HERACLES NEWSLETTER

Nº8 - December 2018

HERACLES

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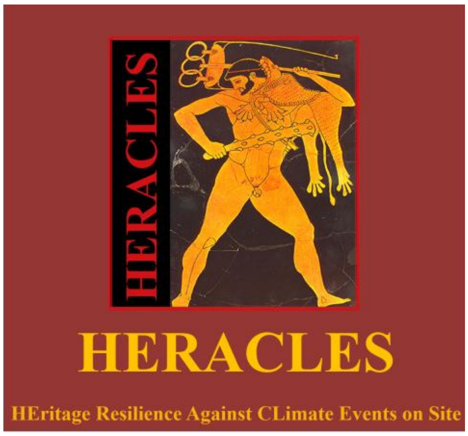
CASE STUDIES

GUBBIO, ITALY:

3. Town Walls
4. Consoli Palace

CRETE, GREECE:

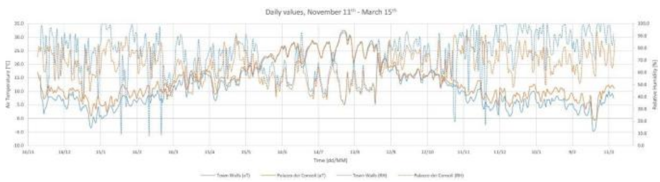
1. Minoan Knossos Palace
2. Venetian coastal fortress of Koules



ANALYSIS OF THE MICROCLIMATE AND ENVIRONMENT INFLUENCING THE DEGRADATION STATE OF CONSOLI PALACE

To dispose of a micro-climate picture around the Consoli Palace and Gubbio historical city center areas, non-invasive tests were specifically carried out with the purpose to exhaustively investigate local microclimate boundary conditions by integrating a novel small-scale microclimate experimental equipment and infrared thermography. The combination of multisensing local analysis provided a clear view not only on each monument, but on the city variability of weather conditions, which of course cannot be detected by fixed weather stations located nearby or global

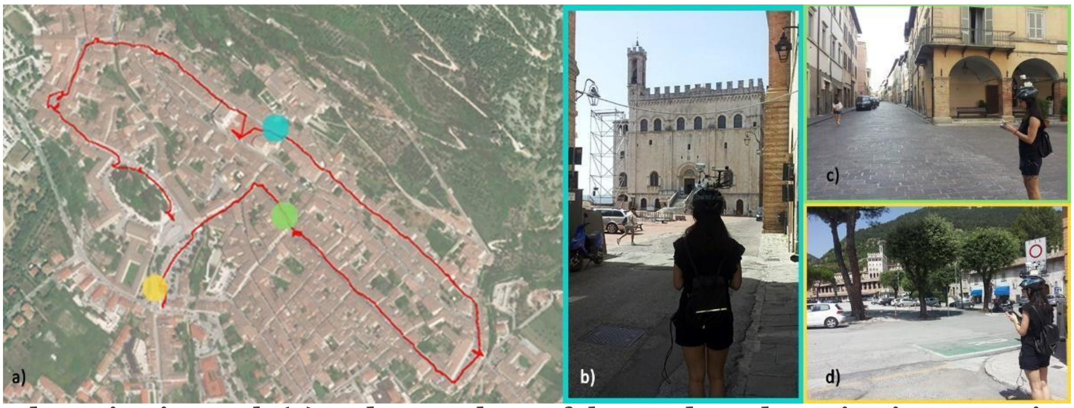
climate and mesoscale models. In this view, the analysis of such local boundaries allows the real identification of those constrains/impacts effectively compromising the CH preservation in terms of structural integrity, material degradation, and design of proper conservation strategies.
That being said, the Consoli Palace and Town Walls sites were the object of specific microclimate assessment, done through one-day survey, during summer. The first analysis, reported in Figure 49, shows that the Consoli Palace and the Town Wall areas are characterized by radically different hygrothermal conditions, which evidence the necessity to investigate local weather conditions in a more site-specific way, not only considering mesoscale effect, modelling or single-spot weather stations.



Air temperature and relative humidity daily values collected in proximity of the two test- beds in Gubbio, i.e. Consoli Palace and the ancient town walls.

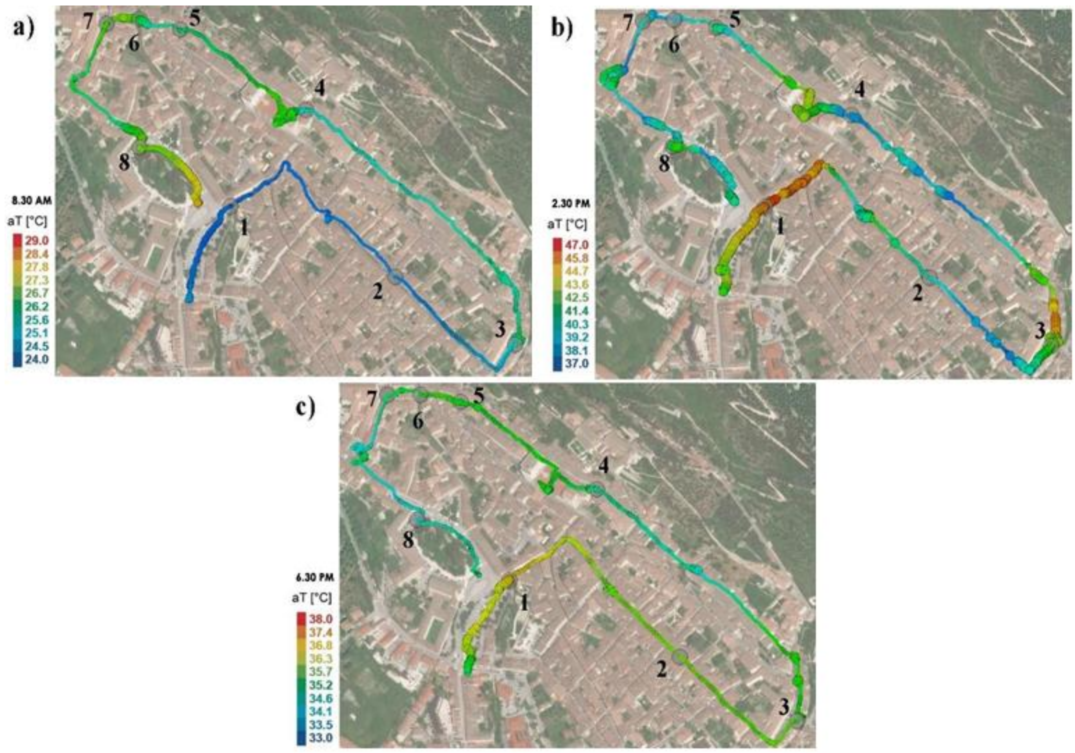
Such difference is particularly evident during winter, in fact this season is critical since icing and deicing paths and water condensation phenomena were shown to be responsible for cracking and micro-cracking, observed in materials and infrastructures.

The site-specific microclimate assessment has been done through one-day monitoring campaign in summer, by means of a miniaturized weather station. The monitoring device is small-size and light-weight in order to be easily carried on by walking people and detect granular microclimate conditions, as possible responsible for local risks The station includes the following sensors: thermos-hygrometer, pyranometer, anemometer and CO_2/VOC concentration detectors. The monitoring device is small-sized and light-weight in order to be easily carried on by walking people (more details are reported in the HERACLES deliverables D8.1 and D8.2). Since the Consoli Palace is located in the heart of the medieval city of Gubbio, the monitoring pathway was planned through different parts of the historic center to get the existing microclimate condition of the whole heritage monument surroundings. The planned pathway crosses the most touristic areas of the city including open green areas, paved squares and narrow urban canyons (Figure 50). The monitoring path was repeated three times, i.e. 8:30 a.m., 2:30 p.m., and 6:30 p.m., during a heat-wave in summer 2017.



Followed monitoring path (a) and some shots of the conducted monitoring campaign taken at the points highlighted on the map (b,c,d)

Figure 51 shows the air temperature variation within the monitored urban environment for all the times of the monitoring. The pictures give also information related to the solar radiation by using markers of various sizes, whereby bigger markers represent higher level of detected solar radiation. Specific spot measurements carried out in the Consoli Palace itself were already described in the previous section.

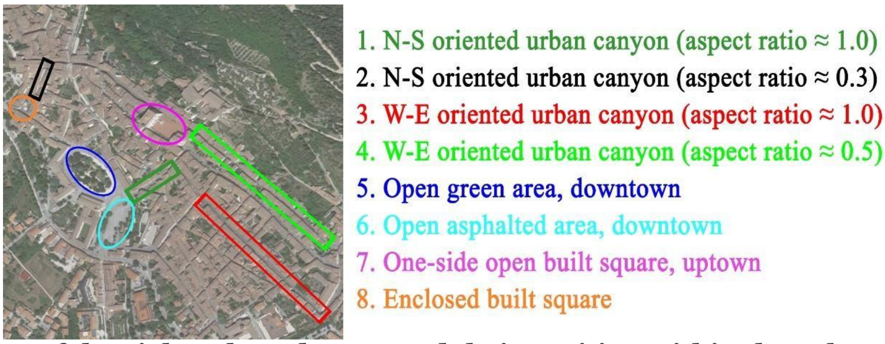


Space-varying distribution of the air temperature and the global solar radiation data collected at 8:30 a.m. (a), 2:30 p.m. (b), and 6:30 p.m. (c).

The huge differences observed in terms of detected air mean temperature during the three repetitions does not allow to maintain the same colour palette range. More in details, the mean air temperature observed in the morning, i.e. 8:30 a.m., is 25.4°C. The air temperature raised up as the global solar radiation increased and an averaged value of 40.9°C is detected at 2:30 p.m. After the midday maximum peak, air temperature naturally deceases and an average of 35.2°C is therefore detected at 6:30 p.m.

The collected global solar radiation never exceeds 500 W/m^2, exception made for some open or south-facing areas at 2:30 p.m. Therefore, the maximum global solar radiation detected was 484,9 W/m^2, 918,4 W/m^2 and 314,6 W/m^2 at 8:30 a.m., 2:30 p.m. and 6:30 p.m. respectively. Finally, a similar mean wind speed was detected all the three times, i.e. 1,4, 1,7 and 1,6 m/s at 8:30 a.m., 2:30 p.m., and 6:30 p.m. respectively. Moreover, values above 4 m/s were more often detected during the hottest hour, i.e. the 4,5% of time at 2:30 p.m. with respect to the 0,8% and 1,5% at 8:30 a.m. and 6:30 p.m. respectively.

Given the outlined overview, a more specific analysis is carried out to highlight intra-urban microclimate variations due to site-specific urban configurations. For this purpose, four typologies of urban canyons and four different kinds of town squares are selected as shown in Figure 55.

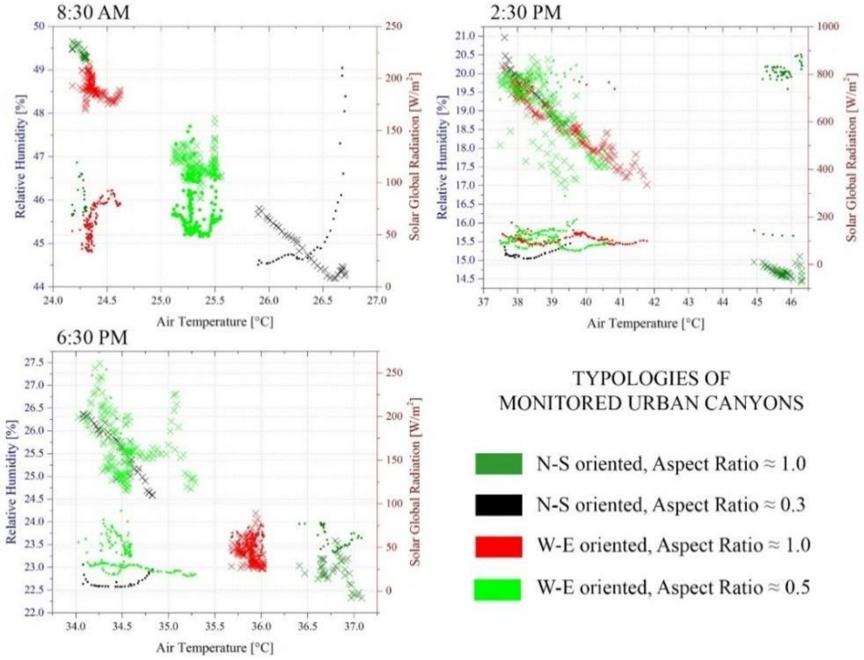


Pictures of the eight selected areas and their position within the urban context.

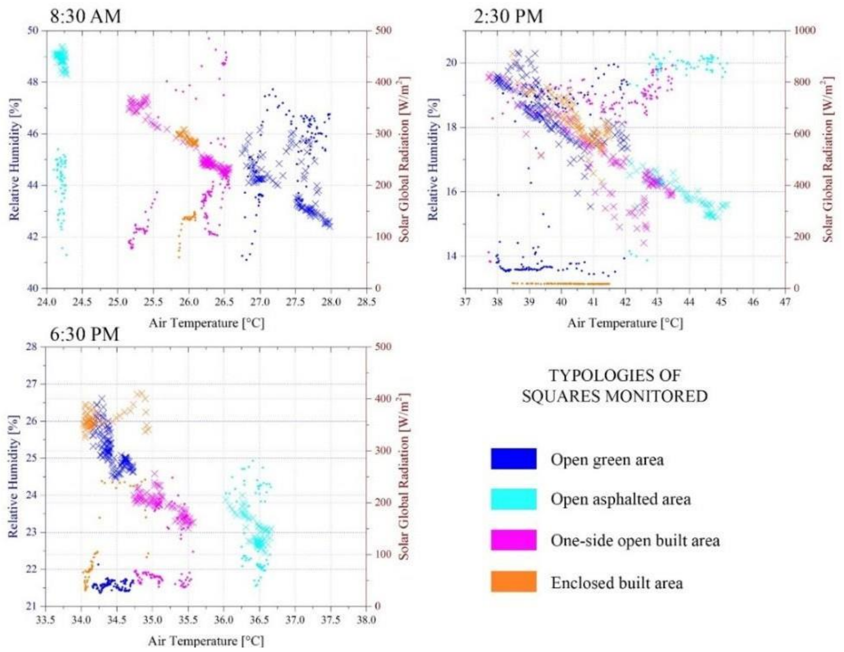
The environmental parameters collected within each selected site depict a non-negligible diversification of the urban microclimate. More specifically, the relative humidity and the global solar radiation are plotted with respect to the air temperature for the four urban canyons and the four town squares previously identified. The plots result in quite clearly defined data clusters with no strong over- lapping conditions between the data collected among the different selected areas. This is particularly evident in the early morning (8:30 a.m.) and late afternoon (6:30 p.m.) when the main external energy source, i.e. the incoming solar radiation, is less strong. The detected global solar radiation depends on the accessibility of the incoming radiation and consequently on the geometrical configuration of the areas. Therefore, sensible differences between the maximum and the averaged values of that parameter are detected during the monitoring. The major differences are shown among the West-East oriented urban canyons where the incoming solar radiation cannot easily access even at 2:30 p.m. For that time, the averaged value of the detected solar radiation is 201,2 W/m^2 and 155,4 W/m^2 among the streets presenting such orientation and 0,5 and 1 as aspect ratio respectively, with respect to a maximum peaks detected of 856,7 W/m^2 and 771,7 W/m^2.

Moreover, focusing on urban canyons collected data (Figure 56), daily temperature fluctuation is maximum in those streets with relatively higher aspect ratio. In fact, the difference between the averaged air temperatures detected at 8:30 a.m. and 6:30 p.m. are 12,5°C and 11,5°C for the streets having a height-to-wide ratio around 1, North-South and West-East oriented respectively, while are equal to 8,2°C and 9,2°C for the other two selected cases, i.e. the North-South oriented street with an aspect ratio of about 0,3 and the West-East oriented street with an aspect ratio of 0,5.

Concerning the analysed town squares (Figure 57), the widest daily temperature range is detected among the open asphalted area, i.e. 12,2°C, which presents the highest sky-view-factor. The most buffered air temperature variation is instead detected among the open green area, i.e. 7°C, which highlights the mitigation capability of the greenery.



Relative humidity and global solar radiation plotted with respect to the air temperature at all the monitored times for the four selected urban canyons.



Relative humidity and global solar radiation plotted with respect to the air temperature at all the monitored times for the four selected town squares (the purple indicators refer to the Consoli Palace square).

Finally, the air quality is analysed through CO_2 and VOC concentration data collected by the wearable system. The Gubbio historic centre is not a polluted area, with relatively low traffic condition. The average levels of CO_2 detected are always between 300 and 400 ppm, exception made just for the open green area at 2:30 p.m. and the main square, mentioned as the one-side open built square during the

analysis, at 6:30 p.m. The green area is a huge open space located at the bottom of the historical city and surrounded by a carriage road. The presence of passing cars has most probably determined an average level of CO_2 slightly higher than the other ones at 2:30 p.m., i.e. 405 ppm. The highest level of CO_2 monitored among the one- side open built square, i.e. 459 ppm, is mainly due to the very high maximum peak detected in that area, i.e. 3501 ppm, which can be attributed to a vehicle passing really close to the monitoring system which affects the air quality statistics of that area. Furthermore, no differences among the selected areas are highlighted in terms of wind speed and VOC concentration monitored ranges.
The present analysis shows how local microclimate varies within the test bed environment. Such variations affect both cultural heritage preservation and pedestrians/visitors thermal comfort and therefore is fundamental to take into account these site-specific characteristics to realize tailored counteracting strategies. In details, the site specific intra-urban monitoring highlighted that it is necessary to analyse site by site each context in order to identify the peculiarity of each CH asset environment, towards its preservation. In detail, the cluster analysis showed that the particular characterization of both microclimate and air quality parameters represents an important integration to the weather conditions info of the site. Therefore, this activity can effectively integrate the classic one-site permanent monitoring carried out by weather stations in fixed positions for better predicting local specific factors that can affect the CH asset.

SUMMARY OF THE DEGRADATION STATE OF CONSOLI PALACE

The diagnostic and analytical activities that took place on the Consoli Palace, with the aim to approach the degradation of materials and assess its structural health conditions are summarized in the following Table 7:

Critical Issues	***Investigation Technique***	***Results***
Structural Health evaluation	*Visual and thermo Graphic inspections on Consoli Palace*	*An existing moderate/significant crack pattern on the whole building Has been highlighted and surveyed/mapped in details including indoor and outdoor environments.*
		Moderate/significant degradation conditions over th main façade of The Consoli Palace have been detected and surveyed/mapped in details.
	GPR surveys	*Information on the structural elements, such as wal texture. Has been provided. No critical elements affecting the Consoli Palace floor structure were detected. The crack affecting the wall of the cross-hall leading to the Loggia is as deep as the first layer stones and requires to be monitored and a further GP survey has been performed in May 2018. The crack patterns at the Loggia walls did not appear critical at the moment of the survey.*
	Ambient Vibration Testing and Operational Modal Analysis	*Baseline modal parameters of Consoli Palace have been obtained and are available as benchmark for future tests with comparative diagnostic purposes, even after the end of the project.*

	Finite element modeling and model calibration	*A structural FEM model of Consoli Palace has been built and calibrated on the basis of experimental results. The model is available for structural analysis under any type of loading, such as a future strong wind event or earthquake.*
	Finite element structural analysis under vertical and lateral (earthquake) loading	*The existing damage pattern (cracks) in the building has been interpreted by identifying the cause of each crack and in particular identifying those caused by vertical loads (virtually stable cracks) and those caused by past earthquakes (potentially unstable ones).*
	Long-term static and vibration-based Structural Health Monitoring	*Natural frequencies of Consoli Palace, as well as major crack amplitudes, have been tracked in time and environmental (temperature) effects on such static and dynamic response parameters have been characterized and removed through statistical filtering. A control chart tool has been constructed that will highlight in the future if structural damages able to modify the dynamic properties of the building or the amplitudes of major cracks will occur.*
	Thermal model	*The thermal model of the palace highlighted how the future climate change projections may be effectively integrated and correlated to site specific thermal inspection, which clearly show the tendency to exacerbate the Palazzo degradation due to relative humidity increase and higher thermal fluctuations on the façades.*
Microclimate environmental measurement	*In-situ measurement campaign*	*Local environmental conditions on the main façades of Consoli Palace have been characterized, highlighting the most critical zones regarding each specific climatic forcing driving material degradation (e.g. solar radiation, temperature fluctuations and more). The site specific intra- urban monitoring highlighted the extremely different microclimate configurations co-existing in the historical town of Gubbio, which cannot be characterized by the only fixed weather station monitoring or large scale climate model. Such Observation confirms HERACLES purpose and effectiveness in correlating and providing interpretative correlation among multiscale models and monitoring systems for more reliable and exhaustive CH resilience protocol.*
Material Characterisation	*In-situ sonic tests*	*Estimates of equivalent elastic properties of materials on site, within the basement of Consoli Palace, have been achieved for a first calibration of the numerical model.*

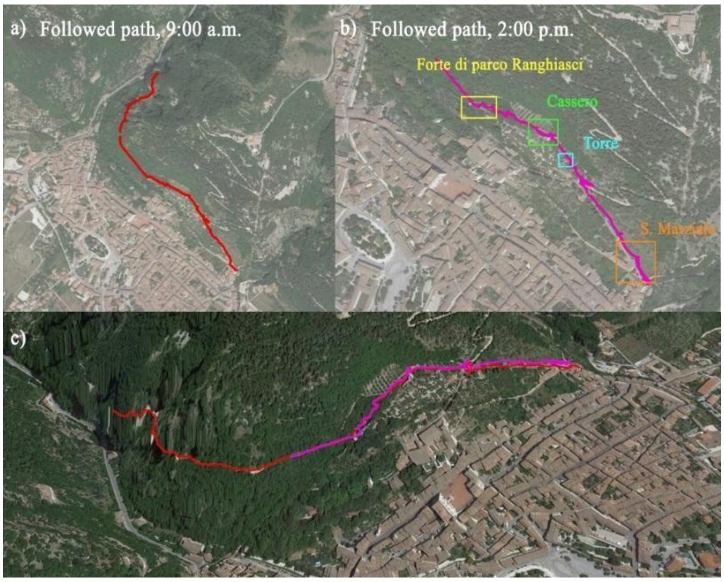
	In-situ non-destructive tests on stones	*DRMS measurements has been carried out to test the conditions of the building stones of the Consoli palace in different environmental exposure conditions. This investigation evidenced a limited weathering condition/state of the stone in comparison with those with similar lithology coming from local quarries*
	Ex-situ materials characterization	*Mortars, black crusts and biological colonization phenomena have been characterized to define the building materials weathering state, with different laboratory techniques. The materials characterization allowed to define their weathering state and design and plan the new materials and possible solutions which are going to be prepared and applied in the frame of WP4 activity*

ANALYSIS OF THE MICROCLIMATE AND ENVIRONMENT INFLUENCING THE DEGRADATION STATE OF TOWN WALLS

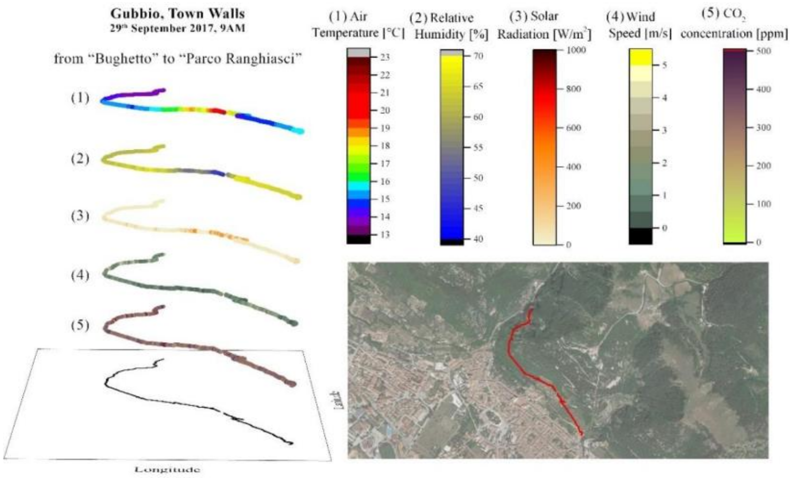
As previously analyzed, this section reports the key microclimate analysis carried out in close proximity to the ancient wall case study, with the final purpose to detail in both the spatial and temporal dimension the observation concerning microclimate forcing affecting the ancient walls preservation. The previous Figure 55, in fact, report the major difference of hygro-thermal behavior detected in the wall area compared to the Consoli Palace area, which recommends to analyze such two case studies in a more detailed way and better spatial resolution.

The site-specific microclimate assessment was carried out according to the visual and IR inspection, and therefore in the most severe conditions during the course of the year, i.e. summer conditions. The detection of winter-related damaging causes is indeed imputable to a more diffuse freezing phenomena which does not require such level of spatial and temporal detail, since daily winter hygro-thermal fluctuation is radically lower compared to the summer one, when massive solar radiation load and huge temperature difference (i.e. thermal shocks) between daily and nightly hours, is found. These data were collected during a one-day monitoring campaign during summer, by means of the miniaturized/portable weather station, already used for the Consoli Palace case. The monitoring device is small-size and light-weight in order to be easily carried on by walking people. Therefore, the perspective of the analysis results to be human-centered and case study centered.

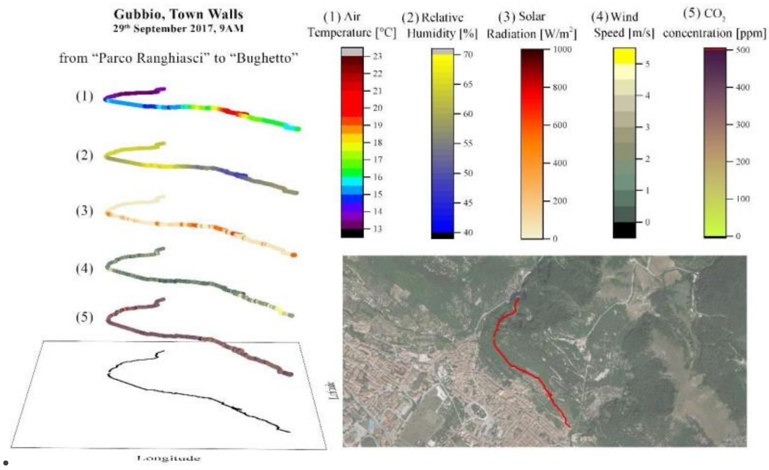
The local meteorological measurements of the ancient town walls took place twice during the day, i.e. at 9:00 a.m. and 2:00 p.m. (Figure 91) and was planned in order to consider all the point of interests highlighted in the context of the HERACLES project. Moreover, the path involved also the west-facing side of the Ingino Mountain at 9:00 a.m., following the existing pedestrian path. The environmental data were collected during both outward and return, i.e. from Bughetto to Parco Ranghiasci and vice versa. The double recording procedure helps to take into account the effect of the sun path and to identify if a particularly detected condition can be imputable to specific configuration of the area.



Monitoring pathway for investigating the Town Walls test-bed at 9:00 a.m. (a) and 2:00 p.m. (b); 3D view of the routs by means of Google Earth (c)

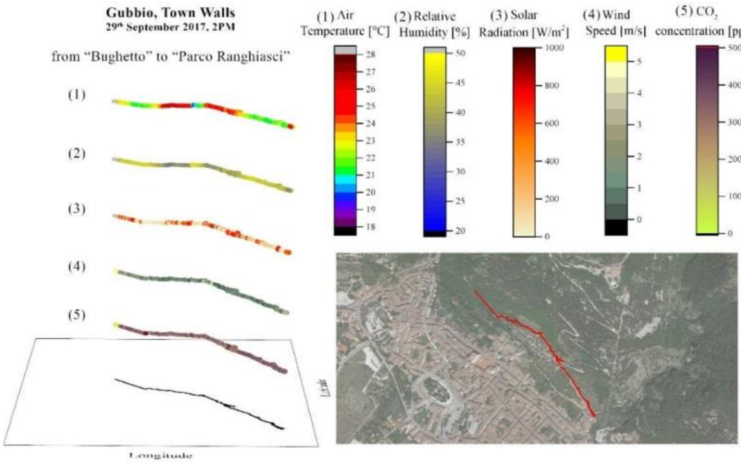


Main environmental parameters collected at 9:00 a.m., outward.

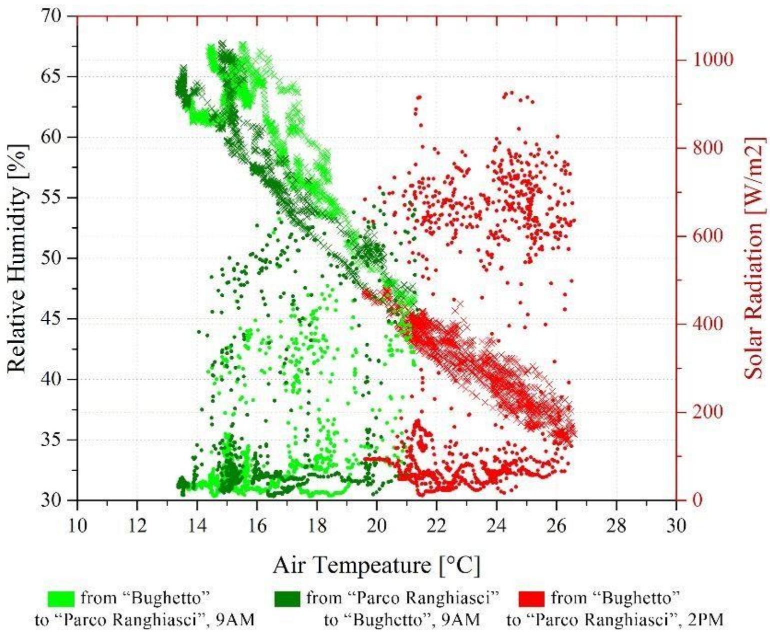


Main environmental parameters collected at 9:00 a.m., backwards

The graphs shown in Figure 92 and Figure 93 present the main collected environmental parameters at 9:00 a.m. both outward and backward respectively. During the elapsed time, i.e. 54 minutes, the space-varying distribution of the presented parameters is not significantly different. The hottest part of the path is always where the vegetation is less dense and therefore the incoming radiation is stronger, i.e. between “Torre” and “Cassero”. The coldest area corresponds to the west-facing side of the mountain since this side is not directly hit by the solar radiation during the whole morning. Therefore, the identified most impacting forcing, i.e. solar direct radiation, shows to differentially involve the ancient wall path, by producing a differential behaviour within the same case study.



Main environmental parameters collected at 2:00 p.m.

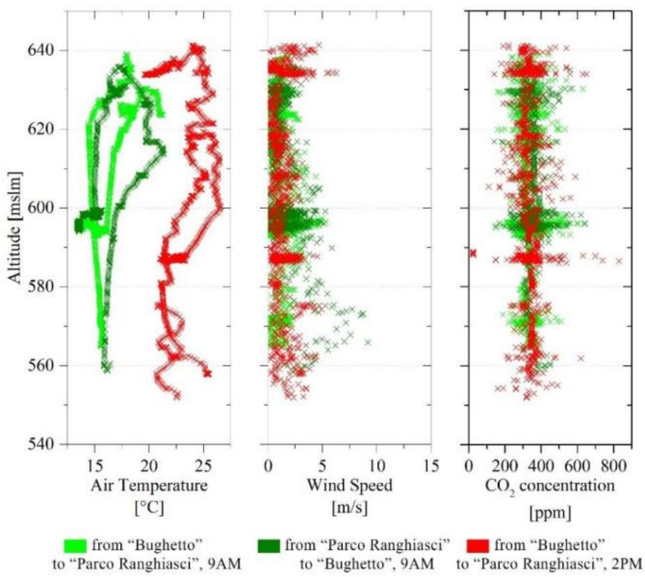


Relative humidity and global solar radiation plotted with respect to the air temperature for all the recording sessions.

The same parameters collected at 2:00 p.m. are shown in Figure 94. The hottest areas detected at pedestrian height are close to the "Cassero", while in correspondence of this element, the thermal comfort of visitors is enhanced. As a matter of fact, the huge dimension of the monument shades its back during the solar radiation peak time. The detected differences in terms of air temperature among the area shaded by the “Cassero” and the closest surroundings are equal to 4°C. In particular, the mentioned environmental parameter decreases from 24°C to 20°C.

Even if the differences detected along the monitoring pathway in terms of air temperature are comparable between the 9:00 a.m. and 2 p.m. recording sessions, (i.e. maximum of 8°C and 7°C respectively), the observed relative humidity range is sensitively wider in the morning, i.e. 21.7% and 23.3% during the outward and backward path respectively, with respect to a variation of 12.8% detected at 2:00 p.m. This result points out how the vegetation works as water vapour source in the monitored areas when the temperature rises up. The relation between the two environmental parameters is given in Figure 95 for all the monitoring sessions, i.e. 9:00 a.m. both outward and backward, and 2:00 p.m.

The influence of the altitude variation on the collected values of air temperature, wind speed, and CO_2 concentration is analysed, but no significant correlations are pointed out (Figure 96). Nevertheless, on the afternoon registration, a relatively more homogeneous CO_2 concentration and air temperature is detected as result of the massive buffering contribution provided by the ancient walls, compared to the morning times, when a relatively more dispersed data were collected in terms of air temperature (due to the wall thermal inertia), wind speed (due to a more variable air pressure and less intense radiation), and CO_2 concentration (probably due to increasing anthropogenic activities during the course of the day).



Air temperature, wind speed and CO_2 concentration related to altitude variation for all the recording sessions.

The presented analysis shows how the microclimate varies along the pedestrian pathway following the Gubbio ancient town walls. Therefore, granular data collection is needed to investigate the vulnerability of such case study which is affected by different microclimate environmental forcing that may be responsible for different degradation process of the whole CH asset. From a visitor perspective, the main elements of the walls shade such track from direct incoming solar radiation enhancing the outdoor thermal comfort for visitors in summer.

SUMMARY OF THE DEGRADATION STATE OF GUBBIO TOWN WALLS

Critical Issues	***Investigation Technique***	***Results***
Structural health	*Visual inspections and Analytical stability analysis*	*Areas of potential instability of the wall under the thrust of the accumulated soil and water have been identified. Critical soil and underground water levels have been analytically estimated in bot static and seismic conditions, based on geometric information obtained from laser scanning data. Some regions of the walls are extremely critical and collapse as a consequence of soil o water accumulation after prolonged rainfalls.*
	Infrared thermography	*The infrared thermographic campaign showed key degradation paths produced by materials weak homogeneity and recent retrofits, which are responsible for different thermal behaviour under microclimate forcing. Since this technique allows a superficial analysis it is not possible to investigate deep degradation phenomena responsible for structural damages. Despite that, greenery and chaotic vegetation growth represent a differential forcing probably responsible for further vulnerability of the test bed, also potentially exacerbated by water retention and freeze-thaw cycles.*

	Long-term static monitoring	*A wireless static monitoring system based on the use of inclinometers has been designed, tested and installed at the end of July 2018 to monitor slow movements of the walls due to the thrust of the accumulated soil. The system comprises three sensors installed in three critical positions on the walls, also complemented by thermo-hygrometers, sending wireless data to the sensor gateway installed inside Consoli Palace. Data will be available for analysis and cross- correlation during the demonstration phase.*
	GPR and ERT	*GPR and ERT surveys revealed that the soil upstream the Town Walls has a quite complex structure and suggest to perform further geophysical analysis, involving local drilling, to obtain a detailed characterization of the soil stratigraphy.*
Environmental measurement	*In-situ measurement campaign through payload*	*Local environmental conditions along the Town Walls have been evaluated, highlighting the most critical zones related to their specific climatic forcing, influencing the material degradation (e.g. solar radiation, temperature fluctuations and more). A non-negligible difference between microclimate forcing is detected within the same measurement paths, meaning that such spatial and temporal granularity is necessary for better identifying and motivating possible on-going degradation phenomena.*
Material Status assessment	*Ex-situ mechanical testing of mortars*	*Stress-strain behaviour of mortars of Town Walls has been characterized through laboratory tests based on new mortar specimens casted in laboratory using the recipes of the original mortars extracted from chemical analysis of in-situmortars. This investigation highlighted very limited strength characteristics, that may represent a critical issue towards the cohesion of stones and the stability of the walls, especially in presence of intensive rainfalls.*
	In-situ non-destructive tests on stones	*DRMS measurements has been carried out to test the conditions of the building stones of the Town Walls in different environmental exposure conditions This investigation evidenced a more severe weathering degradation of the stones, in comparison with the same investigation carried out on the Consoli Palace*

	Ex-situ materials characterization	*Mortars, stone and biological colonization phenomena have been characterized to define the building materials weathering state, with different laboratory techniques. This characterization study evidenced the presence of high degraded mortars, representing a critical issue, considering the cohesion of stones and the structural stability of the walls, in the presence of the effects of the Climate Change. The results of the materials characterization allowed to design and plan the new materials and possible solutions which are going to be prepared and applied in the frame of WP4 activity*

PRESENTATION OF THE PROJECT

1. HERACLES SOCIAL EVENT (HERAKLION, EL – 5 OCT. 2018)

As part of the project's dissemination and public engagement a social event was organized with the aim to estimate the social impact, the societal resilience and the awareness on cultural values in Heraklion. The event was organized in Heraklion, Crete, on the 5th Oct. 2018 following its twin event that took place in Gubbio, Italy on the 5th June 2017.
The social event was organized by Ephorate, FORTH and CNR.
The event was developed in two sections:
During the morning, the project itself as well as highlights of the research works in Crete were presented. Furthermore, the effects of climate changes on the socio-economic and cultural impacts in the local community were also presented while a case-study describing the important relationship between the local communities and conservation was discussed.
In the afternoon session a preparatory workshop took place. The participants were involved in a discussion stimulated by a series of questions leading to conclusion on the socio-economic and cultural impact of HERACLES and suggestion on how the results of the project can be further employed into the development of smart systems for monitoring change in the condition of the monuments, systems and methods for raising public awareness and enhancing the involvement of the public into the protection and safeguarding of cultural heritage assets.

Four presentations have been done:

a. Oral presentation, E. Kavoulaki, E. Politaki, G. Alexandrakis, "Cultural Heritage and socio-economic benefits within HERACLES project: The Palace of Knossos"
b. Oral presentation, V. Sithiakaki, E. Kanaki, G. Katsalis, K. Georgali, K. Patedakis, A. Psaroudaki, "Cultural Heritage and socio-economic benefits within HERACLES project: Rocca a mare (Koules)"
c. Oral presentation, N. Kampanis, "Climatic change impacts on natural and cultural heritage and economy"
d. Oral presentation, P. Pouli, "Portable analytical instruments and methodologies developed within HERACLES for the in-situ monitoring of surface deterioration on monuments"

2. TMM_CH CONFERENCE (ATHENS, EL – 10 OCT. 2018)

The conference focuses on innovative scientific methodologies and challenging projects marking future trends in the protection of cultural heritage, that have initiated a universal conversation within a holistic approach, merging capabilities and know-how from the scientific fields of architecture, civil engineering, surveying engineering, materials science and engineering, information technology and archaeology, as well as heritage professionals on restoration and conservation and policy makers in cultural heritage. The combined utilization of digital documentation technologies with innovative analytical and non-destructive techniques, computational and digital techniques and archaeometric methods supports the creation of a transdisciplinary multispectral modelling towards the sustainable preservation of cultural heritage. Innovation is enhancing and revealing a critical dimension of the preservation of cultural heritage along with social participation and communication.

Four oral presentations have been done:

a. K. Hatzigiannakis, K. Melessanaki, A. Philippidis, O. Kokkinaki, E. Kalokairinou, P. Siozos, P. Pouli, E. Politaki, A. Psaroudaki, A. Dokoumetzidis, E. Katsaveli, E. Kavoulaki, V. Sithiakaki, “Monitoring and mapping of deterioration products on cultural heritage monuments using imaging and laser spectroscopy”
b. G. Alexandrakis, G. Kozyrakis, N. Kampanis, “Interventions on coastal monuments against climatic change”
c. G. Alexandrakis, C. Manasakis, N. Kampanis, “Natural hazards socio-economic impact on cultural heritage sites”
d. G. Padeletti (presented by N. Kampanis), “Heritage Resilience Against Climate Events on Site – HERACLES Project: Mission and Vision”