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Sommario

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The impact of Climate Change on Tangible and Intangible Cultural Heritage

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In this paper, some considerations on Climate Change (CC) effects on Cultural Heritage (CH), both in its material and immaterial components are presented. Moreover, initiatives for their protection through the activities of two European projects funded under HORIZON 2020 and HORIZON Europe are discussed.

1. Climate Change and Cultural Heritage

Climate change, also called global warming, refers to the rise in average surface temperatures on Earth. An overwhelming scientific consensus is concerned with the fact that climate change is due primarily to the human use of fossil fuels, which releases carbon dioxide and other greenhouse gases into the air. The gases trap heat within the atmosphere, which can have a range of effects on ecosystems, including rising sea levels, severe weather events, and droughts that render landscapes more susceptible to wildfires. [https://www.un.org/en/climatechange/what-is-climate-change; National Geographic http://environment.nationalgeographic.com/environment/global- warming/gw- effects/].
There is a broad-based agreement within the scientific community that climate change is real.
The primary cause of climate change is the burning of fossil fuels, such as oil and coal, which emit greenhouse gases into the atmosphere — primarily carbon dioxide. Other human activities, such as agricultural and deforestation, also contribute to the proliferation of greenhouse gases that cause climate change.
While some quantities of these gases are naturally occurring and represent critical factors in the Earth's temperature control system, the atmospheric concentration of CO_2 did not rise above

300 parts per million between the advent of human civilization roughly 10,000 years ago and 1900. Today it is at about 400 ppm, a level not reached in more than 400,000 years.
Even small increases in Earth's temperature caused by climate change can have severe effects. The earth's average temperature has gone up 0.7 °C (1.4° F) over the past century, and it is expected to rise as much as 6 °C (11.5° F) over the next. That might not seem like a lot, but the average temperature during the last Ice Age was about 2 °C or 4° F or lower than it is today.
Rising sea levels due to the melting of the polar ice caps (again, caused by climate change) contribute to greater storm damage. Warming ocean temperatures are associated with stronger and more frequent storms. Additional rainfall, particularly during severe weather events, leads to flooding and other damages. An increase in the incidence and severity of wildfires threatens habitats, homes, and lives. Heat waves contribute to human deaths and other consequences.
Other effects could happen later this century, if warming continues.

- Sea levels are expected to rise between 18 and 59 cm by the end of the century and continued melting at the poles could add between 10 to 20 cm.
- Hurricanes and other storms are likely to become stronger.
- Species that depend on one another may become unsynchronised. For example, plants could bloom before that their pollinating insects become active.
- Floods and droughts will become more frequent. Rainfall in Ethiopia, where droughts are already common, could decline by 10 percent over the next 50 years.
- Less fresh water will be available. If the Quelccaya ice cap in Peru continues to melt at its current rate, it will be gone by 2100 by leaving thousands of people who rely on it for drinking water and electricity without a source of either.
- Some diseases will spread such as malaria carried by mosquitoes.
- Ecosystems will change — some species will move farther north or become more successful; others won't be able to move and could become extinct. Wildlife research scientist Martyn Obbard has found that since the mid-1980s, with less ice on which to live and fish for food, polar bears have gotten considerably skinnier. Polar bear biologist Ian Stirling has found a similar pattern in Hudson Bay. He fears that if sea ice disappears, the polar bears will as well.

Cultural Heritage (CH) is a complex matter, composed of tangible and intangible components, both important for a society's culture and very often closely interrelated. Tangible and intangible

CH often integrate and influence each other, and their correlation reflects the complexity and richness of human culture. Tangible cultural heritage refers to tangible goods such as buildings, monuments, artefacts, works of art and archaeological finds, while intangible cultural heritage concerns oral traditions, ritual practices, artistic expressions, knowledge and skills that have been handed down for generations. The correlation between the two types of cultural heritage is manifested through the relationship between the material object/asset and the intangible meaning it represents. For example, a historic building or monument could be considered important not only for its architectural beauty or history, but also for the symbolic or cultural significance it represents for the community. In addition, tangible and intangible cultural heritage often integrate and influence each other. For example, the ritual practice of a particular cultural group could be celebrated in a specific sacred building that has material importance for the community. Ultimately, tangible and intangible cultural heritage are both essential for preserving and promoting a society's cultural diversity and identity, and their correlation reflects the complexity and richness of human culture.

There is a growing awareness of the importance of safeguarding cultural heritage and the principal benefits of this action can be mentioned as:

- Maintain Cultural diversity
- Supporting the intercultural Dialog
- Encourage the Respect for the Differences
- Promote the Social and Economic Development

Cultural heritage is fragile by nature due to its intrinsic natural weathering and aging. Climate Change certainly represents a factor accelerating this weathering/aging and also capable of producing more serious devastations.

Climate Change can compromise both tangible and Intangible CH components.

Regarding tangible cultural heritage, such as historic buildings, monuments, archaeological sites and works of art, CC can cause direct damage, such as erosion, deterioration and destruction due to extreme weather phenomena such as floods, fires, droughts and storms. In addition, rising sea levels can endanger coastal sites and historic islands, while rising temperatures can accelerate the degradation of materials constituting assets and objects.

Regarding intangible cultural heritage, such as traditions, languages, cultural practices and ancestral knowledge, CC can affect the natural resources needed to maintain them, such as biodiversity, plants, animal species or compromising the sites where rituals take place. In addition, environmental changes can lead to migration and dispersion of communities that carry cul-

tural traditions and knowledge, risking losing them forever.
It is important to deal with CC implications on CH and work for mitigation actions towards its safeguards.

2. European initiatives

The European Commission paid and is paying attention to these issues, funding projects and initiatives in this area. Here, two European projects dedicated to CH protection, both led by CNR, are presented.

2.1 *Tangible CH: HERACLES project*

The first one, HERACLES (Heritage Resilience Against Climate Change Events on Site, HORIZON 2020, Research and Innovation programme GA No. 700395), deals with **tangible CH**, built heritage, in particular (https://www.heracles-project.eu/). It addresses the impacts of climate change on cultural heritage with the aim to help communities and stakeholders in understanding and mitigating the risks that climate change poses to cultural sites, buildings, and landscapes. Key objectives of the HERACLES project typically include:

- *Assessment of Vulnerability*: Evaluating the vulnerability of cultural heritage sites and their surroundings to climate-related risks such as flooding, erosion, and extreme weather events.
- *Research and Innovation*: Contributing to research in the fields of climate science, heritage conservation, and social sciences to create a comprehensive understanding of the issues at hand.
- *Implementation of Solutions*: Testing and implementing innovative solutions for enhancing the resilience of heritage sites, which may include both technological and nature-based approaches.
- *Community Engagement*: Involving local communities and stakeholders in the decision-making process to ensure that strategies are relevant and effective.
- *Development of Best Practices*: Creating guidelines and best practices for the protection and resilience of heritage sites against climate change impacts.
- *Policy Recommendations*: Providing insights and recommendations for policymakers on how to incorporate climate resilience into heritage management practices.

The HERACLES project exemplifies a growing recognition of the need to preserve cultural heritage in the face of climate change, emphasizing the importance of sustainable practices and community involvement in heritage conservation efforts.
Demonstration of the effectiveness of HERACLES was carried out at challenging tests beds, in Italy and Greece.

The philosophy of the project was to pay attention not only to famous centres, but rather to consider smaller centres, still representative of the European essence, made up of alive towns, where people live and work in vital historical contexts

2.1.1 HERACLES testbeds

The Italian test bed is represented by the historical town of Gubbio. It wants to represent all the historical monumental towns in Italy and in Europe that were conceived and built in the past following criteria when the climate conditions were very different from nowadays, and that suffers at present the effects of climate changes, that would endanger their safeguard.

As well, in Greece (Crete), Knossos represents all the important archaeological sites that face many problems deriving from extreme phenomena due to climate change, and Koules fortress in Heraklion, is representing all the coastal monuments present in Europe that face the risk of hazards from climatic change, such as significant impact from the sea, as storms and increased sea level, for instance.

These two European countries and the identified sites are also affected by another common natural hazard, as the earthquake is. Unfortunately, tragic events occurred in central Italy in 2016 and 2017, along the Apennines mountains (where Gubbio is also located), evidenced the vulnerability of Cultural Heritage, but also its social and cultural implications and how it is important to defend it through a preventive maintenance and tailored interventions (on structures and materials, in particular). Consequently, the HERACLES contribution could be very important and useful in this direction, too, through new solutions and systems improving the resilience of a vulnerable heritage at risk.

Based on the end-users' requirements and on investigations made on-sites, it was clear from the beginning the importance of having available an integrated monitoring technologies approach and expertise. HERACLES, then, proposed the integration of wide-area surveillance (satellite) including assets and their surrounding territory, till the observation on-site of the single element of the asset.

This was/is an innovative & pioneering approach, still up-to date nowadays, due also to the difficulties of integrating very different data, coming from different sources and different in scale.

Demonstration activities at testbeds were carried out to evaluate the effectiveness of the HERACLES approach/system. It enables an assessment/awareness situation of the built environment and its surrounding area through information acquired by an integrated monitoring system, including full implementation of diagnosis, monitoring, remediation and crisis management services, through the integration of multi-source data. The method-

ologies and analysis have considered climatic change impact (at European, national and proper regional downscaling) for weather forecasting (with emphasis on extreme events occurrence, frequency and intensity) and the identification of the relationship between meteo-climatic parameters and environmental risks for CH, in a holistic approach of a coupled air-sea-land interaction.
In this respect, HERACLES project is a good example of GLOCAL, thinking GLOBAL, but acting LOCAL.
Here, some activities carried on in Gubbio testbed are presented, since implications with their immaterial meaning will be presented and discussed later, in the part dedicated to Intangible Cultural Heritage (ICH), as well.

2.1.1.1 Italian testbed: Gubbio
As already said, Gubbio was considered the paradigm of the worldwide historical small towns due to its well-preserved status and its lively social life.
Probably, it is not a coincidence that in the period after the World War II, when it was becoming evident the importance of a correct developing of the historical centres, Italian town planners and administrators met in Gubbio where was created the "Gubbio Charter 1960" and the Italian National Association for the historic-artistic centres (ANCSA). The Gubbio Charter sets several criteria for intervening in the historic centres. Until then, the oldest parts of a city could be demolished and reconstructed. The historical centres, after Gubbio Charter, were considered as a whole. Its content was considered in the Venice Charter, 1964 (International charter for restoration) and in the European Charter of the Architectural Heritage adopted by the Council of Europe, 1975, too. According to the historian Leonardo Benevolo, the Gubbio Charter is the most important contribution that Italy has given to the European architecture of the twentieth century.
At a later stage, the "Gubbio Charter 1982" was established. It is important to emphasize the relevance and newness of the message in this document: *"…. - reconsider, the revival of interest in and appreciation for CH (architectural, artistic, historical and traditional) as primary sources of enriching the quality of life in every country; - to develop education, scientific research and technology along these lines"*.
The choice of Gubbio is thus linked also to its ability to message and to propose itself as an educative place for environment defence and harmony of historical settlements against future aggressions and insensitivity, and to be able to represent a reference point for important human and societal issues.
The old town of Gubbio is positioned at the bottom of the Apennines hillside dominating the town from the Northeast side and representing a critical point for hydrogeological risks. The old

town is surrounded by town Walls, that, as appear nowadays, were built in approximately 1.500 years, through elevations, renovations and expansions. HERACLES activities were mainly directed to the mitigation of the hydrogeological risk of the monumental part of the town constituted by the High Town ("*Città Alta*") and the Town Walls which suffer from the increasing torrential rains and humidity characterizing the soil and the surrounding natural areas, and by the fact that this part is strictly connected with the Apennines Mountain chain. In addition, the old Town of Gubbio presents some important issues related to the materials [limestones, travertine, Sandstone (serena stone), plasters, binders] used for building and restoration. These materials suffer from increased deterioration due to climate change effects coupled with pollution, and present damaged parts that can lead to structural instability.

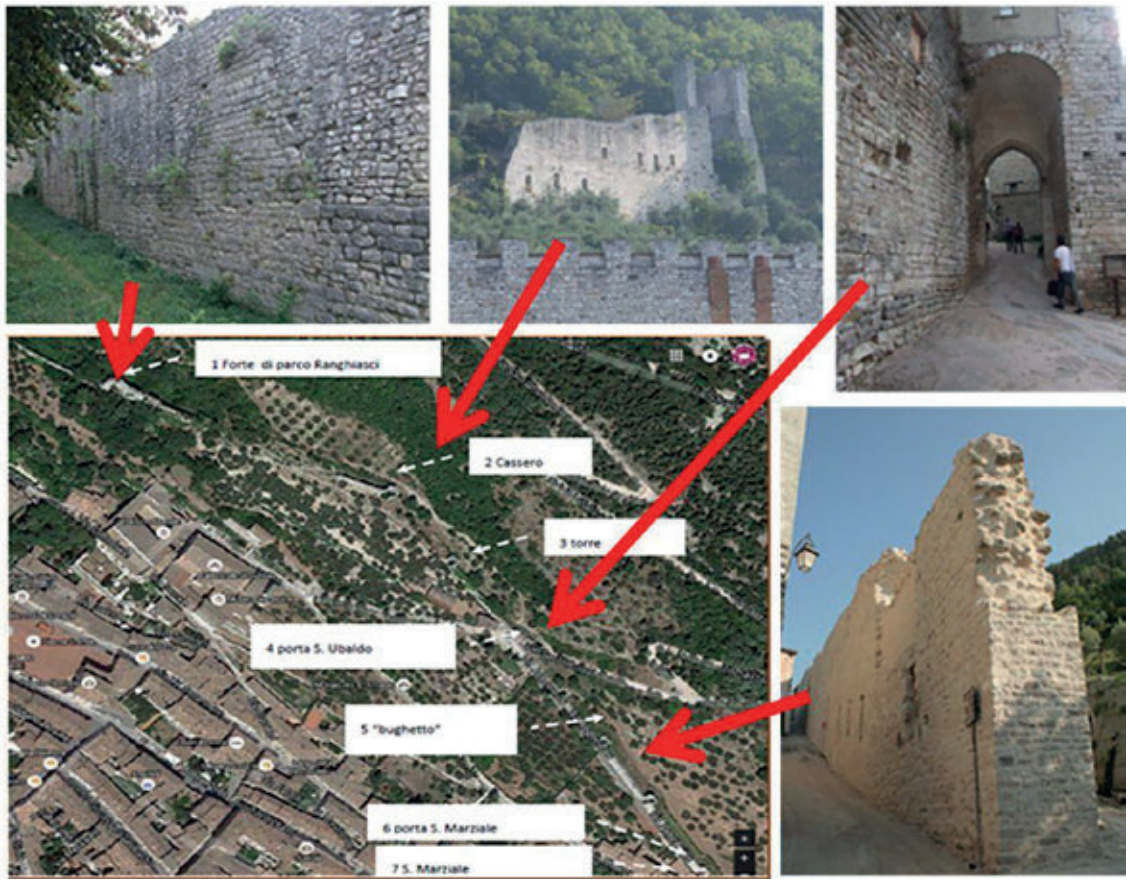
The Gubbio significant cultural heritage, has been affected in the years by a multi-risk scenario with a combined effect of the hydrogeological risk with other kinds of risks related to the pollution, fast temperature changes, seismic hazard, weathering and aging.

Extreme climate events, most in terms of heavy rain and its local effects, are causing possible structural instabilities for the overall historical area, as testified by the existing and progressive slow deformations and crack patterns affecting the ancient structures. The materials suffer from increased deterioration due to the combined effect of the climate change effects and pollution, which produces several damages and deterioration. In particular, limestone, one of the most used materials, is affected by a significant degradation of the surface, which, in the absence of plasters protection for the buildings structure, leads to the presence of black/dark patinas. These critical issues have been worsening in the last years due to a higher concentration of CO_2, associated with more intense rainfalls, producing acid rains, and causing stone detachments by dissolution of carbonates and blackening of the surfaces. In fact, the extreme rain events, more and more frequent in the last decades, led to an increase of moisture inside materials and mould formation on the ancient materials surfaces.

The test areas identified in Gubbio are the monumental part of the town, constituting the "High Town" with the medieval Walls. This upper area of the town is strictly connected with the Ingino Mountain and consequently suffers from the increased torrential rains and humidity, affecting the soil and the surrounding natural areas. In addition, the area is affected by several negative effects concerning the sediment transport, the storm-water runoff and the increase of the water level in the underground, which are the main factors affecting the structural behaviour of the Walls. Ac-

cording to this scenario, the activities of the HERACLES project are directed at monitoring and mitigate the hydrogeological risk in that area.
In this sense, the medieval Walls and the Consoli Palace are well representative of the bad effects of the hydrogeological risk, possibly worsened by other hazards as the pollution and the seismic one, in terms of structural instability and materials deterioration.

a) Town walls



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The town Walls represent a cycloptic structure formed over 1500 years and continuously modified through elevations, renovations, expansions, reinforcements, modifications and demolitions too. The last huge modification was made during the second half of XIX century, on the Marmorea door, one of the main doors of the town. This door was at the entrance of the city, in the lowest part of the main square (now *Piazza 40 Martiri*), in the Southwest side, where the road leading to Perugia begins. The "Marmorea" door was demolished together with 50 meters of the close ancient Walls to give a new architectonic view to the

people arriving in Gubbio. Other various interventions were made through the decades, mainly focusing on restoration.
Two of these interventions were made in the upper part of the Walls, closest to the mountain on whose slope the city has been built. These interventions were performed mainly to remove the thousands of cubic meters of soil carried there by rain, since it was intensifying the load on the Walls and increasing the aquifer water levels.
The part of the urban walls exposed to maximum risk is then located on the slopes of Ingino Mountain in the N/NE direction. The area nowadays is mostly interested in olive plantations, while in the past was also used by woodcutters and farmers. The area inside the Walls was used as military bastions (such as the "Cassero") until the XVI Century, after which it has been used mostly for farming uses. From historical information, i.e., pictures and paintings, it was possible to point out how the forestation, currently visible outside the walls, is very recent and has arisen only just after World War II. In fact, in the past, only a few trees and bushes were present and unable to stop sediments and surface flows.
During the last eight-ten centuries, several meters of ground material accumulated against the walls. The situation was only partially mitigated by the historic aqueduct, which had also the function of retaining the Walls. At present, the estimated soil accumulation, insisting on the Walls, is more than 5/6 meters and increases with a rate of around 50 cm / century.
As risk mitigation action, the water flow out through the Walls and the drainage of the gravel soil were ensured by means of on-purpose designed holes/channels in the structure. However, the ground material obstructed the channels. This caused an increase in the groundwater level and consequently the risk of the structural instability of the Walls.
Currently there are no landslides in place, but collapses of the Walls have occurred over the last centuries and last decades.
For what concerns climatic parameters, the following issues have been addressed:
Temperature changes: some diurnal, seasonal, extreme events (heat waves, snow loading) can lead to changes in freeze-thaw cycles and ice storms, and increase frost, so deterioration of facades due to thermal stress can occur. Damages inside the stone and the mortar are a direct consequence.
Wind: Wind-driven rain can penetrate moisture into porous materials weakening them; combined with ice can create cracks in stones and mortars, inducing structural instability.
Climate and pollution acting together: The main risks are related to the pH precipitation (acid rains) and changes in the deposition of pollutants. These can lead to stone erosion by dissolution of

carbonates and/or stone blackening, as described and shown in the following.

Limestone: the main structural material used for the older historical buildings is the limestone extracted from the quarries site in the neighbouring mountains. There are two types of limestone depending on the extraction period: the oldest, roughly before XV century, presents fewer problems. The second one, more recent (extracted after XV century) in the last years, presented a greater degradation of the surfaces and then black/ dark patinas occurred. These critical issues are due to a higher concentration of CO_2, associated with more intense rainfall and pollution. The dark patina or "black crusts" are related to the chemical degradation. The degradation effects of the outer surface are: loss of material (formation of hollows, differential degradation, erosion, gap, lacking, pitting); decay of the material cohesion (disintegration, pulverization); loss of continuity perpendicular or parallel to the outer surface (fracturing/cracking, peeling, warping, swelling, scaling); addition of foreign material (concretion, crust, surface deposit, efflorescence, scaling, stain, film); colour variations (discoloration and patina).

Mortars: another important problem is linked to the progressive degradation of the mortars that bind the masonry. The wall body-structure behaves/reacts properly as greater is the cohesion between mortar and stones. The mortar is particularly important in the final result of the masonry, and its quantity and quality are important variables. From a static point of view, the whole masonry is more resistant when the individual elements composing it are firmly joined together, so that the transmission forces from stone to stone takes place. The mortar between stones leads to a more uniform distribution through the joints, and if the mortar is deteriorated, the distribution of the stresses on the masonry surface will result heterogeneous (see Figures 2-3).

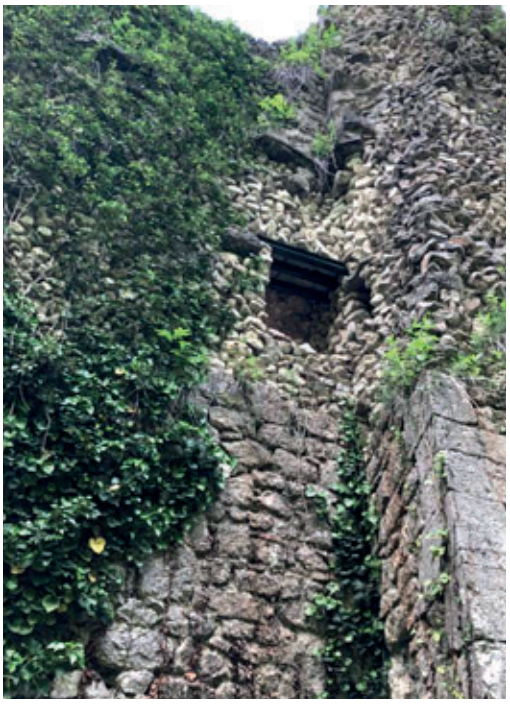
2

3

In conclusion, the Walls suffer mainly from torrential rains and humidity characterizing the soil surrounding the area and are closely connected with the mountain natural area. The heavy rain increases the push on the Walls in two ways: the first one is through the washout producing and transporting rubble, the second one through the increase of the aquifer level. All these conditions can adversely affect the statics of the Walls themselves.

In addition, the Walls of Gubbio exhibit several issues related to the materials degradation (limestones, travertine, sandstone-serena stone, plasters, binders) used for building and restoration. These materials suffer from increased deterioration due to climate change effects coupled with pollution. The structural material principally used is the limestone extracted from the quarries site in the neighbouring mountains in two different extraction periods. The oldest limestone was extracted prior to 1400 and does not exhibit significant criticalities. The second limestone type (extracted after XV century) is affected from a significant degradation with the formation of dark patina ("Black crusts") on the surfaces.

The CC affects structures stability also through material degradation phenomena, amplified by CC as can be seen in figures 4 and 5 where Gubbio Town Walls details are shown. In fact, CC is producing the disaggregation of the masonries external part, making accessible to the degradation also the inner part, producing at the end, the collapse of part of the masonries themselves.



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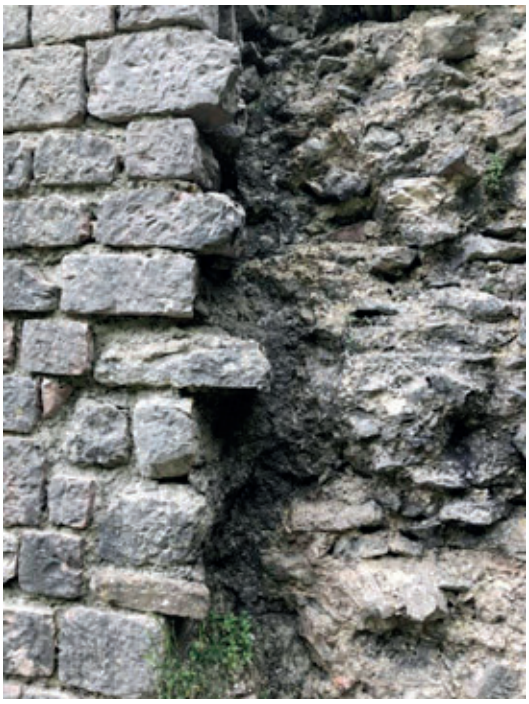

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Ad hoc materials (mortars in this case) with improved characteristics and performances can be designed and realized, offering tailored solutions to solve different issues. Another predominant issue is the gradual degradation of the mortar binding the walls and that makes spatially uniform the stresses through the joints between the stones. The degradation/reduction of the mortar entails the loss of homogeneous distribution of stresses on the surface of the stone and leads to heterogeneous stone-binder system behaviour.
The HERACLES activities for this scenario monitored the stability of the most critical part of the Walls and addressed the quality of the mortars used and their properties. Furthermore, mortars with improved characteristics were designed.

b) Consoli Palace

6

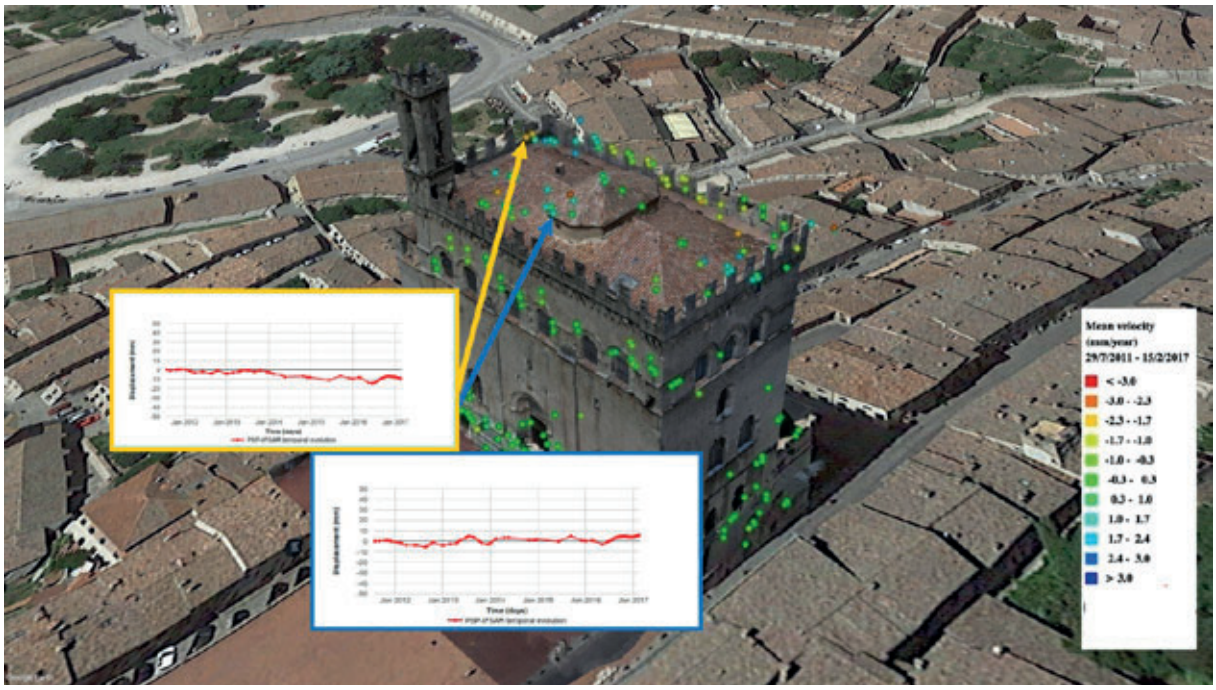
The Consoli Palace is the symbol of the city of Gubbio and the most representative and spectacular monument of the whole monumental town. It was built in 1338 with a daring pensile square ("*Piazza Grande*") in the heart of the four districts of the city. The building was erected on the slope of the mountain and the foundations were built on two levels.
From the structural point of view, it should be noted that the building has foundations placed at two different levels, due to the local topography. This aspect confers to the west side of the structure a remarkable height of about 60 meters. The difference in height of the two levels of the foundations is about 10 meters and this could lead to a first structural problem regarding differential displacements.

At present, the effects of the differential displacements are visible in the west wall and in the cross vaults of the loggia, in the form of activated local mechanisms and crack patterns. At the top of the structure, on the same side of the palace, a slender bell tower is located.
Several restorations were made after the 1982 and 1984 earthquakes and completed in the first half of the '90s. During these restorations, the façades were completely cleaned by accumulations of dirt. After only twenty years, however, smog, concretions and localized phenomena of black patina are again clearly visible. Dark patinas are widely visible and well highlighted by the presence of other adjacent stones that are not minimally blackened, even if experiencing the same environmental conditions.
For what concerns climatic parameters, the following issues have been addressed:
Atmospheric moisture changes and intense rainfall and flooding related: The atmospheric moisture change is a hazard affecting the palace, enhanced by the intense rainfall that leads to flooding, also. The masonry itself is affected, due to erosion of the mortar or cracking of the system stone/mortar. Furthermore, also in this case, two kinds of limestones were used in the construction. The oldest, roughly before XV century presents fewer problems. The second type (extracted after XV century) has been showing a greater degradation of the surfaces, and in the absence of the protection of plasters on the façade, formation of dark patina occurred in a period of time considerably shorter.
Furthermore, the main risks are linked to the consequent variation of the aquifer level that could induce foundation settlement. The main critical aspect is highlighted in the south-west part, where an out-of-plane rocking mechanism is becoming evident by a widespread crack pattern. This aspect could be due to differential settlements of foundations caused by several reasons, also related to environmental actions and other natural hazards as the earthquake (a multi risk, domino effect could be considered (see HERACLES deliverable D1.3- "Definition of methodologies for climate change impact evaluation and risk and vulnerability analysis").
Temperature change: The most frequent events that are consequences of temperature change are diurnal, seasonal, extreme events (i.e. heat waves, snow loading), changes in freeze-thaw cycles and ice storms, and the frost increase. All these factors induce damages inside stone and/or mortars undergoing wet-frozen cycles inside material before drying. The physical erosive processes are:
- *Frost wedging/weathering*: when water comes in contact with masonry, it easily intrudes into the cavities of the material. When the temperature is lowered to the freezing point, the water in-

creases its volume due to the ice formation and will exert considerable pressure inside the hollows, causing intense stress in the material, which will be subjected to a prolonged deformation. The alternation of melting and solidification cycles, in time, results in a series of continuous stress in the stone/masonry. This is the frost wedging phenomenon, a slow, cyclical process, characteristic of the areas where the seasonal temperature range appears to be considerable (Moses 2014).
- *Thermoclastis* or *thermal stress weathering*: the low thermal capacity of the stone, when subjected to changes in temperature, causes stress in the material due to the succession (in short cycles) of expansion and contraction caused by the change of temperature. The increase in the temperature during the day, causes a thermal expansion of the rock, which corresponds to a contraction in colder hours. This continuous alternation causes a series of differential efforts that, especially in the external layers of the masonry, causes the formation of clastic material. The products of this erosion process are called "termoclasts". (Bonazza, 2009)
Wind: Wind make worse the rain erosive and penetrating effect. In fact, wind-driven rain can penetrate moisture into porous materials weakening them and combined with ice can create cracks in stones and mortars, inducing structural instability. Furthermore, the Consoli Palace has in some parts a high and slender structure (the bell tower, in particular), that is especially exposed and sensitive to the wind. Extreme wind produces stresses in the vibrational modes of the structure itself, that could induce structural problems. This is a constant and frequent stress, with an increasing iteration during the last years.
Climate and pollution acting together: The main risks are related to acid rains (pH precipitation) and changes in deposition of pollutants, just like the Town Walls situation. These can lead to stone erosion by dissolution of carbonates and/or stone blackening, as shown in the following (figure 7).

7

As an example of the integrated HERACLES approach, a part of the study carried out on Consoli Place is shown in the following.



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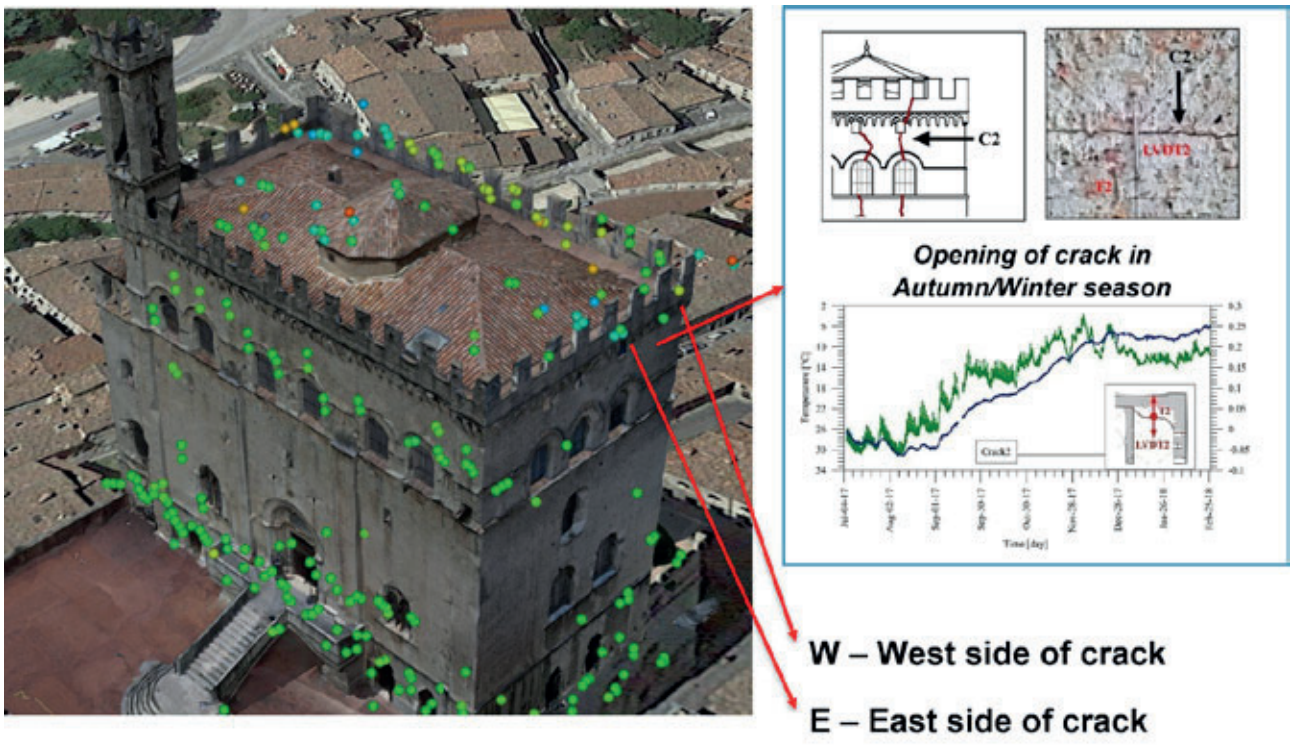
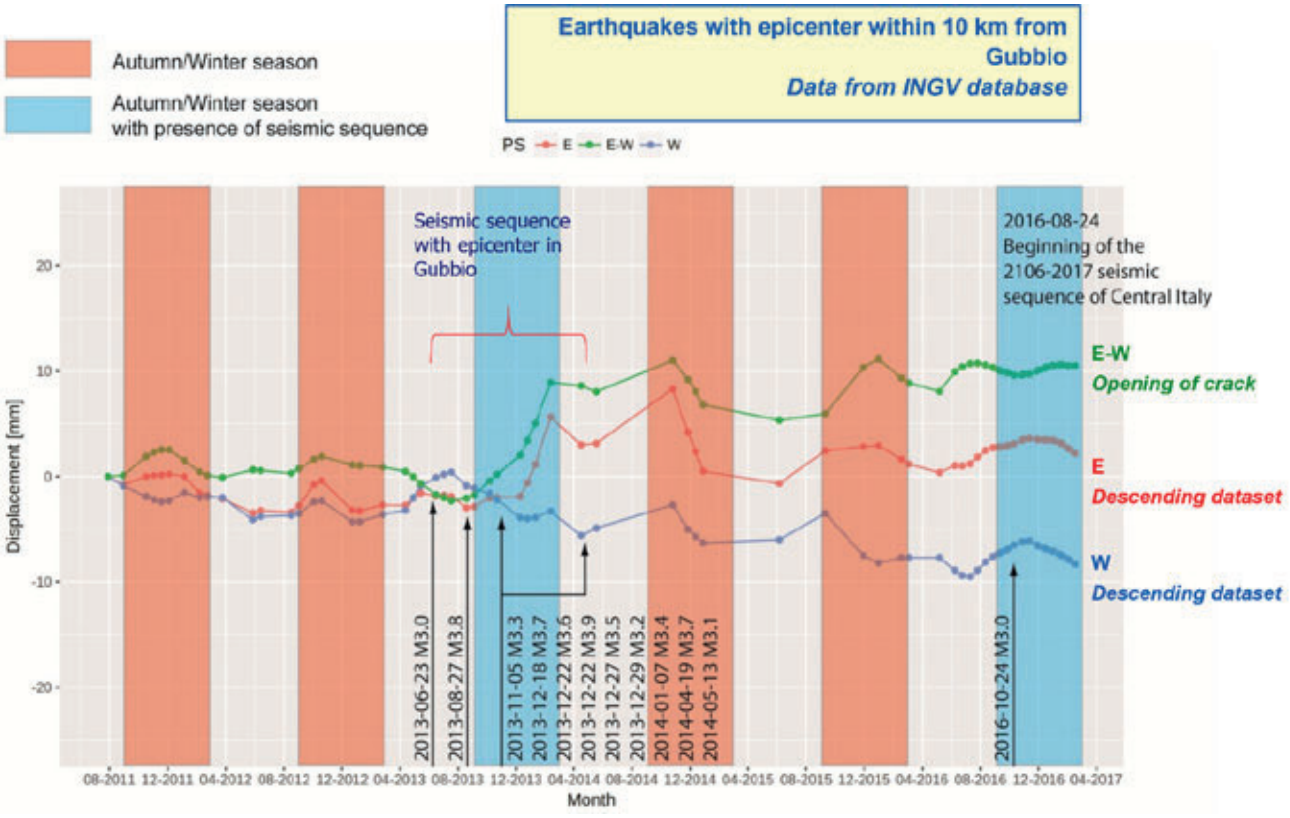
In figure 8 the result of the satellite observation in terms of maps of displacement in time, is reported. It provides timely and accurate geospatial information in terms of potential structural failures of historical structures/buildings, as well terrain deformation in the surrounding areas. The displacement measurements are given with millimetres accuracy. Figure 8 is a zoom showing the Consoli Palace itself, marked with points of different colours. Their colours are associated with displacements of different parts in a building, that can behave in different ways and with deformation in different directions. Zero deformation is represented by the green colour. Red and blue colours indicate the highest values of deformations going in opposite directions. Major criticalities are generally found when two parts of a building present opposite colours (red and blue), since it indicates very serious opposite behaviour in different parts of the same building that can lead to the collapse of the structure. In the case of Consoli Place, no major concerns were found.

Nevertheless, a crack was found on the NW façade (see figure 9). Following an integrated approach, this crack was monitored by applying also linear displacement sensors, to assess the potential influence of CC. The behaviour of the crack amplitude was correlated with the variation in temperature (daily and seasonally). It was found that the crack opens in winter due to the thermal coefficient of the stone, and the opposite happens in summer. It represents cyclic behaviour, not critical per se now.



Furthermore, based on historical data, it was possible to acquire info on the opening extent since 2011 (fig 10).



Following the green line, related to the crack opening, it can be seen that the seismic events, occurred in this area also during the HERACLES project lifetime, are acting as a risk multiplier, producing cascade effects. Due to these events, the opening of the cracks increased by a factor of 5, and there is no way to come back.
This is just an example of what can be observed, acquired, monitored and understood, to provide useful information that should be known by the decision makers responsible for the assets to plan mitigation actions.

2.1.2 Conclusive remarks on HERACLES approach
The possibility to have a unique multi-facet vision of the status of Gubbio monuments was made possible by different levels of integration regarding the use of different technologies capable of capturing a large set of sensed quantities at different levels of temporal and spatial scales. In fact, the demonstration activities have shown the effectiveness and the significant potentialities of the HERACLES approach in going from the wide scale (EO Earth Observation) to the scale of the territory and site and then to the diagnostics of the single elements of the structures, as demonstrated at the Consoli Palace and Town Walls. All this process has been performed also following the HERACLES developed protocols, where the technologies and modelling are deployed according to a workflow designed on the basis of the specific requirements of the end-users. It also accounted for the economic sustainability of the monitoring of the town and of the structures for a short- and long-term prediction of the climatic conditions necessary to evaluate the structures degradation, in relation to CH resilience with respect to climate change events.
The highlights of the demonstration activities are summarized in the following:

- The use of Synthetic Aperture Radar (SAR) technologies to have a global vision and multi-temporal information about the displacements of the Gubbio area, not only in the urban area but even in the surrounding territory. This allowed to gain information about possible risk factors but even to provide a detailed analysis of the single structure as for the Consoli Palace.
- The combined use of Unmanned Aerial Vehicles (UAV) based geometrical surveys with Terrestrial Laser Scanning (TLS) allows to have, for the first time at the test beds in Gubbio, a 3D geometrical modelling/rendering, which is one of the key elements for activating processes such as digital archiving, restoration, visualization, inspection and planning.
- The integrated use of technologies for structural monitoring of the Consoli Palace, where the classical civil engineering analysis observations/methods, such as Linear Variable Displace-

ment Transducer (LVDT) and accelerometers, able to provide information about the slow displacement and vibrations of the structure, were usefully complemented by Ground Penetrating Radar (GPR) monitoring at selected areas of the Palace affected by a significant cracking phenomenon.

- The use of several in-situ technologies for an integrated vision of the Town Walls, exploiting geophysical technologies, for the underground characterization in terms of stratigraphy, for structural assessment carried out by means of inclinometers applied directly on the walls and infrared thermography for the surface and shallower layers of the wall diagnostics.
- The use of a multi-scale integrated approach for the characterization of the meteorological and pollution conditions at Gubbio, with a "spatial" focus on the test beds. This has been made possible by using different technologies, ranging from multi spectral sensors (vision of the overall urban area) to local network of meteorological stations widespread in the town to new sensing tools as portable sensors able to collect temperature and relative humidity data at pedestrian routes.
- For Consoli Palace, also the monitoring of the indoor microclimate conditions was activated by correlating the indoor and the outdoor climatic conditions.
- A very significant effort was carried out for the surface/material characterization at both the two test beds, by using a very large suite of in-situ and ex-situ laboratory techniques. The choice of these techniques was done in a "smart" way to characterize and monitor the effect of degradation phenomena related to the climatic conditions.
- Finally, as a very important activity, it has to be underlined the modelling activity of Climate Change and extreme weather conditions and anthropogenic pressure (pollution) for evaluating the present and future impact on CH assets, that are particularly exposed to material degradation
- For the Gubbio test site, the surface recessions calculated are close to the background corrosion rate since the studied area is not situated in a heavily polluted zone. For CH assets situated in dense urban areas or close to industrial sites, the situation could however be very different. In these areas, maps of exceedance can point out the zones where the actual corrosion rates exceed the acceptable corrosion rates, indicating where damages to buildings and historical and cultural monuments are unacceptably high.
- The process and the correlation of the recovered data provide a clear view of the climatic and microclimatic events of the CH resources.

Generalising this approach and conclusions, it can be affirmed that from the integration of multirisk, multisource, and multiscale

data, it is possible to obtain useful information and solutions to be made available for end-users and managers of CH assets, responsible for their safeguard. To have in advance such a kind of information is clearly crucial to avoid or mitigate serious events produced by CC.

2.2 Intangible CH: GreenHeritage project

The safeguarding of **Intangible Cultural Heritage (ICH)** is of paramount importance, too, allowing to preserve cultures, knowledge and practices of communities across the world. UNESCO, through its Convention for the Safeguarding of Intangible Cultural Heritage, has identified the importance of safeguarding ICH as a means of protecting the diversity of cultural expressions and promoting mutual understanding between communities.
In this framework, the European project GreenHeritage (The impact of Climate Change on the Intangible Cultural Heritage) is a pioneering project because it certainly is among the first to address the effects of CC on ICH. It aims at developing a holistic, innovative and inclusive approach toward direct and indirect climate change (CC) impact on intangible cultural heritage (ICH), a topic which has received little or no attention at all (https://greenheritage-project.eu/).The project seeks innovative tools and methodologies able to promote adaptive and systemic approaches to better manage CC. It also aspires to function as an urgent reminder that climate change is present, affecting both directly and indirectly all aspects of Europe's cultural heritage, and as an urgent call to stir up collective action. GreenHeritage, led by CNR, is co-funded under HORIZON Europe, by the ERASMUS+ programme of the European Union for a duration of three years (12/2022 – 11/2025), GA N°101087596.
The objectives are the following:

- O1: Analysing the state of play at national and European levels regarding ICH and current CC threats.
- O2: Exploring the key role that ICH could have in sustainable and climate-resilient development and mapping existing adaptation practices across EU.
- O3: Developing a methodology, policy recommendations and a handbook for the management, preservation, and protection of ICH in the face of CC implications.
- O4: Adding the preservation and protection of ICH at the heart of the public debate as well as the national & EU policymaking.
- O5: Empowering awareness and active citizenship regarding environmental issues, sustainability and the importance of preserving tangible cultural heritage along with intangible cultural heritage.

- O6: Developing a culture of sustainability and innovation among researchers, practitioners and empowering them by providing a set of cutting-edge training resources building on skills intelligence, available in digital and open media.
- O7: Supporting the development and approach of micro-learning and digital based education by promoting effective use of digital learning practices and capabilities.

The project is implemented in 5 European countries (Belgium, Greece, Italy, Latvia and Spain).

The European dimension of the project is first and foremost in the relevance of the theme that is discussed, which is very important to be brought to the European level. In addition, the replicability and transferability of processes, methodology developed, and results obtained in the project were designed to be implemented and transferred from local to national and European levels. They are also not limited to the covered areas and to the considered case studies but have a general applicability that can be replicated at European level. Moreover, many procedures (quality assurance, private and open data policy, communication guidelines, among others) follow the European Union and Erasmus + guidelines.

The principal added values of the project can be the following: GreenHeritage focuses on a topic that has not been discussed so far but it is very relevant to the reality of Europe and beyond, such as the effect of CC on ICH. In this sense it is a pioneering project. In addition, it should be stressed that ICH is closely related to the identity of individual communities, which however, through comparison and mutual knowledge can act as a powerful glue to the multifaceted and rich European dimension. Mutual knowledge undoubtedly allows enrichment through diversity, along with the discovery of common feelings underling practices and traditions that at first sight, may appear to be very different. These concepts and themes are conveyed through the project's training function, that is making available online courses dedicated to a wide and differentiated audience (students, experts, ICH bearers among others), to inform and solicit their awareness on the topic. With the strategies in place, a great involvement of citizens and communities as well as of stakeholders is observed. It can be considered as an added value towards the consciousness of the civil society on hot topics that clearly influence their life and on the importance of European Commission in supporting this kind of initiatives.

To develop a methodology for the management, preservation and protection of ICH in the face of CC based on a needs analysis in partner countries but also across the EU, 14 ICH case studies from all Europe were considered and studied. The final phase of their study concerns an analysis and discussion about crit-

icalities and issues for their safeguard and valorisation, during dedicated Policy Rond Tables (PRTs). They are organised in the framework of Policy dialogues and formulation of recommendation to policy makers and stakeholders.
To safeguard ICH, various measures have been taken by governments and organisations, such as developing inventories, documentation, and identification of elements of ICH. There are many existing national ICH inventories in Europe, as many countries have recognized the importance of safeguarding their intangible cultural heritage. In Italy, in addition to the national inventory, many regions and municipalities also have their own inventories of intangible cultural heritage, which reflect the diverse cultural expressions found throughout the country. These local inventories are often developed through a participatory process that involves local communities and stakeholders in identifying, documenting, and safeguarding elements of ICH that are specific to their region or municipality. Overall, the national and local inventories of intangible cultural heritage in Italy serve as critical tools for preserving and promoting the cultural diversity and richness of the country's heritage, as well as raising awareness of the importance of intangible cultural heritage for future generations.
In this paper three of the Italian ICH case studies are presented. The National Inventory of Intangible Cultural Heritage in Italy (*Inventario Nazionale delle Espressioni Culturali*) contains a diverse range of intangible cultural heritage elements that have been identified, documented, and safeguarded by the Italian Ministry of Cultural Heritage. The inventory includes a wide range of ICH elements, encompassing traditional practices, knowledge, and expressions that are central to Italian cultural identity. These elements have been identified and documented to raise awareness of their cultural significance, promote their safeguarding and protection, and ultimately foster respect for cultural diversity within Italy and beyond. The inventory's goal is to ensure that these elements are transmitted to future generations and maintained as a valuable and cherished aspect of Italy's cultural heritage.

2.2.1 GreenHeritage Italian Case Studies
The three Italian cases here presented, have been object of discussion during the PRT organized in April 2024 in Ravello by the European University Centre for CH (CUEBC) together with University of Salento and CNR.

2.2.1.1 Knowledge and traditional skills: the Art of dry-stone walls in Amalfi Coast
The first case study related to "Knowledge and Traditional Skills" is the Art of Dry-stone Walls in Amalfi Coast, already recognized as ICH by UNESCO.

It is based on a deep knowledge of the hydro-geological and natural characteristics of the ecosystem of the Amalfi coast, as the territory and its microclimate.
The dry-stone walls system allowed and allows cultivation in a difficult territory with no much land optimizing water regulation practices (figures 11-12).

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The profound knowledge of the hydro-geological and natural characteristics of the ecosystems of the Amalfi coast, combined with its particular microclimate, has over the centuries become a consolidated heritage of the local community which, to encourage cultivation and water regulation practices, developed the dry stone wall technique (here called *macere*), creating a balance between human needs and nature that is conceptually and practically far more developed than the simple terracing technique.
Climate Change is producing harmful effects on dry-stone walls.

- Abundant rains and long droughts affect the outcome of the harvests and influence the precarious balance of the dry-stone walls, causing them first to swell and then collapse, generating stone landslides downstream, in the absence of the traditional protection represented by the constant and widespread presence of farmers.
- The skills and knowledge underlying land management, traceable in technique, traditionally learned and handed down, are today threatened by the growing tendency to abandon agricultural work by the local population, a phenomenon which worsens the harmful effects of climate change.

In the following picture, dry-stone wall degradation (swelling & collapsing), is shown (figure 13).

13

2.2.1.2 Rituals and traditional festivals: the *Madonna Avvocata* festival (Amalfi Coast)

In the wonderful land of Amalfi Coast, another ICH expression, a ritual strictly linked to the territory, and in some way related to the terraces, is the *Madonna Avvocata* festival. It consists of a pilgrimage which ascends from the villages downstream to the sanctuary on top of the hill, often along the water channels and the forest, followed by a procession to the summit and a festival, bringing together in a serene atmosphere of reconciliation, different actors, such as farmers, sailors and shepherds who could have divergent interest on the territory and its exploitation. Nevertheless, this event plays a positive social role, since it represents an opportunity to meet, sing and dance to the sound of *tammorras*, a traditional musical instrument (figures 14-15).

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This is one of the most heartfelt feasts and celebrations of the intangible heritage of the Amalfi Coast, which in the past has also played an important role in terms of raising awareness of the local community in relation to the maintenance and management of the site, including the system of dry-stone walls. In fact, implies knowledge of the territory geography, since it has to be highlighted that through a trans-generational narrative connected to the spiritual event, the pilgrims discovered the characteristics of their territory, literally reading them on the root taking them to the Sanctuary (16).

16

Climate Change is directly influencing pilgrimages, processions, and the festival through the following:

- harmful effects of heavy rains which cause the paths to slip and slide
- severe droughts which deprives the springs and the large cistern near the church at the top of the mountain of water.

- climate change, combined with the abandonment of the fields, leads to a progressive collapse of the terraced system of dry-stone walls and "erases" the ancient paths in many places, effectively blocking the ascent to the mountain.

This entails the risk that pilgrims will no longer be able to climb to the Sanctuary of the Avvocata from the Maiori side, and thus effectively lose the vision and understanding of the main characteristics of the anthropized cultural landscape.

2.2.1.3 Rituals and traditional festivals: the *Feast of the Ceri of Gubbio (Umbria)*

Among all the valuable Italian ICH expressions concerning Ritual and Festivals, here is presented the Feast of the Ceri of Gubbio. Through its inclusion in the Italian National Inventory of Intangible Cultural Heritage, the *Festa dei Ceri* is recognized as an essential element of Italy's cultural heritage and is safeguarded for future generations to enjoy. The festival was chosen as one of the GreenHeritage Case Studies because it represents an emblematic and clear example of how the material and immaterial aspects of cultural heritage are closely related and live on from each other.

The *Festa dei Ceri* is a spectacular event that takes place annually on May 15th in Gubbio. It is one of the oldest and most popular ritual festivals in Italy, testified since 1160 but with pagan evidence dating back to the 3rd-1st century BC. The event consists of the transport in race of the three Ceri. They are old wooden artefacts 5 meters high, weighing almost 400 kilos, dedicated to saints linked to the historical city's guilds: Saint'Ubaldo patron saint of bricklayers, St George patron saint of tradesmen, St Anthony Abbot patron saint of farmers. The three saints' statues stand atop each *Cero* carried on the shoulders of a team of ceraioli. They carry the "ceri" through the town's streets and up to the Basilica of Sant'Ubaldo on Mount Ingino. The event culminates in a race up the mountain, which is a challenging and physically demanding feat (17-18).

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The *Festa dei Ceri* is deeply ingrained in the history and identity of Gubbio, and the town's residents take great pride in this annual event. The event attracts thousands of visitors each year, and it is a celebration of the town's traditions, culture, and communal life. Therefore, Gubbio and its cultural heritage represent a case of exceptional interest, which creates a connection between the material and immaterial nature of cultural heritage. The importance and popularity of the event at a regional level are such that, since 1973, the three Ceri have been chosen to represent the symbol of the Umbria Region and consequently appear in its banner and in the official flag.
However, in Gubbio, it appears very clear that in recent decades the weather conditions have changed greatly, as observed and confirmed by HERACLES project activities, too. Temperatures in Gubbio from 2011 to 2021 show a clear linear growth. Likewise, a positive and worrying trend of increase in precipitation is observed.
Extreme climatic events could produce structural instabilities due to hydrogeological problems for the entire historical area, as evidenced by the existing slow and progressive deformations and cracking patterns affecting ancient structures. This could also cause damage to the streets where the race of the "Feast of the Ceri" takes place and landslides and chasms on the mountain route which represents the final part of the race, a material and ideal path towards the Basilica of the Patron Saint of the city (19-20).

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Both parts of the festival that takes place in the Consoli Palace and on the mountain route along the Town Walls represent fundamental and very significant moments of the festival, which could not take place elsewhere. These tangible sites are those ones studied by HERACLES, which has made it possible to understand clearly the implications of climate change on these cultural sites.
Based on the previous study carried out with HERACLES project

and based on the fruitful discussions during the PRT in Ravello in the GreenHeritage project framework, the Climate Change effects on the Feast of the Ceri can be summarized as follows:

- Extreme climatic events could produce structural instabilities due to hydrogeological problems for the entire historical area, as evidenced by the existing slow and progressive deformations and cracking patterns affecting ancient structures.

This could also cause:

- damage to the streets and places where the race of the "Feast of the Ceri" takes place;
- landslides and chasms on the mountain route which represents the final part of the race, a material and ideal path towards the Basilica of the Patron Saint of the city (figure 21).

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3. Conclusive remarks

The experiences gained within the two European projects presented, clearly indicate how important are the CC effects on both the CH components and why it is important the CH safeguard. The challenge that CC represents for CH implies mitigating the CC effect on Tangible and Intangible CH through actions that can be briefly summarized as follows:

- careful and integrated monitoring (territory and assets)
- Actions & policies
- Involvement of local communities in decision making

The preservation of Knowledge, Cultural Traditions and Cultural Heritage Assets is essential for long-term environmental and social sustainability. Together with the use of advanced technological tools, in monitoring and research it will be of crucial importance to involve the communities and society in this loop to deliver in the end the findings of these efforts as final recommendations on:

- risk mitigation strategies
- useful actions to generate awareness and proactivity among communities.

The role and function of Policy Round Table and Policy Briefs is crucial to reach communities and propose shared solutions. Local communities and practitioners are encouraged to participate in these safeguarding measures, as they are the primary custodians of knowledge and practices.

Another aspect to underline, is the importance of education and awareness-raising programs towards the CH safeguard. In fact, education provides knowledge and understanding of the significance of both CH components and promotes respect for cultural diversity and appropriate behaviours. Awareness-raising programs help to create a sense of ownership and responsibility for safeguarding CH, promote the transmission of knowledge and practices to future generations and attract investment in the culture sector.

Finally, the involvement of the international community can support the safeguarding of CH by providing technical assistance, capacity-building, and financial resources.

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