	0,2887
Total Effectiveness (averaged averages)		**7,25 (+/-0.2887)**					
Jute/raffia bag barrier							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	7	8	7	8	7,5	0,5774
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	5	6	5	6	5,5	0,5774
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
(If pertinent) Environmental impact/eco-compatibility	- Product origin and disposal - Toxicity (to humans or environment.	5	5	6	5	5,25	0,5
Average values						**7,0625**	0,4137
Total Effectiveness (averaged averages)		**7,06 (+/-0,4137)**					

Comments

The difference between the two options considered relies solely in the material used for the sandbags: either geobags, purposely developed for marine environments; or jutte + raffia bags, used in combination for added resistance. Following this reasoning both options were given the same scores in terms of material and immaterial impacts, and only differ in terms of eco-compatibility – a parameter which was deemed important in this context because of the natural park setting.

In terms of environmental impact, the second option was considered to be less optimal than the first: although jute is a natural fibre, the white raffia considered here is synthetic, and features a polyethylene coating to make it less permeable, and is therefore less environmentally friendly. Nevertheless, because it was considered that this barrier would be a short-term solution, only to be placed in emergency scenarios and removed as soon as a more permanent solution for safeguarding these structures is found, the environmental factor was not rated lower.

9.2.3.3 Cost analysis – Temporary window shoring

	Temporary window shoring	Costs			
		un.	quantity	unit price	total (€)
Brick up window	**Planning and documentation**				
	HR – structural engineer	hour	3	15,00 €	45,00 €
	Travel	lump	1	100,00 €	100,00 €
	Execution				
	HR – conservator-restorer	hour	9	13,50 €	121,50 €
	HR – conservation technician	hour	5	10,00 €	50,00 €
	Materials (bricks, mortar, etc.)	lump	1	50,00 €	50,00 €
	Total costs (€)				**366,50 €**
Wooden pole shoring	**Planning and documentation**				
	HR – structural engineer	hour	1	15,00 €	15,00 €
	Travel	lump	1	100,00 €	100,00 €
	Execution				
	HR – conservator-restorer	hour	6	13,50	81,00 €
	HR – carpenter	hour	14	6,00 €	84,00 €
	Materials (wooden poles, shock absorbing materials, etc.)	lump	1	80,00 €	80,00 €
	Total costs (€)				**360,00 €**

9.2.3.4 Effectiveness analyses – Temporary window shoring

Parameter	Indicators	Assessment					Uncertainty
		Expert 1	Expert 2	Expert 3	Expert 4	Average	Std.dev.
Brick wall							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	9	9	8	9	0,8165

Parameter	Indicators	Assessment					Uncertainty
		Expert 1	Expert 2	Expert 3	Expert 4	Average	Std.dev.
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	5	7	7	6	6,25	0,9574
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
(If pertinent) Environmental impact/eco-compatibility	- Product origin and disposal - Toxicity (to humans or environment.	10	9	9	9	9,25	0,5
Average values						**8,625**	0,5685
Total Effectiveness (averaged averages)		**8,63** (+/- 0,5685)					
Wood shoring							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	9	10	10	9,75	0,5
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	8	8	5	8	7,25	1,5
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
(If pertinent) Environmental impact/eco-compatibility	- Product origin and disposal - Toxicity (to humans or environment.	8	9	9	9	8,75	0,5
Average values						**9**	0,6666667
Total Effectiveness (averaged averages)		**9,00** (+/- 0, 6667)					

Comments

Both options are highly effective, i.e., they both fulfil the window stabilisation objective with very low harmfulness to be expected. However, bricking up the window was generally considered to hamper fruition to a higher extent than the shoring system. On the other hand, bricking up the wall would be relatively more difficult to remove, which is undesirable in a temporary solution such as the one undertaken in the context of a drill.

9.2.4 CEA x Preparedness – Basilica, wall m

9.2.4.1 Cost analyses – Stabilisation of immovable elements

Stabilisation of immovable elements		Costs			
		un.	quantity	unit price	total (€)
Cyclododecane	**Application***				
	1st application	m2	3	66,63	199,89
	2nd application	m2	3	33,31	99,93
	Total costs (€)				**299,82 €**
Paraloid ®B72	**Application***				
	Facing application	m2	3	128	384,00
	Total costs (€)				**384,00 €**
*** Includes planning, documentation, equipment and HR costs.**					

9.2.4.2 Effectiveness analyses – Stabilisation of immovable elements

Parameter	Indicators	Assessment					Uncertainty
		Expert 1	Expert 2	Expert 3	Expert 4	Average	Std.dev.
Cyclododecane							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	9	9	9,5	0,5774
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	10	10	9	10	9,75	0,5
Operator skills	Training and experience of the involved operators/ professionals	10	10	10	10	10	0
Average values						9,75	0,3591
Total Effectiveness (averaged averages)		**9,75** (+/- 0,3591)					
Paraloid®B72 + gauze facing							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	7	6	7	8	7	0,8165
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	8	6	7	6	6,75	0,9574
Operator skills	Training and experience of the involved operators/ professionals	10	10	10	10	10	0
Average values						7,92	0,5913
Total Effectiveness (averaged averages)		**7,92** (+/- 0,5913)					

Comments

The extreme fragility of the frescoes caused the Paraloid®B72 facing to be generally considered inadequate for this intervention: while capable of ensuring the fixation of the paint layer for a longer period than the cyclododecane spray, its safe removal would be made impossible by the active detachment in progress. The heavy presence of salts within the wall painting, with widespread efflorescences, is yet another deterrent to the use of the stronger adhesive (Paraloid®B72).

The cyclododecane spray, on the other hand, because it sublimates after a relatively short period, allows for an immediate fixation of the paint layers, whilst not hampering future treatments. In terms of harmfulness, therefore, the cyclododecane was rated as a much better solution for the temporary stabilisation of the frescoes in Wall m.

9.3 Appendix 3: CEA in the Baths of Diocletian

9.3.1 CEA x Prevention

9.3.1.1 Cost analysis - Documentation

	Catalogue recording	Costs				(Future)	
		un.	quantity	unit price	total (€)	repet/y	total (€)
Option A	Initial Investment costs						
	Human Resources						
	1 archaeologist 1 conservator	lump	1	3000,00	3000,00		
	Equipment/Products						
	Cards, SC record, PC, photo	lump	1	2000,00	2000,00		
	Total initial costs (€)				**5000,00**		
	Future costs						
	Regular survey						
	HR – conservator-restorer	lump	1	1000,00	1000,00	1	1000,00
	Equipment	lump	1	150,00	150,00	1	150,00
	Yearly costs						1150,00
	Total future costs – discounted to 2019						**9 327,53**
	Total costs (initial + future discounted)					**14 327,53 €**	

	3D relief, video	Costs				Future	
		un.	quantity	unit price	total (€)	repet/y	total (€)
Option B	Initial Investment costs						
	Human Resources						
	1 expert technician 1 conservator-restorer	lump	1	5000,00	5000,00		
	Equipment/Products						
	3D relief, video	lump	1	2000,00	2000,00		
	Total initial costs (€)				**7000,00**		
	Future costs						
	Regular survey						
	HR – conservator-restorer	lump	1	1000,00	1000,00	1	1000,00

Equipment	lump	1	500,00	500,00	1	500,00
Yearly totals (€)						1500,00
Total future costs – discounted to 2019						**12 166,34**
			Total costs (initial + future discounted)		**19 166,34 €**	

9.3.1.2 Cost analysis - Monitoring

Visual control	Visual control, SC record, photo	Costs				(Future)	
		un.	quantity	unit price	total (€)	repet/y	total (€)
	Initial Investment costs						
	Human Resources						
	1 conservator-restorer	lump	1	2000,00	2000,00		
	Equipment/Products						
	(existing at the site)	-	-	-	-		
	Total initial costs (€)				**2000,00**		
	Future costs						
	Regular survey						
	HR – conservator-restorer	lump	1	2000,00	2000,00	1	2000,00
	Yearly costs						2000,00
	Total future costs – discounted to 2019						**16 221,79 €**
				Total costs (initial + future discounted)		**18 221,79 €**	

Biological analysis	Biological analysis, digital microscope video and photo, visual control	Costs				Future	
		un.	quantity	unit price	total (€)	repet/y	total (€)
	Initial Investment costs						
	Human Resources						
	2 expert technicians 2 conservator-restorers	lump	1	5000,00	5000,00		
	Equipment/Products						
	(existing at the site)	-	-	-	-		
	Total initial costs (€)				**5000,00**		
	Future costs						
	Regular survey						

HR – conservator-restorer	lump	1	2000,00	2000,00	1	2000,00
Yearly totals (€)						2000,00
Total future costs – discounted to 2019						**16 221,79 €**
			Total costs (initial + future discounted)	**21 221,79 €**		

9.3.1.3 Cost analysis – Biocide application

Benzalkonium chloride	Costs				(Future)	
	un.	quantity	unit price	total (€)	repet/y	total (€)
Initial Investment costs						
Human Resources						
Conservator-restorers	h	70	100,00	7000,00		
Equipment/Products						
Biocide	l	20	40,00	800,00		
Total initial costs (€)				**7800,00**		
Future costs						
Maintenance						
HR – conservator-restorer	h	30	100,00	3000,00	1	3000,00
Products – Biocide	l	20	20,00	400,00	1	400,00
Yearly costs						3400,00
Total future costs – discounted to 2019						**27 577,05 €**
Total costs (initial + future discounted)				**35 377,05 €**		

Natural biocide	Costs				Future	
	un.	quantity	unit price	total (€)	repet/y	total (€)
Initial Investment costs						
Human Resources						
Expert biologists	h	10	100,00	1000,00		
Conservator-restorers	h	60	100,00	6000,00		
Equipment/Products						
Biocide	kg	50	40,00	2000,00		
Total initial costs (€)				**9000,00**		
Future costs						
Maintenance						
HR – conservator-restorer	h	8	100,00	800,00	1	800,00
HR – expert biologist	h	19	100,00	1900,00	1	1900,00
HR – technician	h	8	100,00	800,00	1	800,00
Products – Biocide	kg	10	40,00	400,00	1	400,00

Yearly totals (€)		3900,00
Total future costs – discounted to 2019		**31 632,49 €**
Total costs (initial + future discounted)	**40 632,49 €**	

9.3.2 CEA x Preparedness: Drill 1

9.3.2.1 Cost analysis – Documentation

Documentation		Costs			
		un.	quantity	unit price	total (€)
Classic documentat.	**Human Resources**				
	Archaeologist	hour	10	100,00 €	1000,00 €
	Conservator restorer	hour	10	100,00 €	1000,00 €
	Equipment				
	Cameras, PC, etc.	lump	1	1000,00 €	1000,00 €
	Total costs (€)				**3000,00 €**
STORM platform	**Human Resources**				
	Archaeologist	hour	5	100,00 €	500,00 €
	Conservator restorer	hour	5	100,00 €	500,00 €
	Equipment				
	PC, tablet	lump	1	1000,00 €	1000,00 €
	Total costs (€)				**2000,00 €**

9.3.2.2 Cost analysis – Pre-impact activities

Pre-impact safeguard of movable objects		Costs			
		un.	quantity	unit price	total (€)
Evacuation	**Human Resources**				
	Archaeologists	hour	1	100,00 €	100,00 €
	Conservator restorers	hour	7	100,00 €	700,00 €
	Handlers (outsourced)	hour	18	100,00 €	1800,00 €
	Equipment				
	Data collection equipment	lump	1	100,00 €	100,00 €
	Packaging and transport	lump	1	600,00 €	600,00 €
	Total costs (€)				**3300,00 €**
Onsite protection	**Human Resources**				
	Archaeologists	hour	1	100,00 €	100,00 €
	Conservator restorers	hour	13	100,00 €	1300,00 €
	Workmen	hour	4	50,00 €	200,00 €
	Equipment				
	Data collection equipment	lump	1	100,00 €	100,00 €
	Packaging	lump	1	300,00 €	300,00 €
	Total costs (€)				**2000,00 €**

9.3.3 CEA x Preparedness: Drill 2

9.3.3.1 Cost analysis – Stabilisation of immovable elements

Pre-impact safeguard of immovable objects		Costs			
		un.	quantity	unit price	total (€)
Scaffolding	**Human Resources**				
	Conservator restorers	hour	20	100,00 €	2000,00 €
	Workmen	hour	22	50,00 €	1100,00 €
	Equipment				
	Scaffolding	lump	1	5000,00 €	5000,00 €
	Shock absorbing materials	lump	1	200,00 €	200,00 €
	Total costs (€)				**8300,00 €**
Airbags	**Human Resources**				
	Conservator restorers	hour	8	100,00 €	800,00 €
	Technician	hour	2	100,00 €	200,00 €
	Workmen	hour	12	50,00 €	600,00 €
	Equipment				
	Coverage and protection equipment	lump	1	200,00 €	200,00 €
	Paper airbags, compressor, etc.	lump	1	500,00 €	500,00 €
	Total costs (€)				**2300,00 €**

9.4 Appendix 4: CEA in Rethymno

9.4.1 CEA x Prevention: Desalination

9.4.1.1 Cost analysis – Documentation

	Photography	Costs				(Future)	
		un.	quantity	unit price	total (€)	repet/y	total (€)
Photography	**Initial Investment costs**						
	Human Resources						
	1 archaeologist	day	2	75,00 €	150,00 €		
	1 conservator	day	2	49,00 €	98,00 €		
	Equipment/Products						
	Camera	item	1	500,00 €	500,00 €		
	Memory card	item	2	50,00 €	100,00 €		
	Total initial costs (€)				**848,00 €**		
	Future costs						
	Regular surveying						
	HR – archaeologist	lump	1	75,00 €	75,00 €	2	150,00 €
	HR – conservator	lump	1	49,00 €	49,00 €	2	98,00 €
	Yearly costs						248,00 €
	Total future costs – discounted to 2019						**1 104,05 €**
	Total costs (initial + future discounted)				**1 952,05 €**		

	Conservation condition mappings	Costs				Future	
		un.	quantity	unit price	total (€)	repet/y	total (€)
Drawings	**Initial Investment costs**						
	Human Resources						
	1 archaeologist	day	2	75,00 €	150,00 €		
	1 conservator	day	2	49,00 €	98,00 €		
	1 designer	day	2	49,00 €	98,00 €		
	Equipment/Products						
	Printing designs	item	2	1,50 €	3,00 €		
	Total initial costs (€)						
	Future costs						

Regular surveying						
HR – archaeologist	day	1	75,00 €	75,00 €	2	150,00 €
HR – conservator	day	1	49,00 €	49,00 €	2	98,00 €
HR – designer	day	1	49,00 €	49,00 €	2	98,00 €
Equip. – printing designs	item	1	1,50 €	1,50 €	2	3,00 €
Yearly totals (€)						349,00 €
Total future costs – discounted to 2019						**1 553,69 €**
Total costs (initial + future discounted)						**1 902,69 €**

9.4.1.2 *Effectiveness analysis – documentation*

Parameter	Indicators	Assessment					Uncertainty
		Expert 1	Expert 2	Expert 3	Expert 4	Average	Std.dev.
Photography							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	10	10	10	0
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	10	10	10	10	10	0
Operator skills	Training and experience of the involved operators/ professionals.	9	9	9	9	9	0
Total Effectiveness (average value)		9,(6)					
Drawings							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	10	10	10	0
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	8	8	8	8	8	0
Operator skills	Training and experience of the involved operators/ professionals.	9	9	9	9	9	0
Total Effectiveness (average value)		9					

Comments

Eco-compatibility was not considered relevant for the effectiveness analysis.

Experts considered that photography can picture efflorescence better and more directly than mapping.

9.4.1.3 Cost analysis – desalination

	Paper pulp	Costs				(Future)	
		un.	quantity	unit price	total (€)	repet/y	total (€)
Paper pulp	**Initial Investment costs**						
	Human Resources						
	Conservators	day	20	49,00 €	980,00 €		
	Conservation technician	day	20	46,00 €	920,00 €		
	Equipment/Products						
	Scaffolding	item	2	300,00	600,00 €		
	Portable conductivity meter	item	1	76,00	76,00 €		
	Deionised water	litre	40	3,00	120,00 €		
	Beakers	item	5	11,78	58,90 €		
	White tissue paper pulp	Kg	30	4,96	148,80 €		
	Plastic boxes	item	3	15,00	45,00 €		
	Total initial costs (€)				**2 948,70 €**		
	Future costs						
	Regular desalination						
	Human Resources						
	Conservators	days	10	49,00 €	490,00 €	2	980,00 €
	Conservation technician	days	10	46,00 €	460,00 €	2	920,00 €
	Equipment/Products						
	Scaffolding	item	1	300,00 €	300,00 €	2	600,00 €
	Deionised water	litre	20	3,00 €	60,00 €	2	120,00 €
	White tissue paper pulp	Kg	15	4,96 €	74,40 €	2	148,80 €
	Costs after five years						2 768,80 €
	Total future costs – discounted to 2019						**2 747,17 €**
	Total costs (initial + future discounted)				**5 695,87 €**		

Sepiolite		Costs				Future	
		un.	quantity	unit price	total (€)	repet/y	total (€)
Sepiolite	**Initial Investment costs**						
	Human Resources						
	Conservators	days	20	49,00 €	980,00 €		
	Conservation technician	days	20	46,00 €	920,00 €		
	Equipment/Products						
	Scaffolding	item	2	300,00 €	600,00 €		
	Portable conductivity meter	item	1	76,00 €	76,00 €		
	Deionised water	litre	40	3,00 €	120,00 €		
	Beakers	item	5	11,78 €	58,90 €		
	Sepiolite	Kg	80	1,70 €	136,00 €		
	Plastic boxes	item	3	15,00 €	45,00 €		
	Total initial costs (€)				**2 935,90 €**		
	Future costs						
	New desalination after 5 years						
	Human Resources						
	Conservators	days	10	49,00 €	490,00 €	2	980,00 €
	Conservation technician	days	10	46,00 €	460,00 €	2	920,00 €
	Equipment/Products						
	Scaffolding	item	1	300,00 €	300,00	2	600,00 €
	Deionised water	litre	20	3,00 €	60,00	2	120,00 €
	Sepiolite	Kg	40	1,70 €	68,00	2	136,00 €
	Costs after five years						2 756,00 €
	Total future costs – discounted to 2019						**2 734,47 €**
Total costs (initial + future discounted)					**5 670,37 €**		

9.4.1.4 Effectiveness analysis – desalination

Parameter	Indicators	Assessment					Uncertainty
		Expert 1	Expert 2	Expert 3	Expert 4	Average	Std.dev.
Paper pulp							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	10	10	10	0
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	10	10	10	10	10	0
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
Total Effectiveness (average value)		10					
Sepiolite							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	10	10	10	0
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	8	8	8	8	8	0
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
Total Effectiveness (average value)		9,25					

Comments

Eco-compatibility was not considered relevant for this specific effectiveness analysis.

Paper pulp poultices: High quality outcomes and easy, non-toxic disposal of the white tissue paper.

Sepiolite poultices: Difficult to remove the sepiolite from the porous stone.

9.4.2 CEA x Preparedness: Drill 1

9.4.2.1 Cost analysis – Documentation

Documentation		Costs			
		un.	quantity	unit price	total (€)
Video	**Human Resources**				
	Archaeologist	day	1	75,00 €	75,00 €
	Video editing service				
	Contractor	service	2	240,00 €	240,00 €
	Total costs (€)				**315,00 €**
Photogrammetr y	**Human Resources**				
	Archaeologist	day	1	75,00 €	75,00 €
	IT support service				
	Contractor	service	1	400,00 €	400,00 €
	Total costs (€)				**475,00 €**

9.4.2.2 Effectiveness analysis – Documentation

Parameter	Indicators	Assessment					Uncertainty
		Expert 1	Expert 2	Expert 3	Expert 4	Average	Std.dev.
Professional video							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	10	10	10	0
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	10	10	10	10	10	0
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
Total Effectiveness (averaged averages)		10					
Photogrammetry							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	10	10	10	0
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	8	8	8	8	8	0
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
Total Effectiveness (averaged averages)		9,(3)					

Comments

It is easy to make a video by skilled professionals. On the other hand, photogrammetry requires some interference with the monument.

9.4.2.3 Cost analysis – Onsite stabilisation

Onsite stabilisation		Costs			
		un.	quantity	unit price	total (€)
Shoring	**Human Resources**				
	Conservator-restorers	day	1	49,00 €	49,00 €
	Technicians	day	3	46,00 €	138,00 €
	Equipment/Products				

	4x25x5 wooden planks	item	20	15,00 €	300,00 €
	4x10x10 wooden planks	item	12	12,00 €	144,00 €
	2x10x10 wooden planks	item	15	15,00 €	225,00 €
	6m stainless steel rods	item	40	15,00 €	600,00 €
	2m stainless steel rods	item	50	5,00 €	250,00 €
	Metal screws	item	120	10,00 €	1 200,00 €
	Plastic fence chain	item	50	15,00 €	750,00 €
	Scaffolding protection	lump	1	500,00 €	500,00 €
	Metal piles	item	20	2,50 €	50,00 €
	Total costs (€)				**4 206,00 €**
Pointing	**Human Resources**				
	Conservator-restorers	day	10	49,00 €	490,00 €
	Technicians	day	20	46,00 €	920,00 €
	Equipment/Products				
	Scaffolding	lump	1	3 000,00 €	3 000,00 €
	Lime	m3	0,5	30,00 €	15,00 €
	Sand	m3	3	30,00 €	90,00 €
	Latex	l	20	2,50 €	50,00 €
	Natural hydraulic lime	20kg bags	10	10,00 €	100,00 €
	Coloured marble powder	kg	2	10,00 €	20,00 €
	Total costs (€)				**4 685,00 €**

9.4.2.4 Effectiveness analysis – Onsite stabilisation

Parameter	Indicators	Assessment					Uncertainty
		Expert 1	Expert 2	Expert 3	Expert 4	Average	Std.dev.
Steel shoring							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	10	10	10	0
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	10	10	10	10	10	0
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
Total Effectiveness (averaged averages)		10					
Pointing							
Material non-harmfulness	Physical-chemical aggressiveness – short run and long run	10	10	10	10	10	0
Immaterial non-harmfulness	- Type of approach (preventive; curative; reconstruction) - Compliance with conservation guidelines - Visibility of interferences or disturbances to fruition	8	8	8	8	8	0
Operator skills	Training and experience of the involved operators/ professionals.	10	10	10	10	10	0
Total Effectiveness (averaged averages)		9,(3)					

Comment

Steel shoring: Direct structural stabilisation.

Mortar pointing: Requires much more time.

10 Appendices: Data Analysis

10.1 Introduction

On October the 8th 2018, in the Michelangelo's Cloister garden, in the framework of Prevention pilot of STORM project, some experiments were carried out for the treatment of bio-deteriogens through the use of innovative, eco-friendly substances based on natural or bacterial origin. These testing have the aim of identifying, among the eco- friendly technologies, the most effective ones for the treatment of biological growth that afflicts this area and doing so propose an effective mitigation effect.

10.2 Material and methods

The solutions employed in the treatments are reported in table 1, and they were applied using both cellulose pulp and a natural gel, xanthan gum (Vanzan®)

Table 29: Products used for experimentation

N°	Name	Characteristics	Application
1	BioZ	Bio-emulsifier of microbial origin	Cellulose pulp
2			Xanthan gum
3	Liquorice	Alcoholic extract of 3% liquorice leaves	Cellulose pulp
4			Xanthan gum
5	Nopal Cap	Opuntia mucilage and chili extract	Cellulose pulp
6			Xanthan gum
7	SME1.11	Bacterial strain	Xanthan gum
8	H_2O	Deionized water	Cellulose pulp
9	MIX 10 bis	Mixture of essential oils 1.3%	Cellulose pulp
10	BAK	Benzalkonium chloride 1%	Cellulose pulp

Before the application of the products, the surfaces were examined using a digital microscopephotographs of the surface areas to be treated, and some sampling of bio-patina to identify the present species.

10.3 Treatments results

From the macroscopic point of view, results from this first application have highlighted a good performance of SME1.11, Liquorice, and Mix10b (Essential Oils), all applied with a gel (xanthan gum), while the reference control, benzalkonium chloride, shows a high chromatic alteration towards yellow.

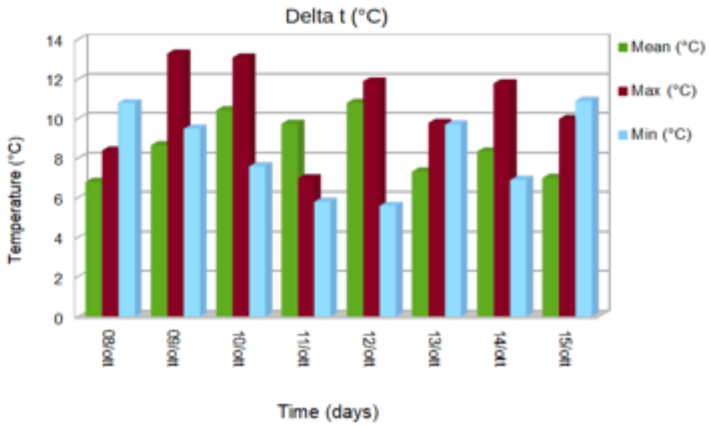


Figure 23. Temperature differences between the two experimental periods

With the best-resulted products new tests have been made on a different artefact, but with fewer results. This poor treatment result can be attributed to the adverse weather conditions, in fact, the analysis of the meteorological data (fig. 1) showed a greater amount of precipitation associated with a lowering of about 10 °C of temperature.

10.4 Monitoring results

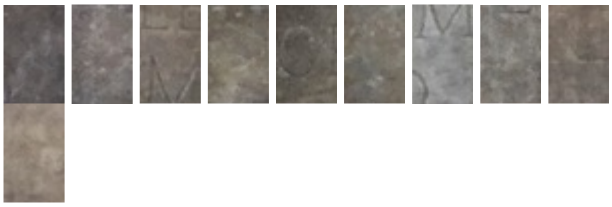
Since the monitoring activity has concerned before the treatment only photographic and microphotographic documentation of some points, to monitor the effectiveness of the treatments, photographic shots[32] were taken at prefixed times (3 and 7 months later). In the last survey microphotograph with digital microscope Dino-Lite (AM4815ZT, 75-120 magnifications) and bio-luminometer measurements for an estimate of the bio-deteriogens present were carried out.

The photographic documentation was first elaborate with the Adobe Photoshop software to achieve the selection (figure in table 2) of the small areas to be analysed with the Image Analysis Software Image-Pro Plus 6 (Media Cybernetic). Through the analysis in the RGB colour space, we tried to monitor the chromatic variations over time.

Table 30: Photographic images over time of marble surface and related selections for image analysis

<table>
<tr><td rowspan="2"></td><td colspan="10">Surface of the marble before the biocide treatment</td></tr>
<tr><td>BioZ + pulp</td><td>BioZ + Gel</td><td>Liq. +Pulp</td><td>Liq. + Gel</td><td>NopC+Pulp</td><td>NopC + Gel</td><td>SME + Gel</td><td>H2O + Pulp</td><td>Mix + Pulp</td><td>Bak + Pulp</td></tr>
<tr><td></td><td colspan="10">Tested surface after the treatment. 16 October/2018 16.05 pm</td></tr>
</table>

[32] The photographic images were taken around the same hour with the same camera (iPad mini 4, color space RGB, focal length 3,3mm, Latitude 41° 54' 15,03" N, Longitude 12° 29' 52,41" E

	
	Tested surface after 3 months from treatment. 16 January/2019 – 16.45 pm 
	Tested surface after 7 months from treatment. 23 May/2019 – 15.40 pm 

The analysis provides a colour histogram formed by 256 pixels scales (from 0 to 255, the maximum of intensity) for each of the Red, Green, and Blue channels plotted them on 3 individual distribution graphs. The averages of these distributions were used in the histograms below (fig. 1), to monitor and compare the individual chromatic components over time.

For a better understanding of the analysis, in terms of pixels the subtraction of the average values from the maximum intensity of 255 was performed. In this way, the increasing intensity trend indicates a decrease in surface luminosity, relative to the increase in the layer of dirt or biological colonization.

All average values of the intensities for the three colour channels of each image are visible both in the histograms and in table 3.

We can obviously observe an important variation of the untreated (white) surface followed by the water (H_2O) and BioZ-G tests. A slight variation is reported by SME1.11, all the others have a limited change, except BAK (Benzalkonium Chloride), where the decrease in values indicates a reduction in the initial yellowing.

Figure 24. Histograms of the RGB mean values obtained from the photographs rectangular sections related to different exposure times. *Black* and *White* are respectively the most darkening and lightening intensity of not treated surface.

Table 31: Average intensity or n° of the pixels for each colour channel related to the three exposure times

	R1	R2	R3	□□R	G1	G2	G3	□□R	B1	B2	B3	□□R
BAK1	109	108	94	**9**	136	120	101	**18**	160	134	112	**23**
Mix10b	112	137	130	**-4**	121	146	131	**2**	131	155	137	**4**
H_2O	89	131	149	**-26**	96	134	149	**-23**	106	140	155	**-21**
SME1.11	85	114	113	**-9**	85	113	115	**-11**	83	115	124	**-16**
NOP-G	118	139	126	**2**	122	143	128	**3**	123	152	140	**-1**
NOP-P	108	158	136	**-2**	122	162	138	**3**	140	171	147	**6**
LIQ-G	101	135	129	**-7**	112	142	136	**-6**	126	153	145	**-3**

LIQ-P	128	137	122	**7**	134	145	123	**11**	140	154	134	**8**
BioZ-G	105	135	143	**-15**	110	141	147	**-14**	112	144	158	**-20**
BioZ-P	136	161	157	**-6**	140	165	160	**-5**	137	166	155	**-2**
Black	189	180	157	**18**	200	182	160	**21**	196	189	155	**25**
White	71	122	206	**-73**	79	126	206	**-69**	88	128	207	**-66**

*The Delta-R is calculated by subtracting of the R3 value from the three-exposition values average for each channel.

As previously mentioned, in the last monitoring survey we have introduced the use of bio-luminometer. This is a portable instrument that transforms ATP (Adenosine Triphosphate) into RLU (Relative Light Unit), allowing us to determine the extent of biological activity present on the artworks before and after biocide treatments. Measures with bioluminometer (3 per each point) and microphotographs were taken around the same point.

The data obtained from the bio-luminometer analysis provided comparable results with the image analysis conducted on the photomicrographs of the treated surfaces (fig. 2).

Bak and Mix10bis seem to have the best effect, while Nop, Liq-p, BioZ-p and White, the worst.

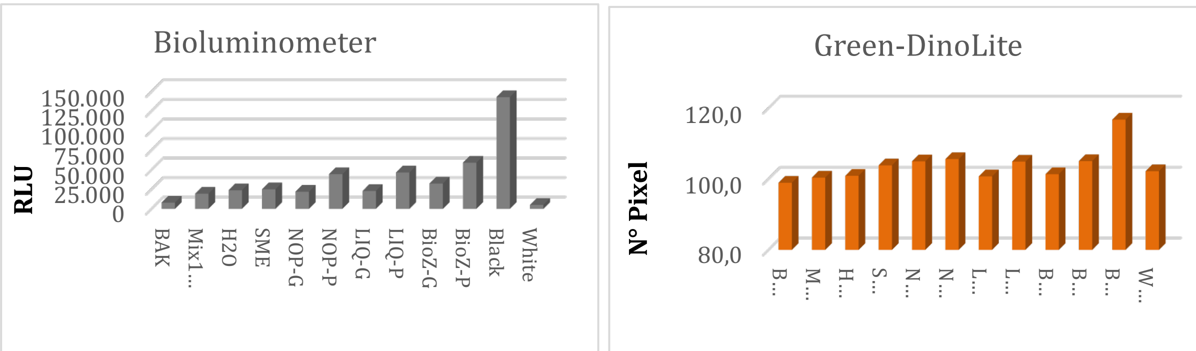


Figure 25. Histograms of bioluminometer and microphotographs

Bioluminometer measurements were repeated on the trabeation fragment, where the tests with the best products had been carried out. We can observe that the results obtained in this case confirm those achieved on the Ara (fig. 3).

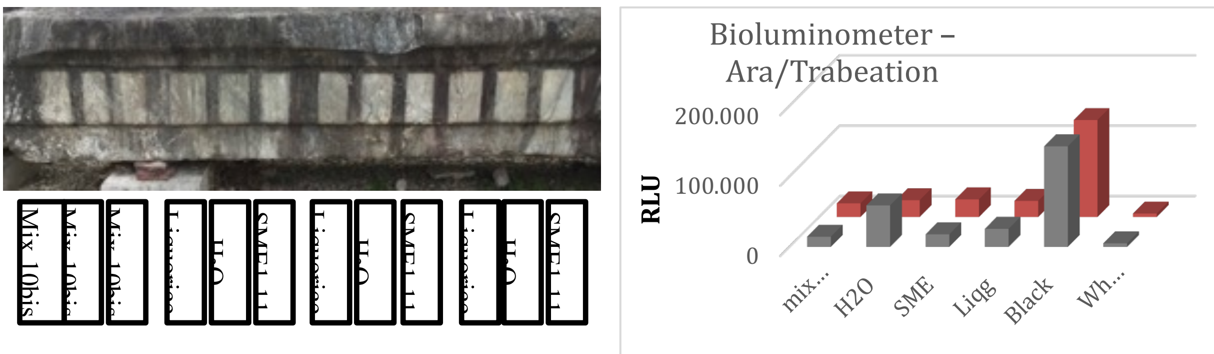


Figure 26. Image of the trabeation fragment with the tests, and on the right the bioluminometer results

10.5 Conclusion

The biocide treatments results based on natural products underlined the best behaviour for SME1.11, Liquorice, and Mix10b (Essential Oils), applied with gel, compared to the same applied with cellulose pulp and to the other products. What has been visually observed has been confirmed by the image analysis and, in the last survey, also by the microphotographs and bioluminometer analysis.

Despite the efficacy for biofilm control, insufficient action is observed to the total reduction of the biomass, which however remains high in the range between 8000 RLU of the surface treated with Bak, and 60000 of that treated with BioZ-P, while the untreated areas, white and black, show respectively 5000 and 145000 RLU.

These values, related to the monitoring carried out seven months after the intervention, together with the obtained results by the whole experimentation, provide the basis for the definition of a treatment methodology that includes the identification of the type and number of applying, their contact time, and the monitoring system necessary to obtain a good result.

Whit regard to the monitoring methodology, a good match can be observed between the analysis of the RGB colour space of microphotographs and the use of the bioluminometer, which should be implemented for future observations.

11 Appendices: Data Analysis 2

In this section an overall data analysis of sensors installed by TUSCIA in BoD Pilot site has been provided

11.1 Fibre Bragg Grating (FBG) sensors data analysis (TUSCIA)

As written in D9.1 TUSCIA is currently monitoring, by using FBG sensors, Strain, Rising Humidity, in the external and internal wall Hall I and wall and vault of Michelangelo's Cloister.

Sensors on the wall in Hall I are monitoring on the inside strain on the lesions and movements of a layer of plaster and, on the outside, rising humidity. Sensors have been installed, as described in D4.1, both inside and outside, from top to bottom, with Sensor S0 in the highest position, between wall and plaster.

In Figures 5 and 6, the graphs show the data recorded in 2018, from Hall I internal sensors (strain) do not shows significant dilations or contractions of the lesion in the wall nor worrying vibrations (see in particular graph's lines colours grey, blue, orange).

By the evaluation of the data collected in 2019 (from January to May), on the other hand, slightly more significant fluctuations have been recorded by S0 sensor, which recorded some quite rapid contractions in January and, in the following months, recorded ever wider expansions and contractions. It should be remembered that S0 is positioned between the masonry and the plaster which is particularly movable. This could represent a danger for the preservation of the material that, because of this continuous vibration, may detach and consequently fall from the wall. The other sensors, on the other hand, registered balanced and constant expansions and contractions of the lesions, not detecting particularly worrying values for conservation purposes.

The situation recorded in 2018 by the sensors positioned outside the Hall I, which measure the rising humidity (both for capillary rise and for percolation of rainwater) is quite different. In figure 7 a fluctuating trend of humidity is evident, which increases and decreases according to external climatic and meteorological conditions (see graph's lines indicated with the colours yellow, green, blue). The values recorded start from low values, which indicate that the surface is dry until it is completely saturated (maximum 100% humidity of the brick). From the data it is also possible to notice how the greater oscillations are recorded by sensor 7.

In the following graphs, all dating back to 2019 (from January to May) it is important to notice, again, a fluctuating trend of humidity, whose variations depend on external climatic and meteorological conditions. The sensors generally record uniform humidity values, especially when it exceeds 35%. Values rarely reach 100% (water on the sensors) and 0% (completely dry surface). When the humidity values are low, a greater difference can be observed between the different sensors at the same time, equal to about 5%. In these cases the S6 and S4 sensors (on the upper and lower part of the wall) register a slightly higher humidity than the S5 and S7 sensors. This is due to their positioning. In some periods, i.e. February, values of 100% and 0% of humidity are found more frequently, this is probably due to weather conditions.

Both in 2018 and 2019 have been possible to see that such a high presence of humidity inside the walls, and the sudden variations of it are certainly problematic for conservation purposes. The continuous decrease of humidity can cause, in fact, the appearance of salt efflorescence, while the increase of humidity causes biogrowth, the presence of algae and, above all, the disintegration of the mortars between the bricks. All these phenomena are already present and clearly visible in the masonry of Room I.

The data collection in Michelangelo's Cloister began, although in a discontinuous manner, in October 2018. FBG sensors have been installed, as described in D4.1, both on the Vault and on the upper part of the wall, for the lesion monitoring, and in the lower part of the wall in order to monitor the Rising Humidity. In the figure 15 is possible to see that data recorded by the sensors monitoring strain of the lesions in the masonry, does not show significant dilations or contractions nor worrying oscillations (see in particular the red and black colours), the only peak that could arouse concern is the S3 sensor, dated 11/16/2018. Also the data collected in January 2019 do not record expansion or contraction to be considered dangerous for conservative purposes, while, starting from February, in a first phase there has been a slow but continuous reduction of the values recorded by the sensor S3 (on the vault), this means that the two faces of the monitored lesion tend to gradually approach one each other, while later on there are numerous oscillatory movements of the lesions. This phenomenon must certainly be carefully checked since, in the long run, it could lead to loss of surface material but, above all, to an elongation of the lesion which may cause serious problems on the stability of the structures.

The values recorded in 2018 by the sensors positioned along the wall for monitoring the rising humidity are not particularly dangerous, since no significant differences in the values have been recorded (see in particular the graph's lines in colours green, beige, purple, blue). The only sensor whose trend is slightly more fluctuating is the sensor S4 (blue), positioned lower down along the wall, which records maximum peaks of humidity 10% higher than the other sensors; this trend could be due to the capillary rise of humidity from the ground. The slightly fluctuating movement of all the sensors can be linked to the day / night alternation. The recorded values are in the range that allows a proper conservation of the masonry.

The values recorded in January and February 2019 do not show significant fluctuations in rising humidity, without problems for a conservative purpose. The situation recorded since March, on the other hand, is quite different; starting from this period, in fact, the trends turn out to be more fluctuating and the peaks reach, and sometimes also exceed, 45% of humidity on the walls, it can also be noticed that the humidity increases and decreases in a rather sudden manner. These values are recorded by all the installed sensors, allowing to hypothesize the occurrence of phenomena that caused the presence of water on the masonry and, subsequently, the direct solar radiation on the wall.

A high presence of humidity on the masonry, and the sudden variations of it, recorded during this period, are certainly dangerous for conservation purposes. The continuous decrease of humidity can cause, in fact, the appearance of salt efflorescence, while increase of humidity can cause biogrowth, presence of algae and, above all, detachment of the plaster covering the masonry.

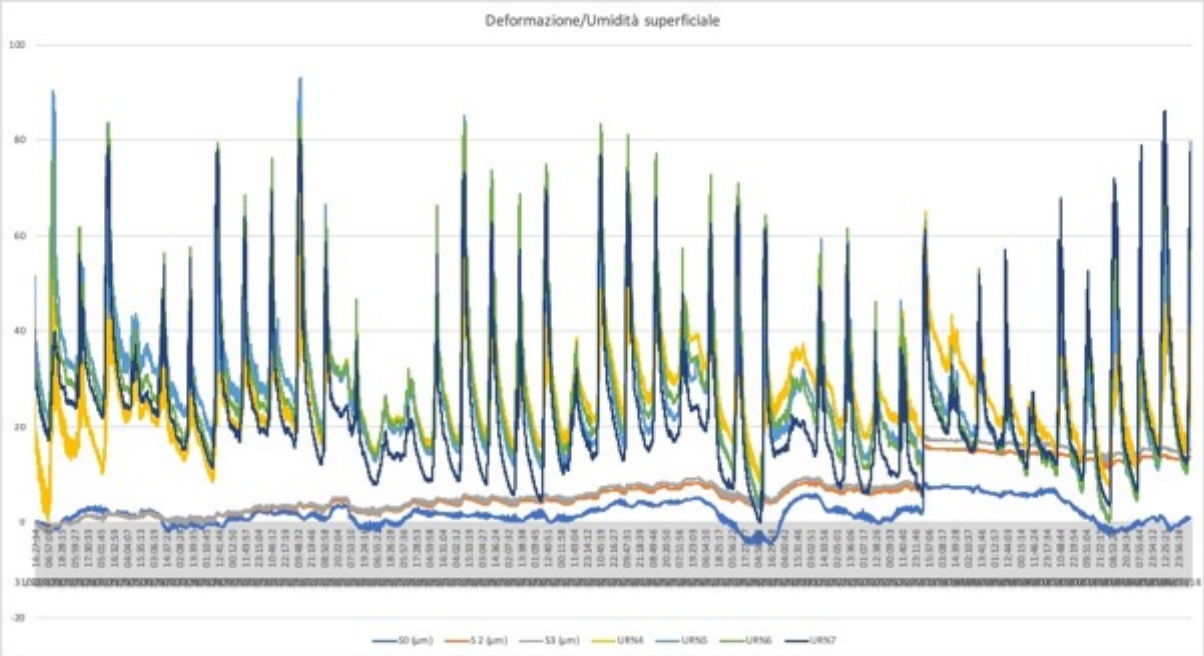


Figure 27 Trends of the value recorded both inside and outside Hall I by FBG sensors (October 2017- June 2018)

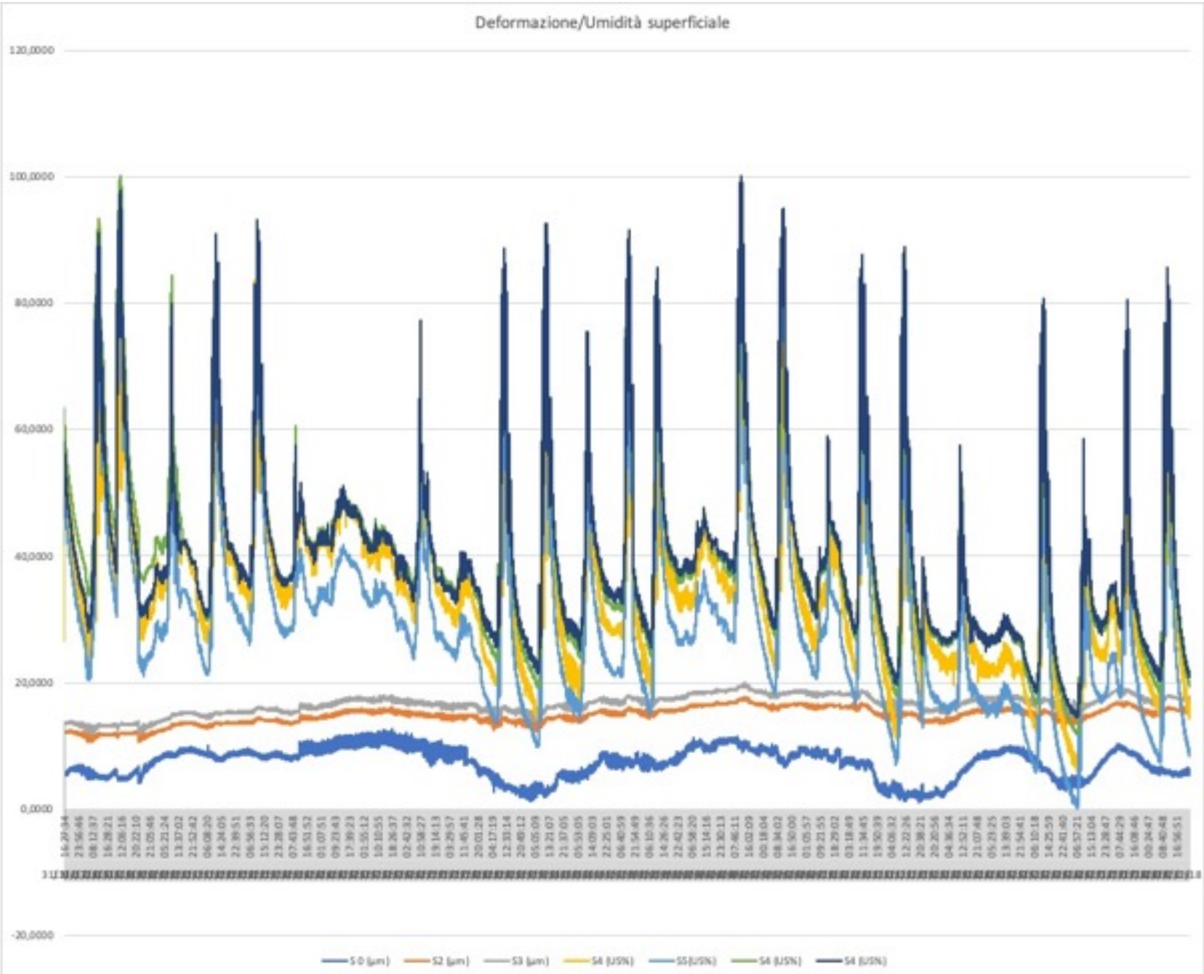


Figure 28 Trends of the value recorded both inside and outside Hall I by FBG sensors (October – December 2018)

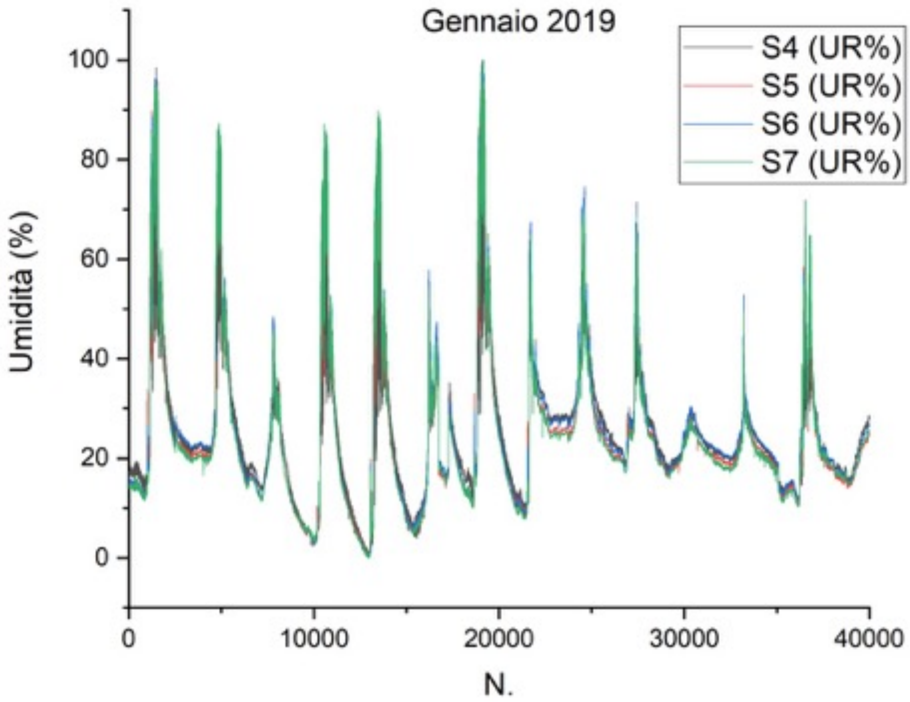


Figure 29 Trend of the Rising humidity recorded outside Hall I in January 2019

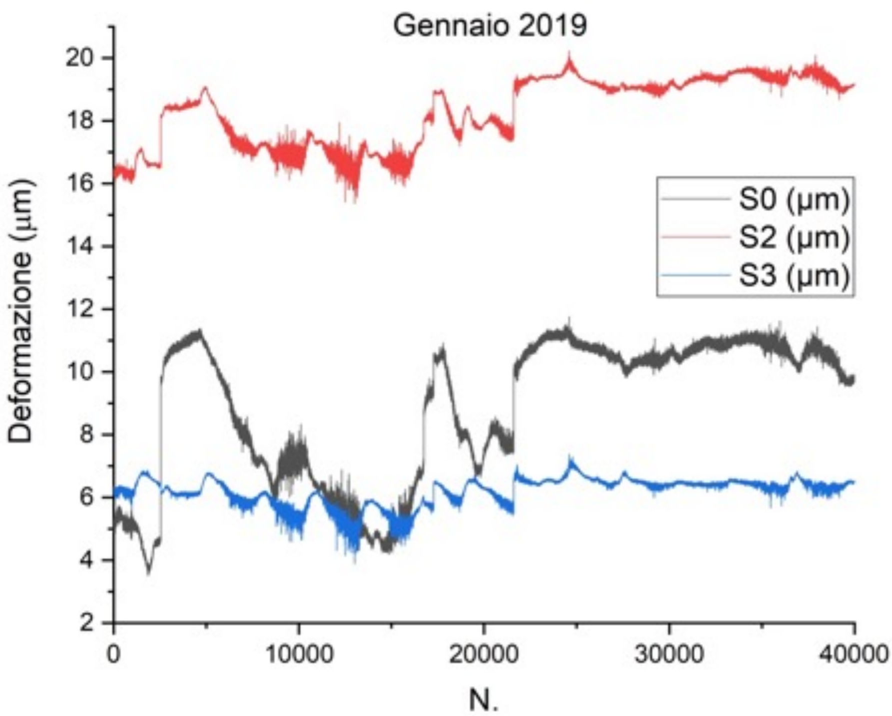


Figure 30 Trend of the strain recorded by FBG sensors inside Hall I, January 2019

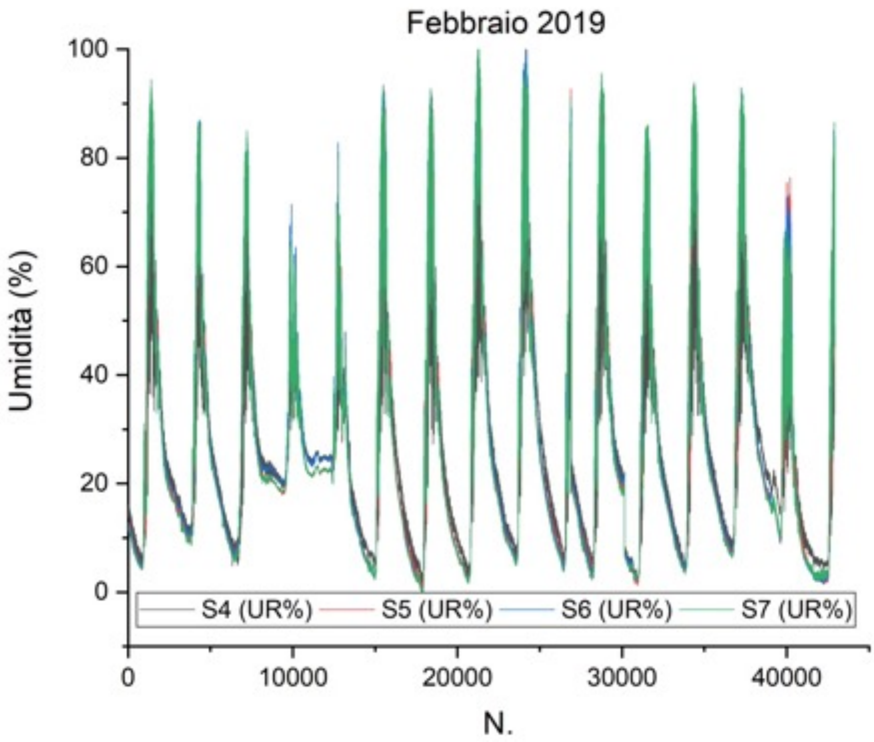


Figure 31 Trend of the Rising humidity recorded outside Hall I in February 2019

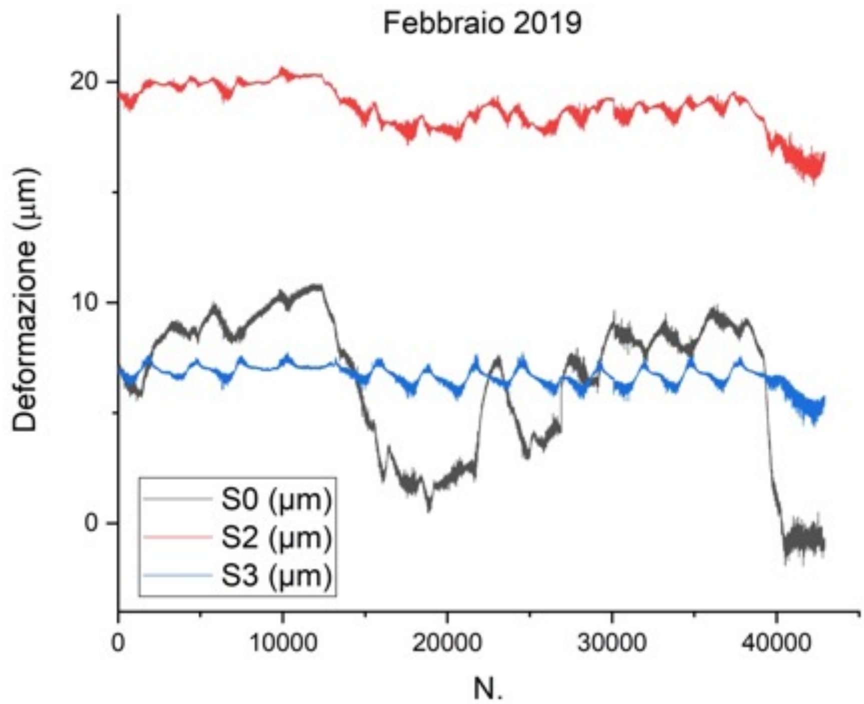


Figure 32 Trend of the strain recorded inside Hall I in February 2019

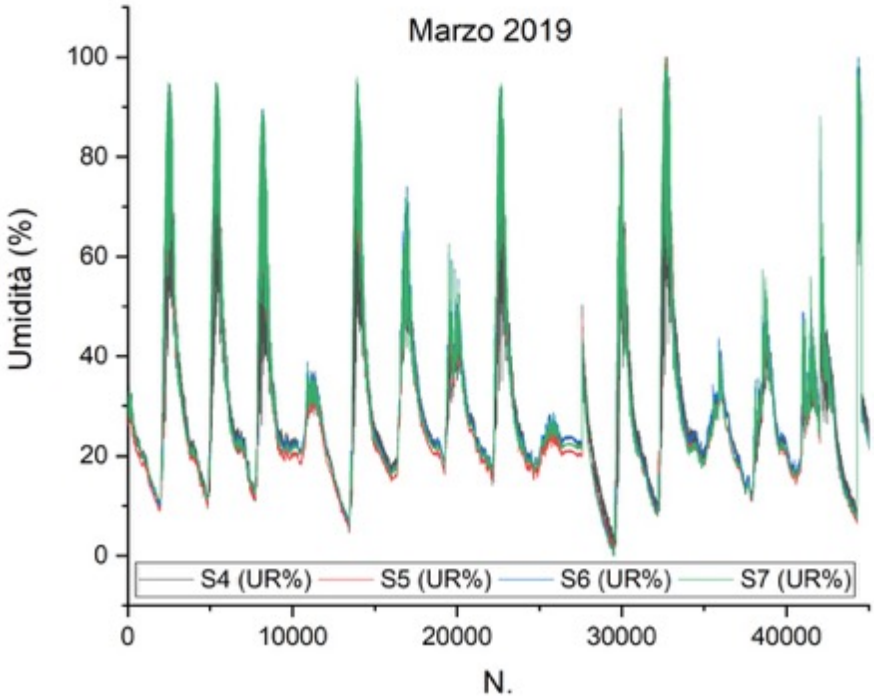


Figure 33 Trend of the rising humidity recorded outside hall I in March 2019

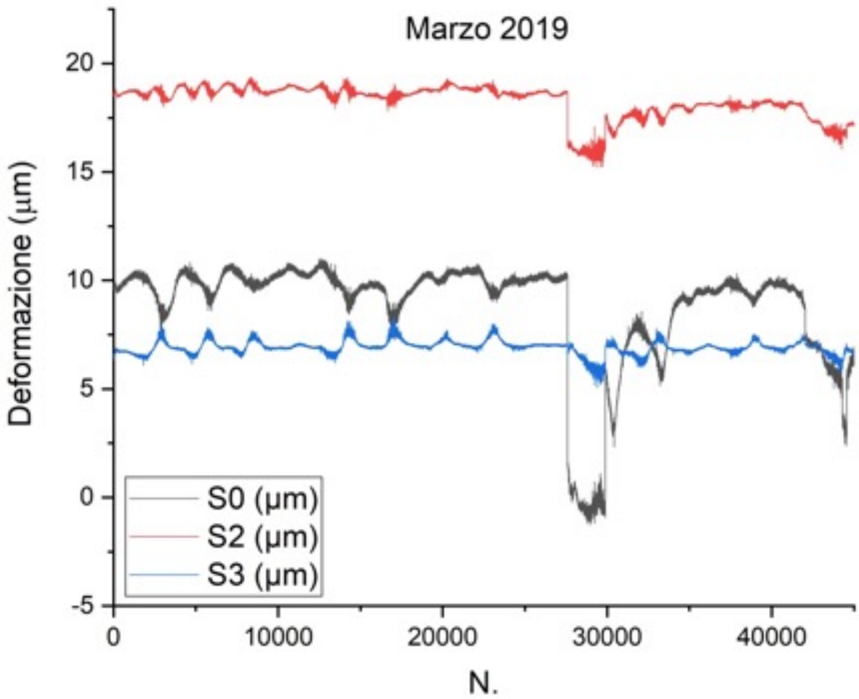


Figure 34 Trend of strain recorded by FBG sensors in Hall I, March 2019

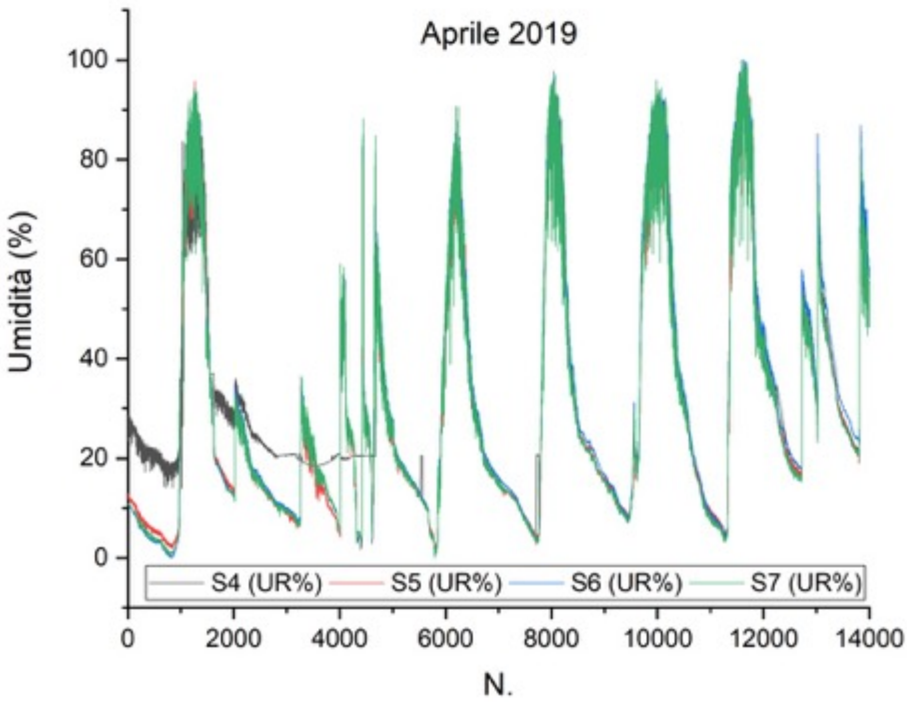


Figure 35 Trend of rising humidity recorded by FBG sensors in April 2019

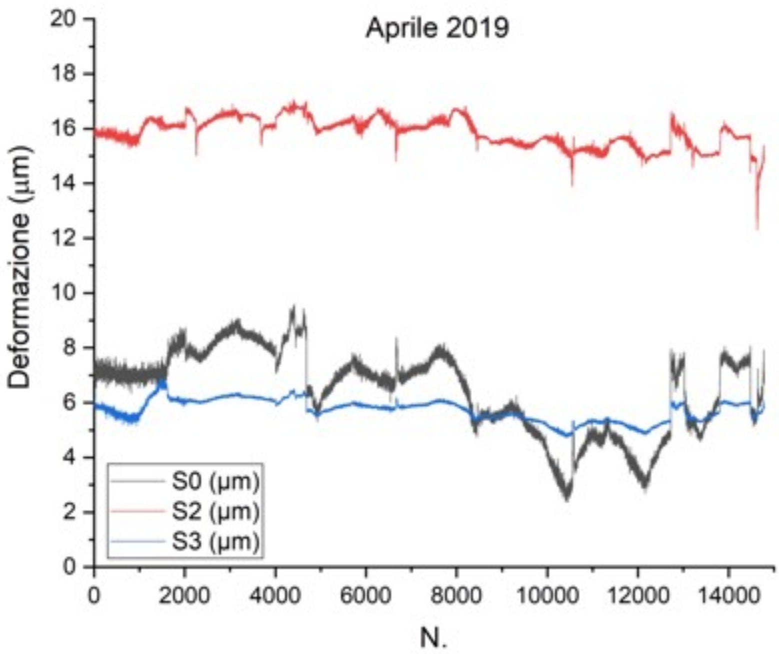


Figure 36 Trend of the strain recorded by FBG sensors inside hall I in April 2019

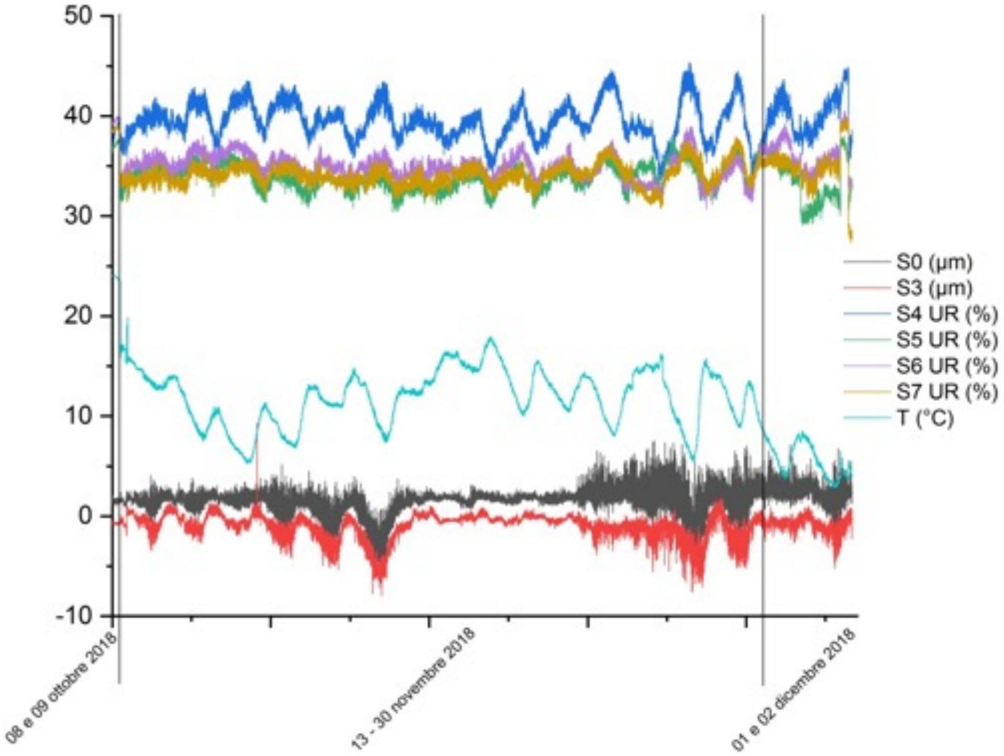


Figure 37 Trend of the values recorded in Michelangelo's Cloister (october-december 2018)

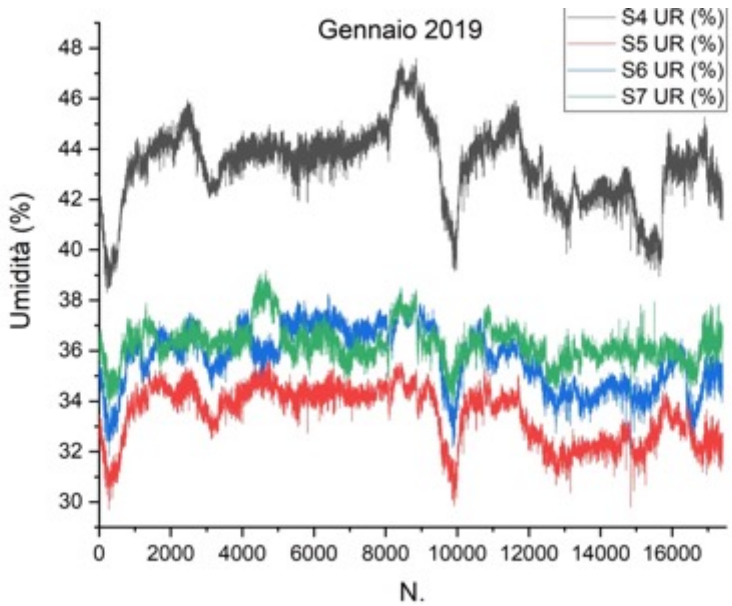


Figure 38 Trend of rising humidity recorded in Michelangelo's Cloister, January 2019

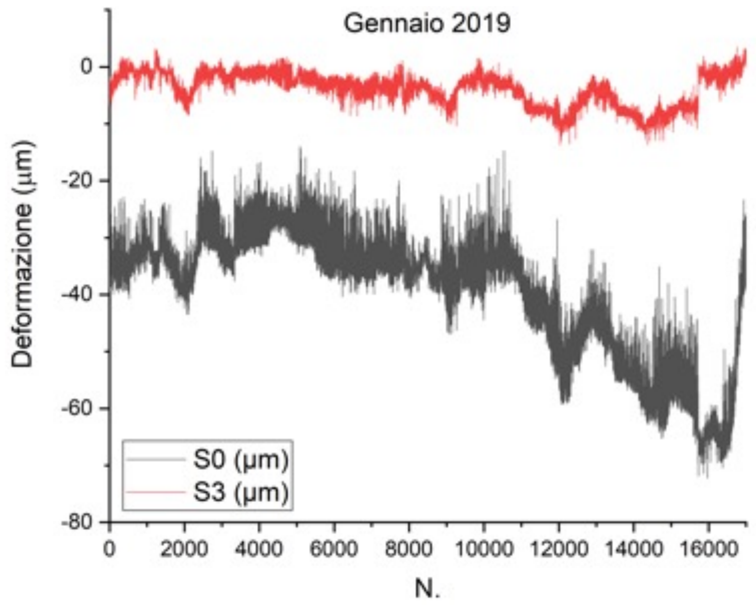


Figure 39 Trend of the values of strain recorded in Michelangelo's Cloister, January 2019

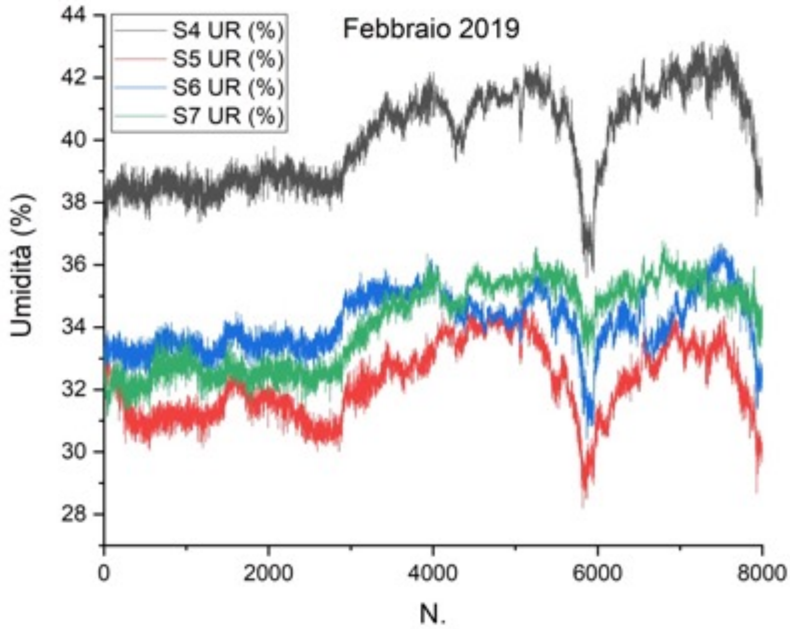


Figure 40 Trend of the values of rising humidity recorded in Michelangelo's Cloister, February 2019

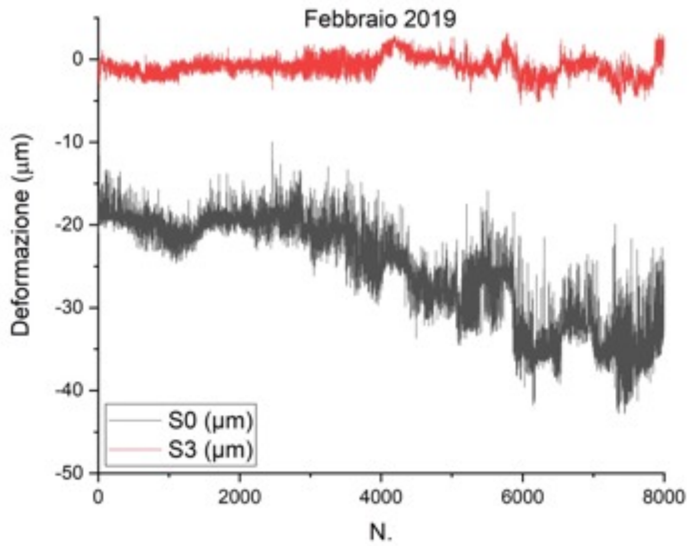


Figure 41 Trend of the values of strain recorded in Michelangelo's Cloister, February 2019

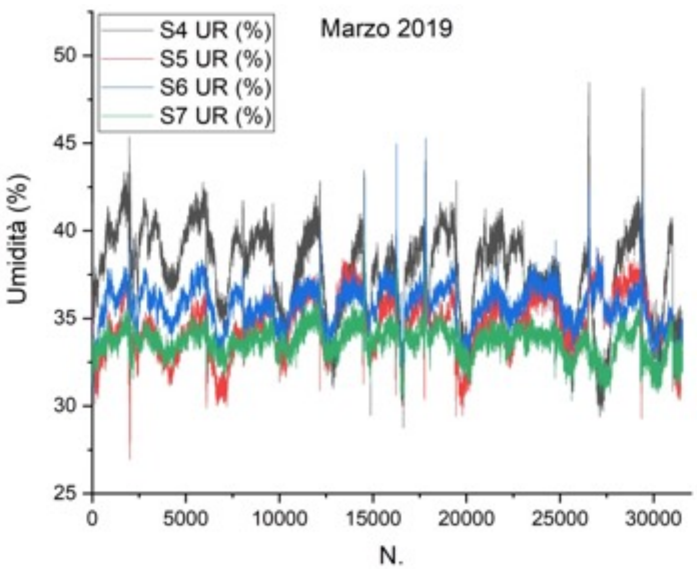


Figure 42 Trend of the values of rising humidity recorded in Michelangelo's Cloister, March 2019

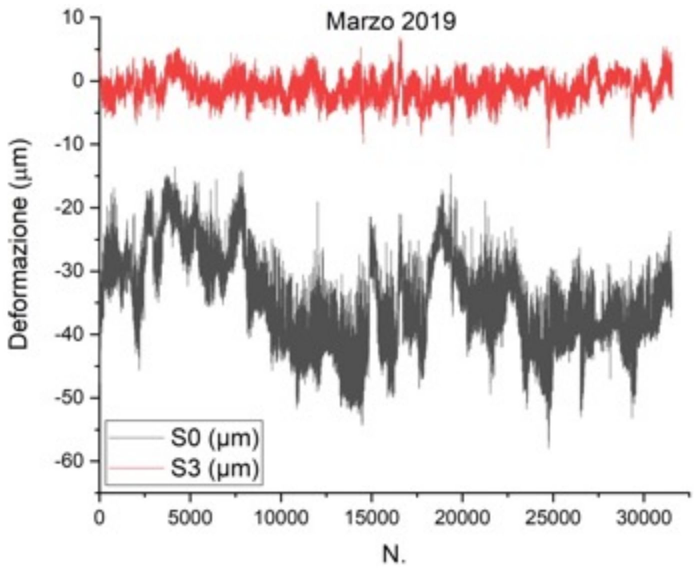


Figure 43 Trend of the strain recorded in Michelangelo's Cloister, March 2019

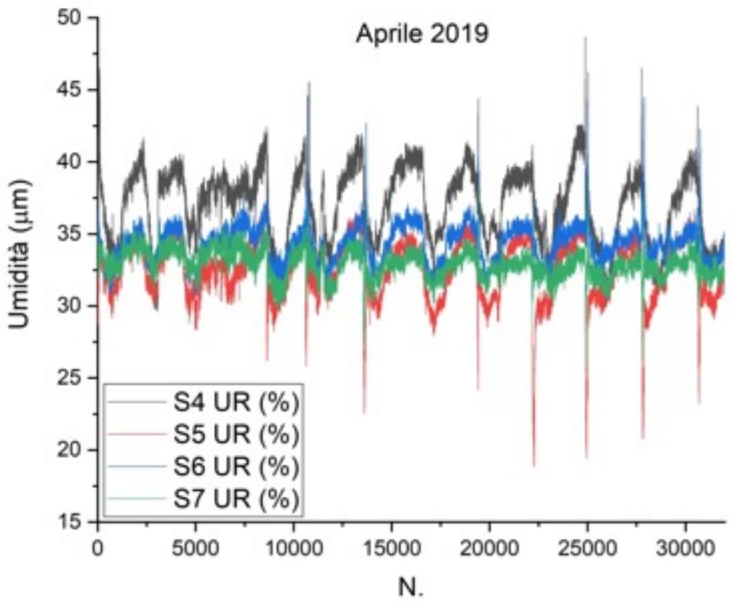


Figure 44 Trend of the values of rising humidity recorded in Michelangelo's Cloister, April 2019

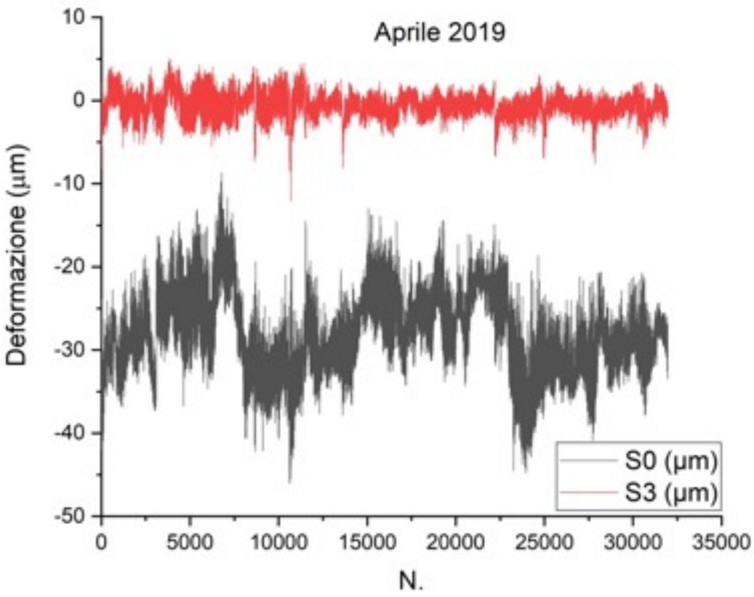


Figure 45 Trend of the values of strain recorded in Michelangelo's Cloister, April 2019

11.2 Arduino sensors network data analysis

The graphs show the trends of both environmental and contact humidity recorded during the years 2017,2018, 2019. The values of contact humidity, generally around 45-60%, show a trend similar to that of the environmental humidity which generally has values 5-10% higher. This can mean that in the masonry area investigated percolation or rising humidity does not produce stagnation. The increase of environmental humidity is due to the climate changes and variations. Probably, since the hall is not an isolated environment, the humidity comes from the ground, by rising dump, and from the external environment. The trends recorded, for the entire period under investigation, are not good for a proper conservation. As already written, a lower level of humidity can cause the production of salt efflorescence, otherwise a higher level of humidity argillification and more generally changes in the nature of the building material. The pressure inside the lesion of masonry is measured inserting in it for some centimetres the FlexiForce sensor, which allows to monitor the stress of the masonry since during its contraction the two inner faces of the wall press on the sensor thus giving a percentage value recorded by the Arduino. During the monitoring period, there were, in particular in the months of November and December 2018, February March 2019, quite significant masonry stress, in terms of expansion or contraction of the investigated lesion. This kind of movements can be dangerous for the preservation of the structure and must surely be kept under control, since they can cause worsening of the lesions and loss of the stability of the wall.

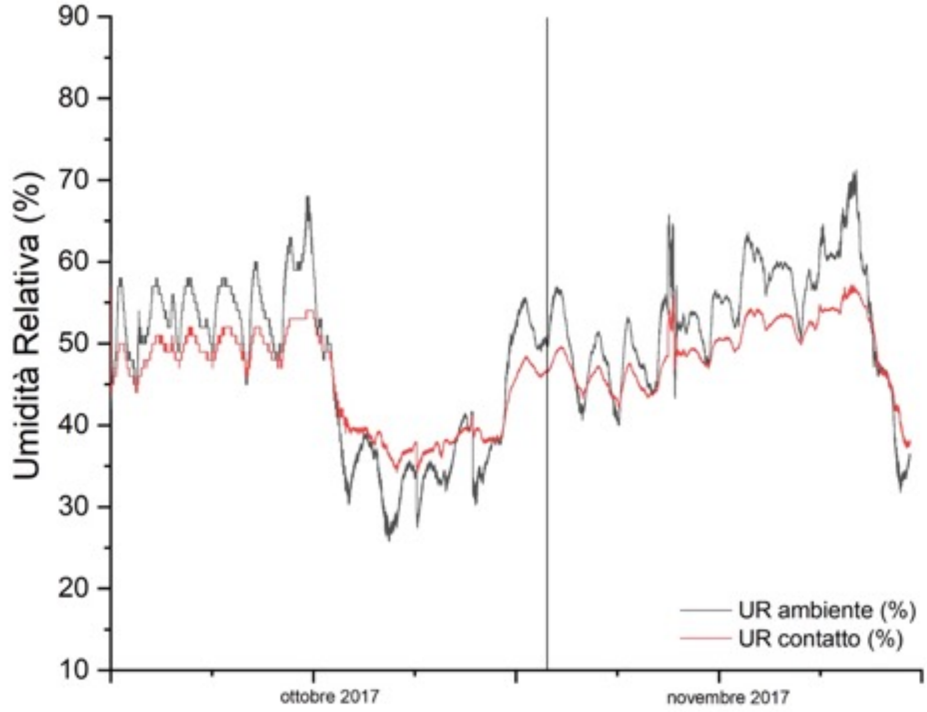


Figure 46 Trend of humidity value by Arduino sensor, October - November 2017.

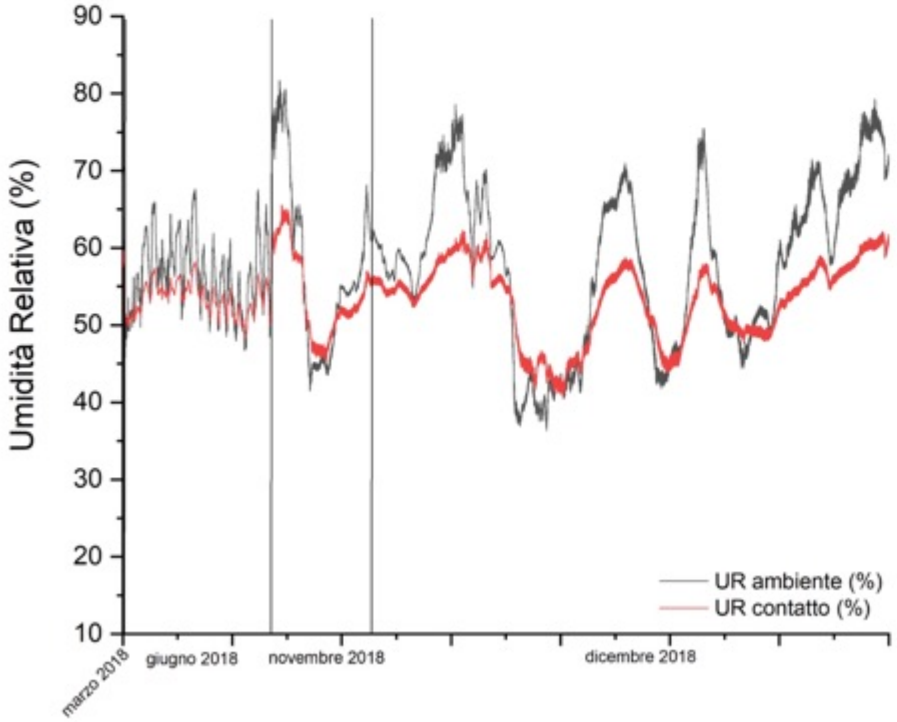


Figure 47 Trend of humidity value by Arduino sensor, March, June, November and December 2018.

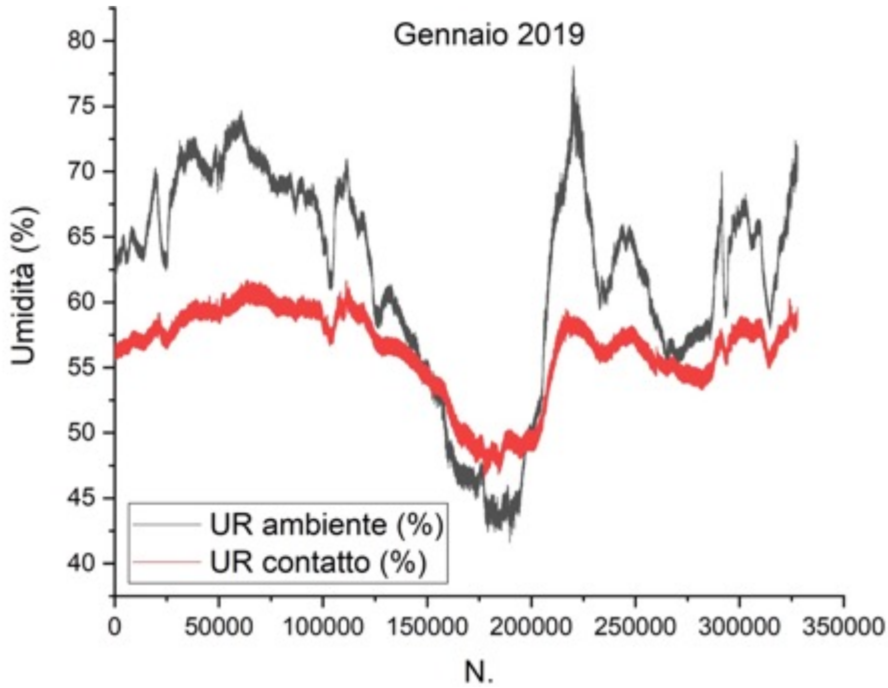


Figure 48 Trend of humidity value by Arduino sensor, January 2019.

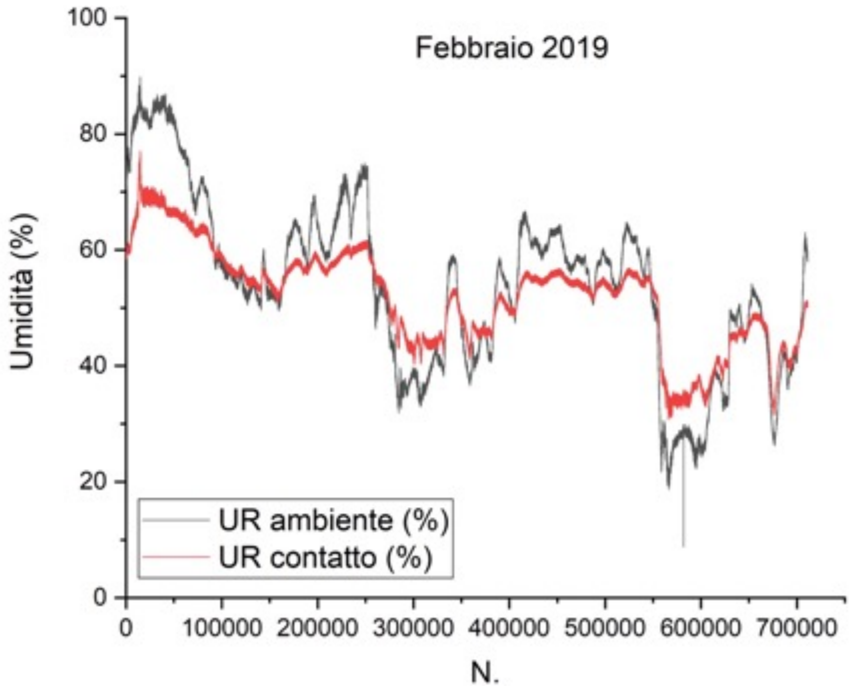


Figure 49 Trend of humidity value by Arduino sensor, February 2019.

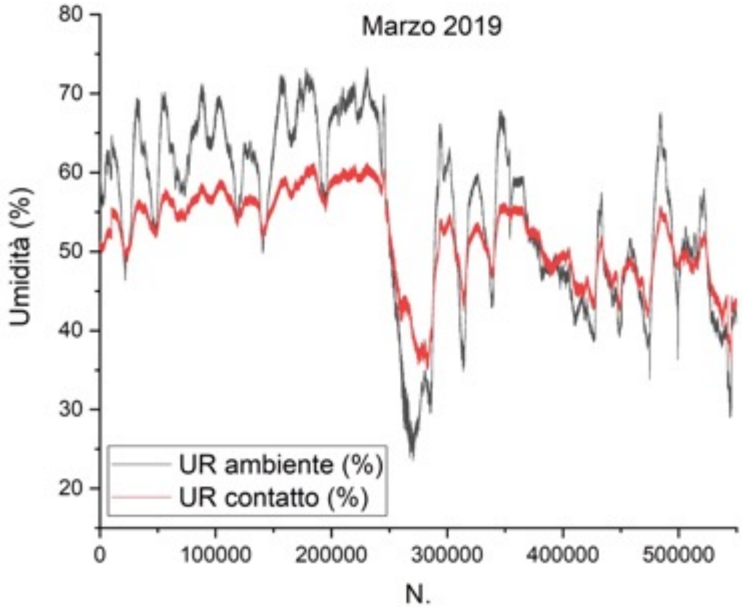


Figure 50 Trend of humidity value by Arduino sensor, March 2019

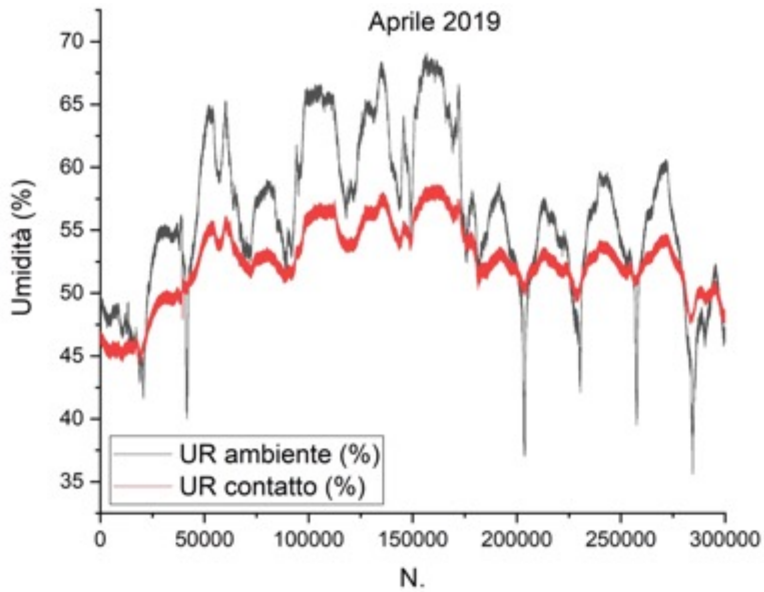


Figure 51 Trend of humidity value by Arduino sensor, April 2019

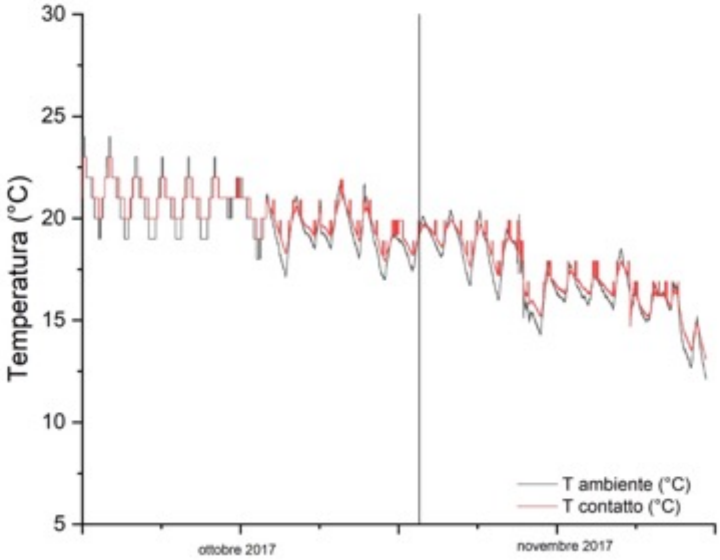


Figure 52 Trends in Temperature values, by Arduino sensor, October and November 2017.

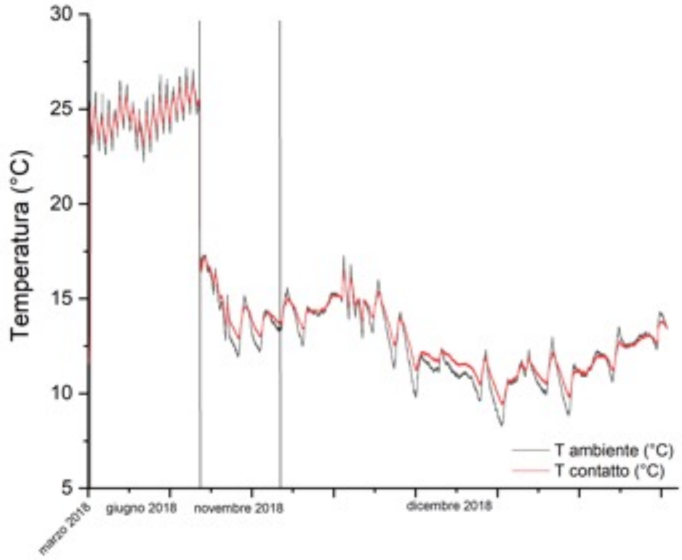


Figure 53 Trends in Temperature values, by Arduino sensor, March, June, November December 2018.

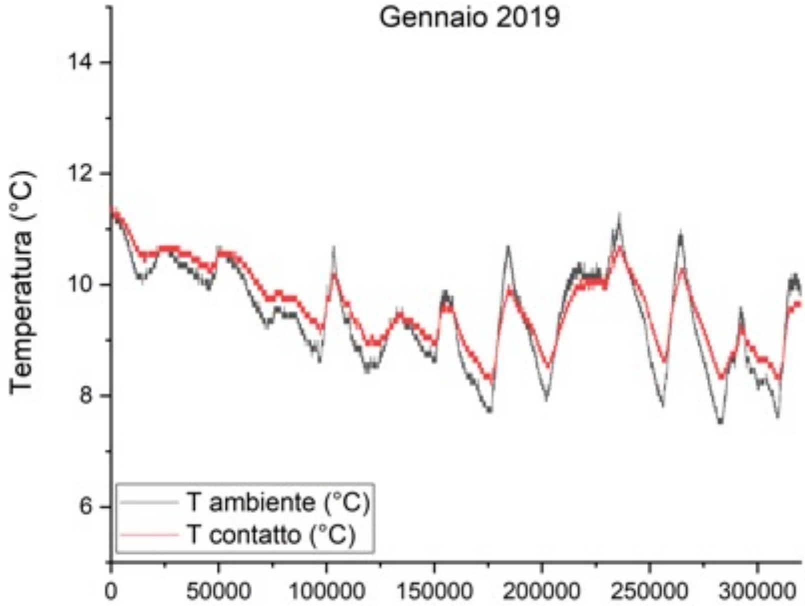


Figure 54 Trends in Temperature values, by Arduino sensor, January 2019.

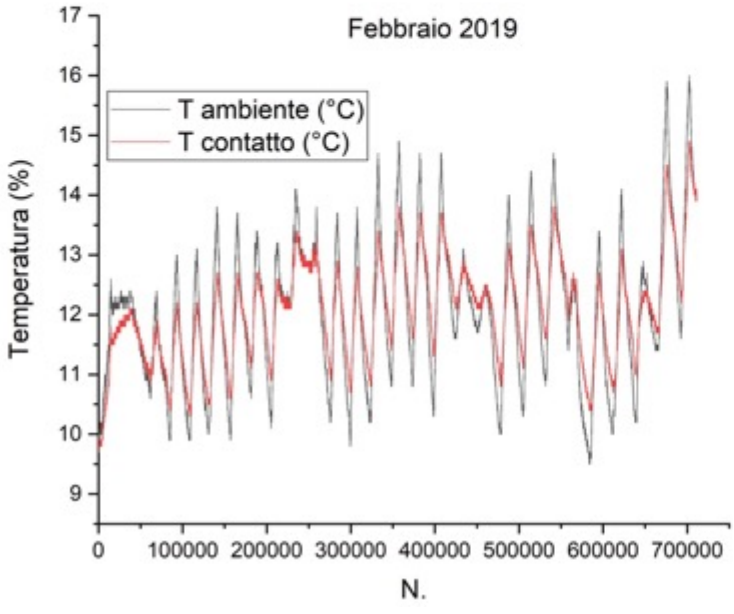


Figure 55 Trends in Temperature values, by Arduino sensor, February 2019.

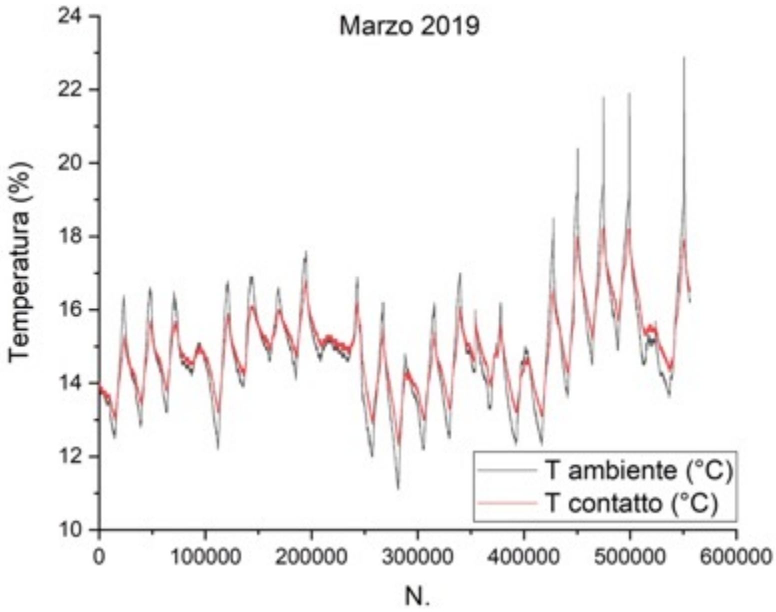


Figure 56 Trends in Temperature values, by Arduino sensor, March 2019.

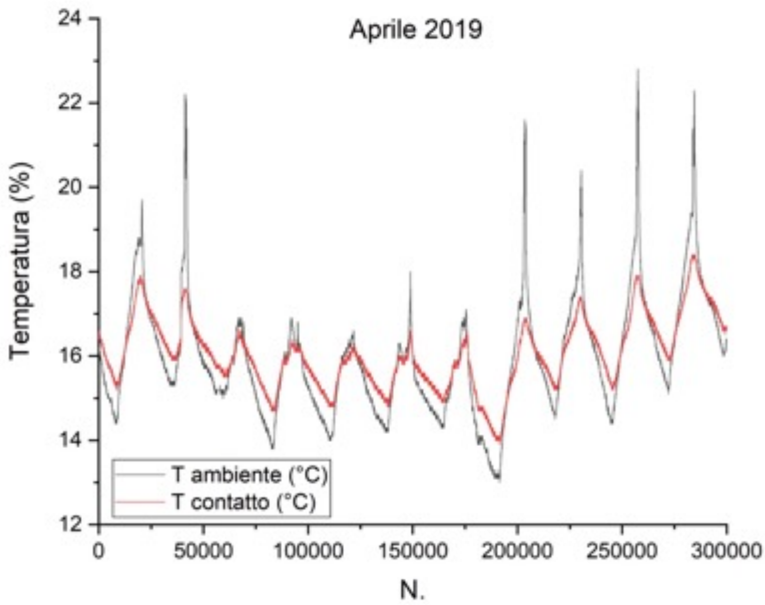


Figure 57 Trends in Pressure values, by Arduino sensor, April 2019.

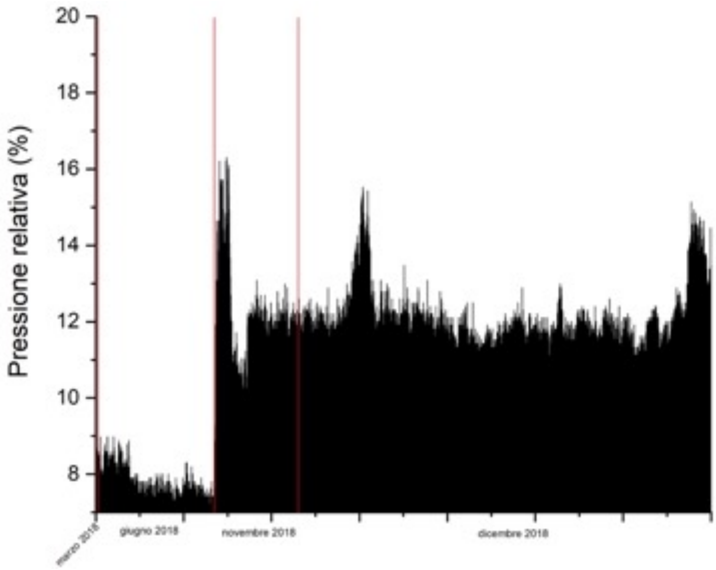


Figure 58 Trends in Pressure values, by Arduino sensor, March, June, November, December 2019

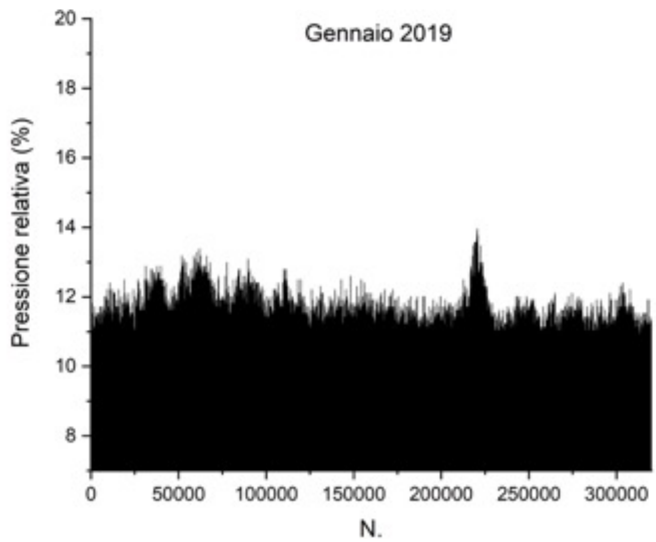


Figure 59 Trends in Pressure values, by Arduino sensor, January 2019

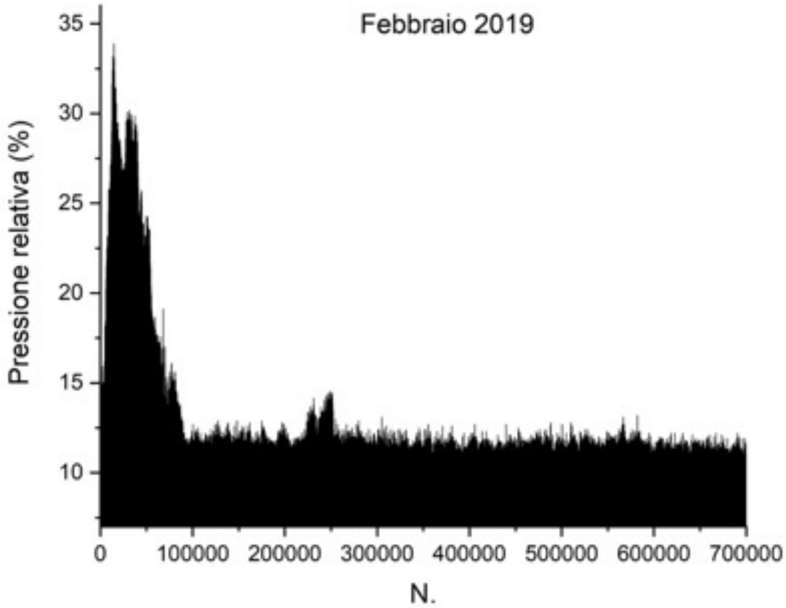


Figure 60 Trends in Pressure values, by Arduino sensor, February 2019

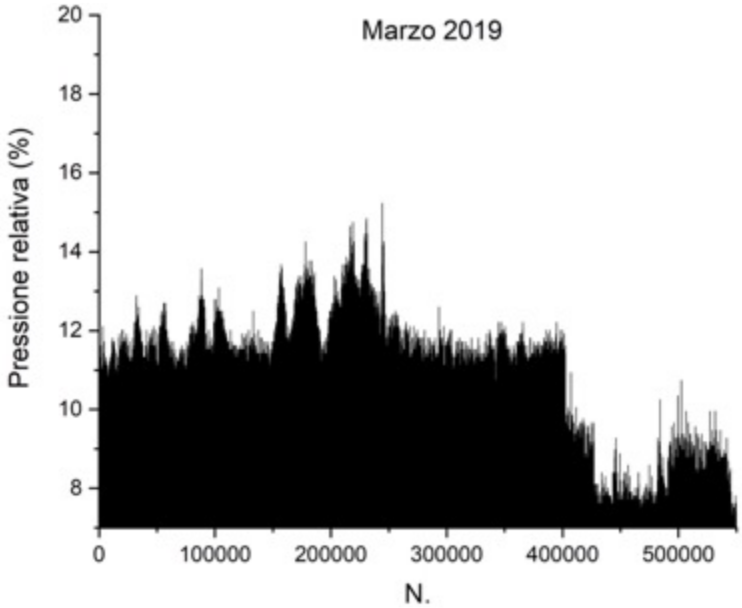


Figure 61 Trends in Pressure values, by Arduino sensor, March 2019

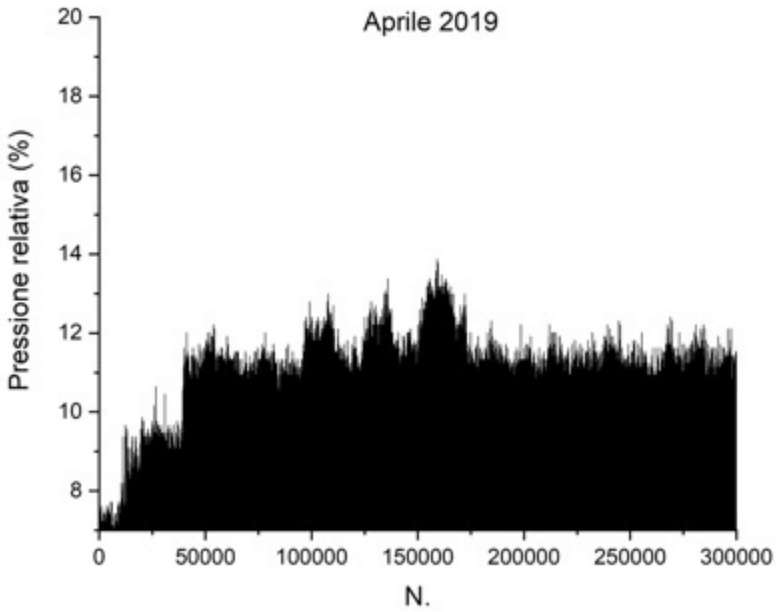


Figure 62 Trends in Pressure values, by Arduino sensor, April 2019

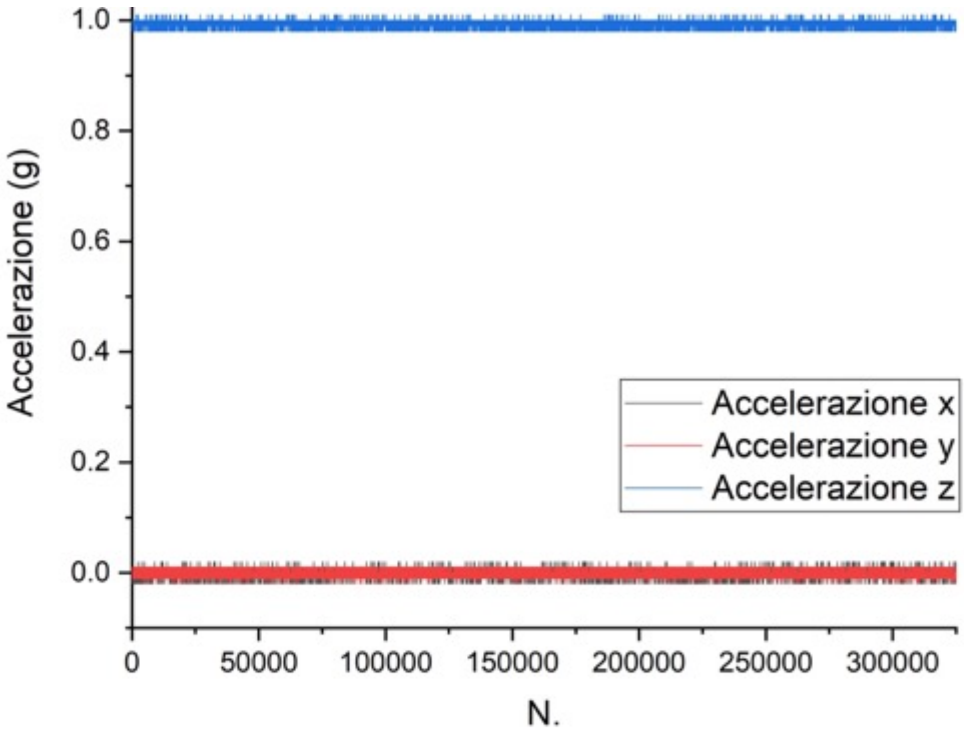


Figure 63 Trends in spatial movement values (XYZ), recorded by Arduino in January 2019

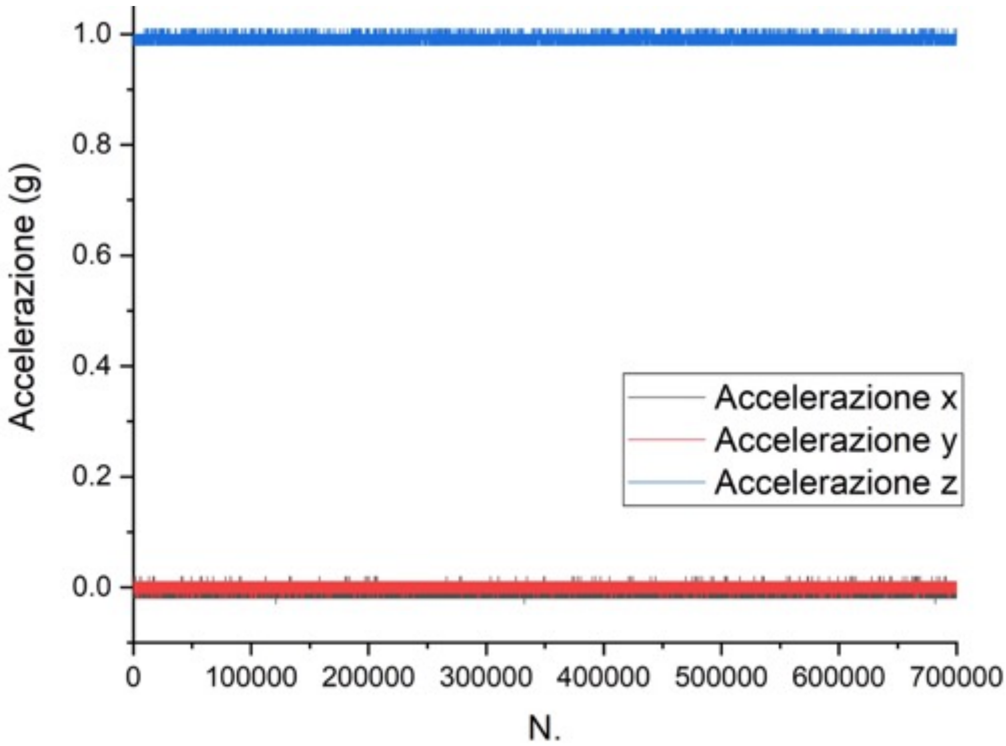


Figure 64 Trends in spatial movement values (XYZ), recorded by Arduino in February 2019

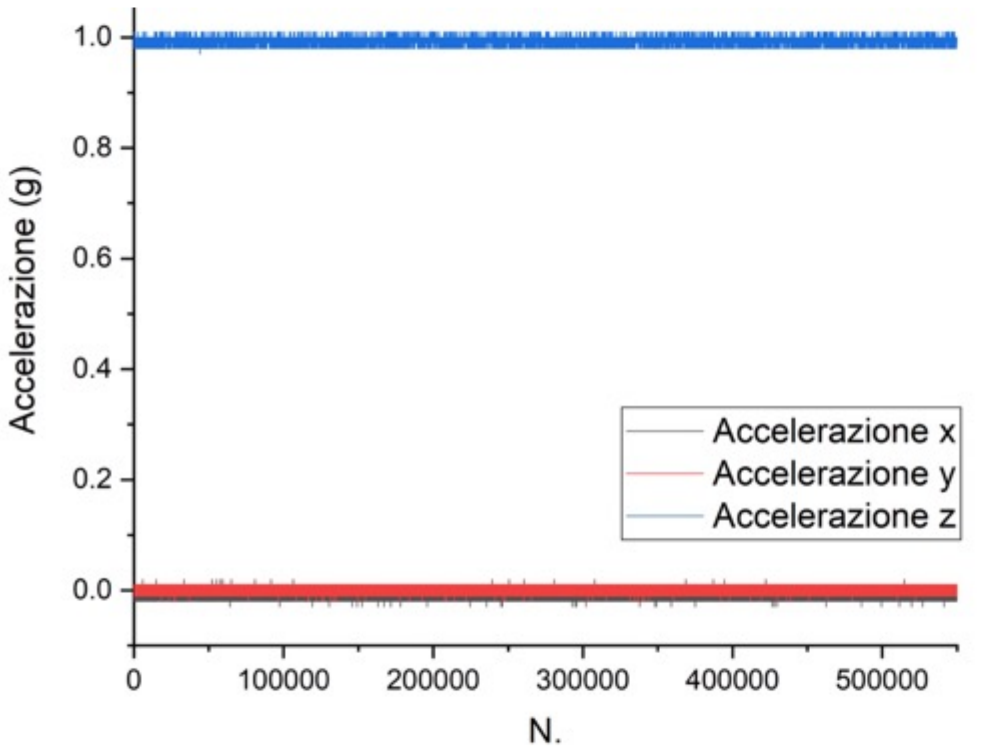


Figure 65 Trends in spatial movement values (XYZ), recorded by Arduino in March 2019

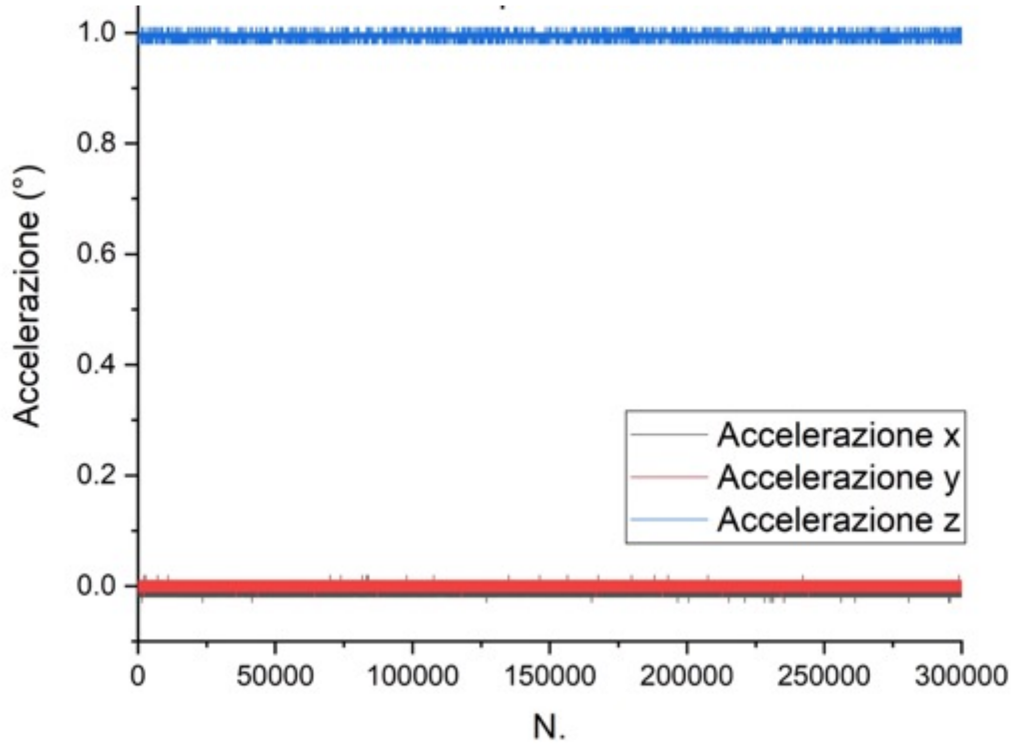


Figure 66 Trends in spatial movement values (XYZ), recorded by Arduino in April 2019

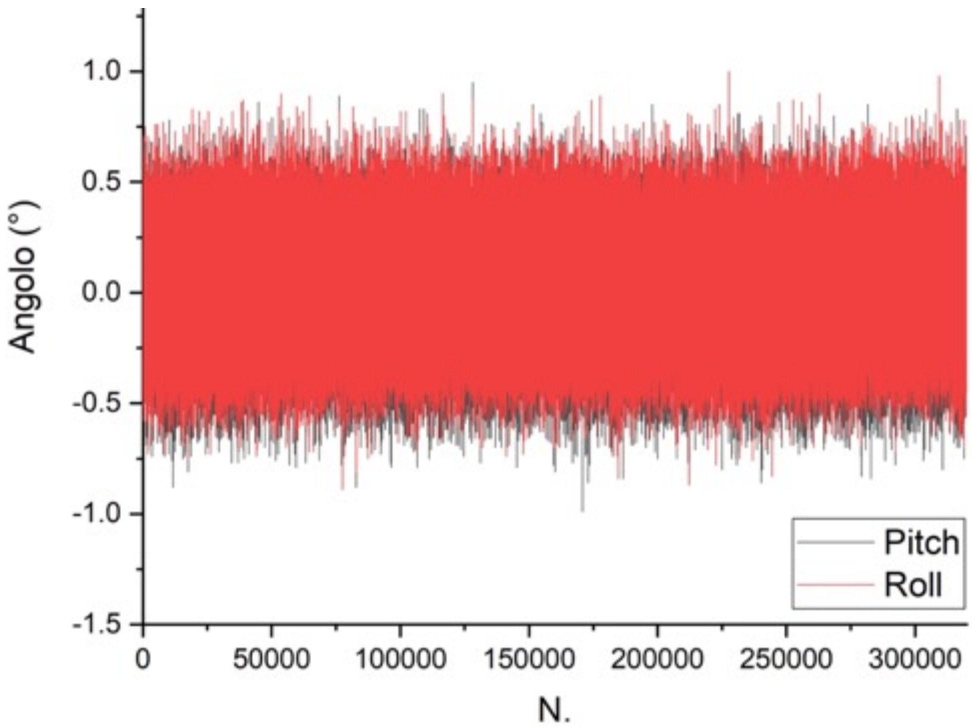


Figure 67 Pitch and Roll Index movements, by Arduino, January 2019.

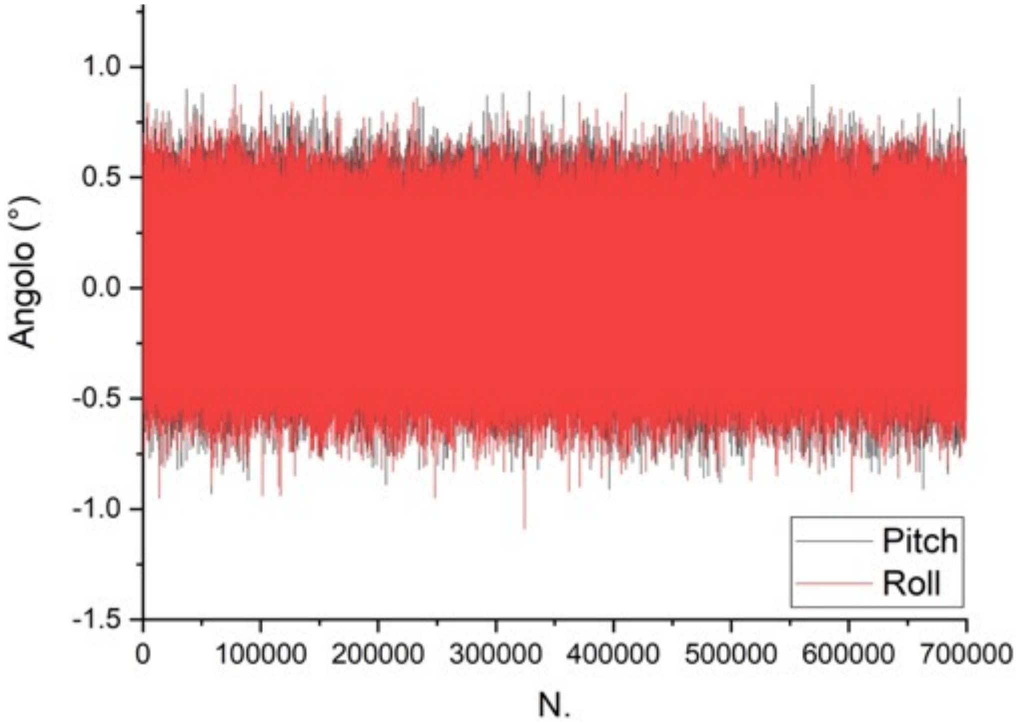


Figure 68 Pitch and Roll Index movements, by Arduino, February 2019.

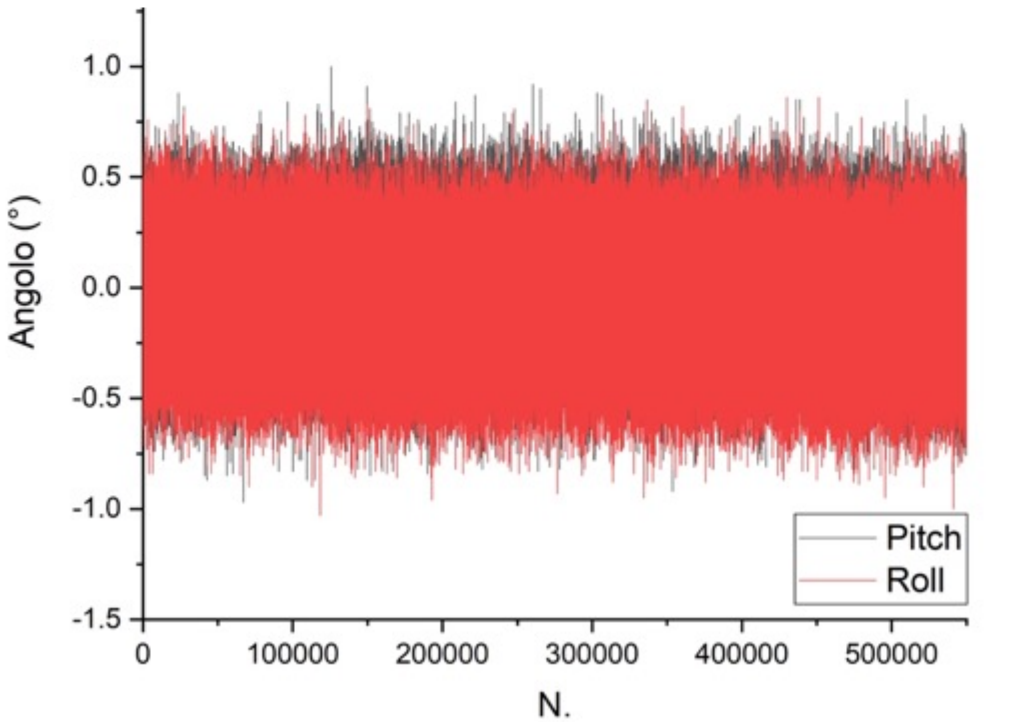


Figure 69 Pitch and Roll Index movements, by Arduino, March 2019.

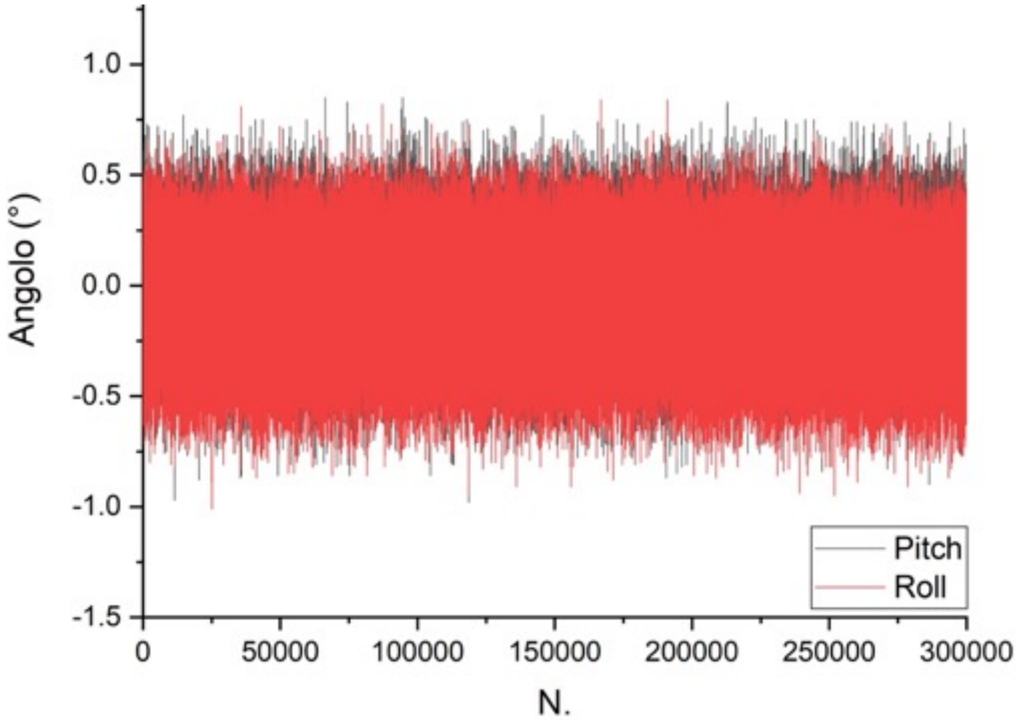


Figure 70 Pitch and Roll Index movements, by Arduino, April 2019.

12 Annexes: Chromatography analysis of salt efflorescences

The aim of this section is the characterization of the salt efflorescence present on the walls of Hall I in Bath of Diocletian.

12.1 Introduction

As reported in D2.2 contribution (A methodological approach with a low environmental impact for Cultural Heritage conservation and maintenance management), in Baths of Diocletian Pilot Site, some of the ancient wall bricks and plasters suffer of different degradation forms as efflorescence, detachments, loss of material, lesion and so on, due to environmental parameters variations such as i.e. humidity, temperature and rainfall, pollution, vibrations (caused by traffic or earthquakes) and structural movements.

In particular, salts efflorescence phenomena in the wall bricks Hall I (reference in D 5.3 and D9.1), triggered by the extreme changes that occur in humidity cycles and monitored by FBG sensors, have been characterized with chromatographic analysis

12.2 Materials and Methods

For soluble salts analysis, efflorescences were taken from the surface of the external and internal wall of the Hall I. Due to atmospheric conditions and by gravity the superficial crystallizations on the outside wall are easily lost, for this reason, for having a sufficient sample for the analysis, the salts were taken from three different points (fig. 24a), thus with an average value for the masonry.

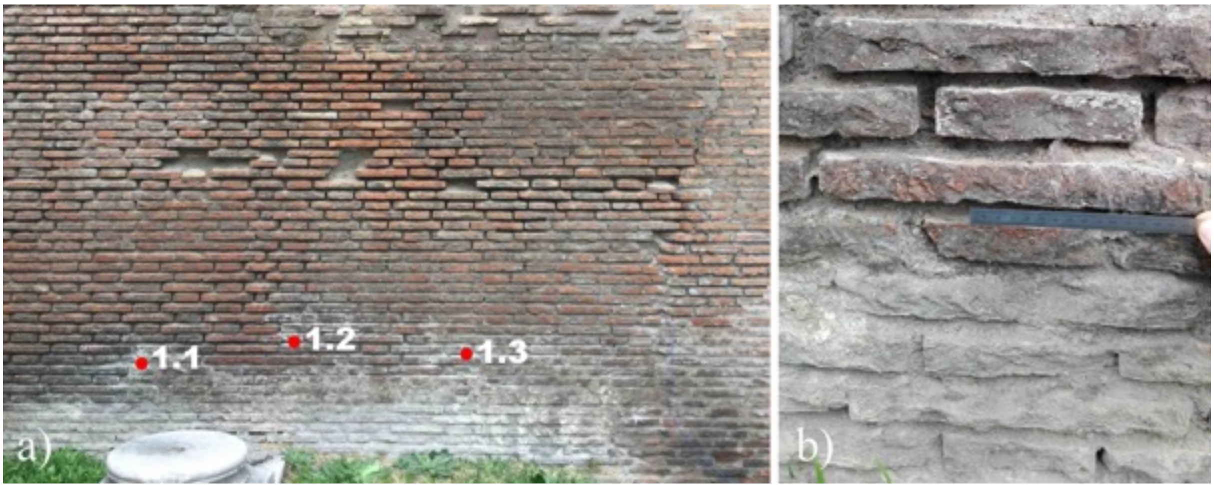


Figure 71 (a) Sampling points of the external wall with minimal presence of efflorescence. b) detail of wall bricks.

Inside, the samples were taken in three points, one for each part of the masonry investigated with FBG optical fibre (figure 24a). The slow thermo-hygrometric variations, due to the closure to the public of Hall I, allowed dissolved salts to migrate to the surface by the capillary effect of the water, and crystallize in long beards (figure 25b-c).

The samples were stored in Eppendorf tubes and bring in the laboratory where 0.1g was dissolved in 100 mL of distilled water (Still 3b Intercontinental distiller, Λ <2 μS) and placed in an ultrasonic bath at room temperature, as required by the UNI 11087: 2003 normative. The soluble salts in the solution were quantified on a Metrohm 761 Ion Chromatograph, equipped with Metrohm pre-column and Metrosep AS14 column 4x250. The mobile phase composition was sodium carbonate (Na_2CO_3) 2.3 mM, sodium bicarbonate ($NaHCO_3$) 2.2 mM and methanol (CH_3OH) 1%.

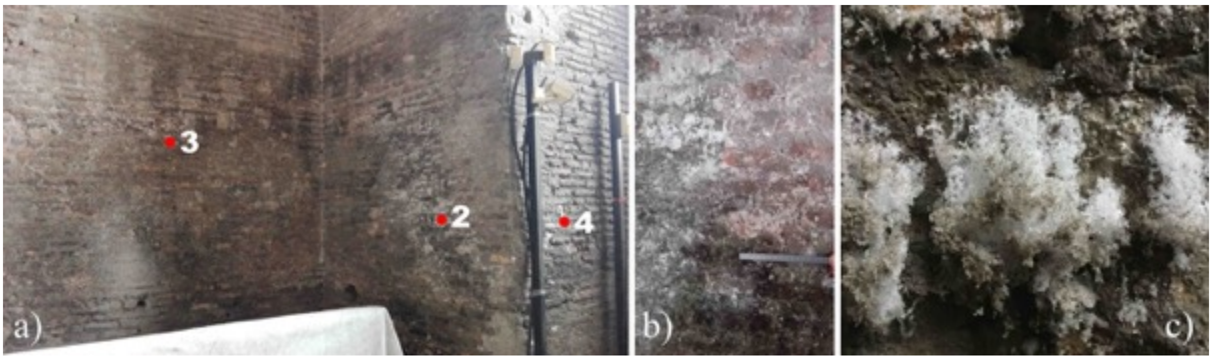


Figure 72 (a) Points of the masonry inside the Hall I where the samplings were made (b) Detail of the masonry and (c) of the salt efflorescences.

12.3 Results

Some anions (Cl^-, NO_3^- and SO_4^{2-}) were determined. For chromatograms elaboration, the Metrohm's IC-NET v.2.3 software was used. In table 1 are shown the results of the average concentration values in ppm, with associated standard deviations (±). All samples were analyzed in triplicate.

No significant differences were noted between inside and outside wall bricks; in all the points analyzed the amount of chlorides is similar, while the sulphates, probably coming from making up masonry materials, are greater inside due to the environmental conditions previously exposed. Still in sulphates relation, as shown in table 4, the same values are highlighted in samples 2 and 4 (two angle faces connected), index of the same capillary rising source.

Table 32 Concentration values and standard deviations of the investigated anions.

Sample	Chloride Cl^-		Nitrate NO_3^-		Solfate SO_4^{2-}	
	Conc. (ppm)	Standard dev. (ppm)	Conc. (ppm)	Standard dev. (ppm)	Conc. (ppm)	Standard dev. (ppm)
1	4.4	0.2	774.2	8.3	1.1	0.1
2	4.2	0.1	689.7	0.9	6.1	0.1
3	3.8	0.1	667.4	3.2	13.8	0.1
4	5.6	0.1	664.9	1.5	6.3	0.1

The significant amount of nitrate, which is greater on the outside and very similar among the internal samples, is warrying and leads to think about to its high amount in the soil. Other trace anions were evident, such as: fluoride F^-, acetate CH_3COO^-, nitrite NO_2^-, bromide Br^-, oxalate $C_2O_4^{2-}$ as shown in figure 26.

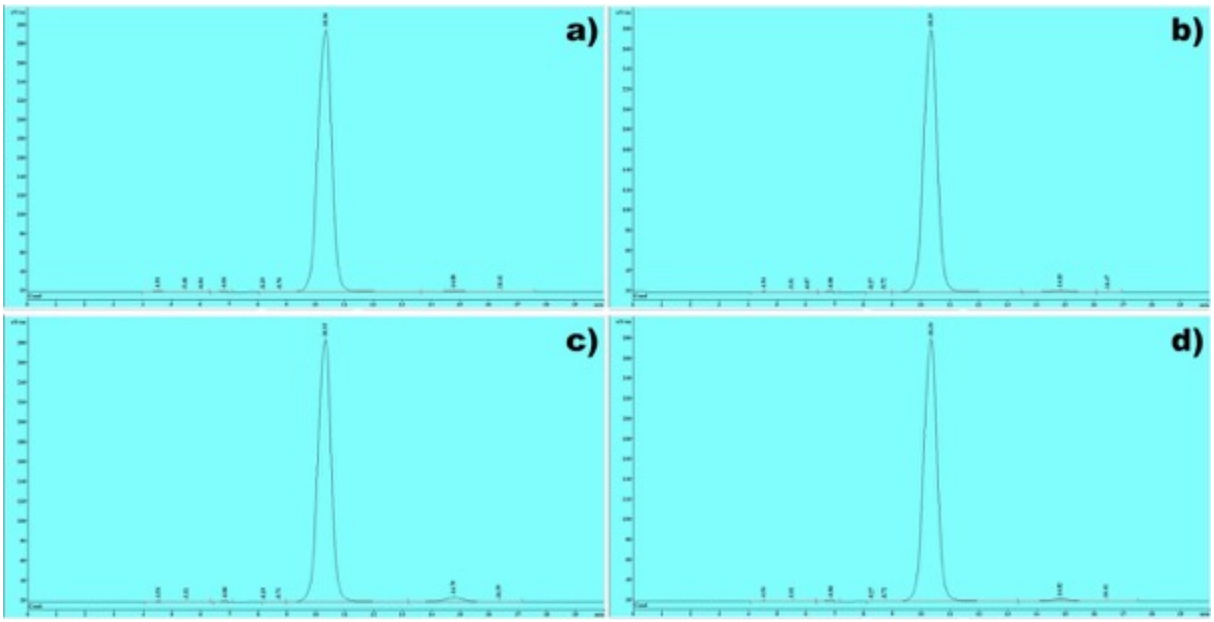


Figure 73 Chromatograms of the first repetition of the salt solutions. (a) Sample 1 obtained from samples taken outside Room I; (b) sample 2, sampling on the south face of the masonry; (c) sample 3, taken from the east face (optical fibre present); (d) sample 4, taken from the right edge of the east face.