HERACLES

HEritage Resilience Against CLimate Events on Site

Deliverable D1.2-Milestone MS1

Definition of the end users requirements with emphasis on HERACLES test-beds.

Version: V3.0

HORIZON 2020

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EXECUTIVE SUMMARY

The deliverable D1.2 “Definition of the end-users requirements with emphasis on HERACLES test-beds” represents also the first Milestone (MS1)of the HERACLES project. This document is particularly important because here are defined the end-users’ needs requirements for the HERACLES platform.

The information collected and included in this deliverable are and will be decisive for the project and the platform development. As was already stated in the project, the HERACLES approach is to consider the end-users’ requirement as the starting point for the definition of the actions to be undertaken. Nevertheless, it has to be underlined that this represents a methodological approach of general applicability, that will allow to extend the platform functionalities and specificities to other requirements and consequently to other end-users.

The aim is to acquire information on the sites and their territory, from a technical and socio-economic point of view, to acquire information on the problems and risks affecting the maintenance and preservation of CH assets there and on the end-users’ needs, as well as on the current risk management procedures in order to plan a step forward with respect to the current situation.

The document is organized in Sections, as will be described in the following Introduction, Section 1.

1 INTRODUCTION

1.1 Document organization

The present document D1.2 “Definition of the end-users requirements with emphasis on HERACLES test-beds” is organized in Sections.

In Section 2, a series of term definitions, used in the text are included.

In Section 3, a description of the CH sites and their territory is given, highlighting and accounting for the HERACLES choices too, and the test beds criticalities. The socio-economic framework is also briefly illustrated.

In Section 4 a detailed description of the different risks and their related impact on the sites is provided, together with a brief review of previous realized interventions.

In Section 5,a study is reported on the social and economic issues and implications of the HERACLES sites. It was done using different and mixed methodologies in order to collect info related with the end-users' requirements, in the different perspectives and contexts. Personalities representing the local political and Superintendences point of view have been selected and interviewed for both sites (Heraklion and Gubbio, representing Greece and Italy, respectively).

In Section 6 the general methodology that can be applied to address the risk and disaster management of CH sites, is presented as well.

In Section 7 the current risk management procedures used in Heraklion (representing Greece) and in Gubbio (representing Italy) sites is discussed. A discussion of the limits present in the current CH risk management, is also given.

In Section 8, taking into account the info and the analysis provided by the previous Sections and taking into account the identified end-users requirements, the description of a new tool, the HERACLES platform, is given, highlighting its novelty and improvement with respect to the current CH management status.

In Section 9 the documents and sources used for D1.2 are listed.

In Section 10, further info on the deliverable are given.

1.2 General Objective

This deliverable is devoted to the definition of the end-users requirements related to long term maintenance and risk management for CH, also by covering all the social, economic and technical aspects. In particular, a set of well-defined use-cases describing the possible interactions between users and HERACLES system will be identified. The focus will be on the detailed specification of users' requirements for the scenarios at the HERACLES test-beds, which can be considered as guidelines for the description of other useful scenarios, too.

This document has been prepared also with the useful and valuable contribution of the AB and EB members, for the specific fields of interest.

Acronym	Abbreviations
AB	Advisory Board
ALARP	As Low As Reasonable Practicable
ANCSA	Associazione Nazionale Centri Storico Artistici
APAT	Agenzia per la Protezione dell'Ambiente e per i servizi Tecnici
CNR	Consiglio Nazionale delle Ricerche
CSF	Community Structural Funds
CH	Cultural Heritage
COBC	Centro Operativo Beni Culturali
CP	Civil Protection
CPP	Civil Protection Plan
DICOMAC	Dipartimento di comando e controllo
DPC	Dipartimento Protezione Civile (Civil Protection Department)
DPC	Decreto Presidenza del Consiglio
EB	Ethical Board (alias SSHERC: Social Science and Humanities & Ethics Review Committee)
EC	European Commission
ENEA	Ente Nazionale Energie Alternative
EU	European Union
FEMA	Federal Emergency Management Agency
FESR	Fondi Europei Sviluppo Regionale
GA	Grant Agreement
GTS	Gruppi Tecnici di Sostegno
ICOMOS	International COuncil of MOnuments and Sites
INGV	Istituto Nazionale Geofisica e Vulcanologia
ISCR	Istituto Superiore Centrale del Restauro
ISCS	International Scientific Committee for Stone
ISO	International Organization for Standardization
MiBAC	Italian Ministry : Ministero per i Beni e le Attività Culturali
MiBACT	Italian Ministry : Ministero per i Beni e le Attività Culturali e Turismo
NEET	Not (engaged) in Education, Employement or Training
NSRF	National Strategic Reference Framework
OECD	Organisation for Economic Cooperation and Development
OICD	Organization for Identity Cultural Development
PON	Programma Operativo Regionale
RFI	Rete Ferroviaria Italiana
SIUBC	Sistema Informatico Unico dei Beni Culturali
TIM	Telecom Italia Mobile
TV	Tele Vision
UCCN	Unità di Crisi-Coordinamento Nazionale
UNESCO	United Nations Educational, Scientific and Cultural Organization
VHS	Video Home System
WP	Work Package
WRF	Weather Research and Forecasting

2 DEFINITIONS

Alveolization: formation, on the stone surface, of cavities (alveoles) which may be interconnected and may have variable shapes and sizes (generally centimetric, sometimes metric). (ICOMOS, 2008)

Biodeterioration: is the process by which organic/inorganic materials are decomposed by micro-organisms (mainly aerobic bacteria) into simpler substances such as carbon dioxide, water and ammonia (OECD Glossary)

Chromatic alteration (Discolouration): Change of the stone colour in one to three of the colour parameters**:** hue, value and chroma. Hue corresponds to the most prominent characteristic of a colour (blue, red, yellow, orange etc.). Value corresponds to the darkness (low hues) or lightness (high hues) of a colour. Chroma corresponds to the purity of a colour. High chroma colours look rich and full. Low chroma colours look dull and grayish. Sometimes chroma is called saturation. (ICOMOS, 2008). Another definition for **chromatic alteration** is the following natural variation of the stone components of the parameters that define the colour. It is generally extended to the whole litotype; if the alteration is localized, it is preferable to use the term stain. (Bugini-Folli, 2008)

Cracking: may be due to weathering, flaws in the stone, static problems, rusting dowels, too hard repointing mortar. Vibrations caused by earth tremors, fire, frost may also induce cracking. (ICOMOS, 2008)

Crumbling: detachment of aggregates of grains from the substrate. These aggregates are generally limited in size (less than 2 cm). This size depends of the nature of the stone and its environment. (ICOMOS, 2008)

Crust: generally coherent accumulation of materials on the surface. A crust may include exogenic deposits in combination with materials derived from the stone. A crust is frequently dark coloured (black crust) but light colours can also be found. Crusts may have a homogeneous thickness, and thus replicate the stone surface, or have irregular thickness and disturb the reading of the stone surface details. (ICOMOS, 2008)

Black crust: kind of crust developing generally on areas protected against direct rainfall or water runoff in urban environment. Black crusts usually adhere firmly to the substrate. They are composed mainly of particles from the atmosphere, trapped into a gypsum ($CaSO_4.2H_2O$) matrix. (ICOMOS, 2008)

Salt crust: crust composed of soluble salts, which develop in the presence of high salt levels, and form from wetting and drying cycles. (ICOMOS, 2008)

Disintegration: detachment of single grains or aggregates of grains. (ICOMOS, 2008)

Efflorescence, efflorescing salt: generally whitish, powdery or whisker-like crystals on the surface. Efflorescences are generally poorly cohesive and commonly made of soluble salt crystals. Efflorescence is commonly the result of evaporation of saline water present in the porous structure of the stone. Efflorescences are often constituted of soluble salts such as sodium chloride (halite: NaCl) or sulphate (thenardite : Na_2SO_4), magnesium sulphate (epsomite: $MgSO_4$. 7H2O), but they may also be made of less soluble minerals such as calcite ($CaCO_3$), barium sulphate ($BaSO_4$) and amorphous silica (SiO_2 . nH2O). (ICOMOS, 2008)

Encrustation: compact, hard, mineral outer layer adhering to the stone. Surface morphology and colour are usually different from those of the stone. (ICOMOS, 2008)

End-user: an end-user is defined as a person or group in a position to apply the information or tools being produced, evaluated or transferred through a project.

Erosion: loss of original surface, leading to smoothed shapes. (ICOMOS, 2008)

Exfoliation: detachment of multiple thin stone layers (cm scale) that are sub-parallel to the stone surface. The layers may bend, twist in a similar way as book pages. (ICOMOS, 2008)

Flaking: scaling in thin flat or curved scales of submillimetric to millimetric thickness, organized as fish scales. (ICOMOS, 2008)

Hydrogeological risk is represented by events such as landslides and floods that produce measurable damages to people and belongings (APAT, 2008)

Patina: chromatic modification of the material, generally resulting from natural or artificial ageing and not involving in most cases visible surface deterioration. (ICOMOS, 2008)

Peeling: shedding, coming off, or partial detachment of a superficial layer (thickness: submillimetric to millimetric) having the aspect of a film or coating which has been applied on the stone surface. (ICOMOS, 2008)

Plants, climbing plants: presence of plant organisms on the substrate, recognizable microscopically (algae, fungi, lichens, mosses, higher plants. (Bugini-Folli, 2008). This is considered related to the more general phenomenon of the biological colonization, a colonization of the stone by plants and micro-organisms, such as bacteria, cyanobacteria, algae, fungi and lichen (symbioses of the latter three). Biological colonization also includes influences by other organisms such as animals nesting on and in stone. (ICOMOS, 2008)

Pitting: point-like millimetric or submillimetric shallow cavities. The pits generally have a cylindrical or conical shape and are not interconnected, although transitions patterns to interconnected pits can also be observed. (ICOMOS, 2008)

Scaling: kind of detachment totally independent of the stone structure. (ICOMOS, 2008)

Spalling: in the case of flat surfaces, may be called contour scaling, scaling in which the interface with the sound part of the stone is parallel to the stone surface. Case hardening is a synonym of spalling/contour scaling. (ICOMOS, 2008)

Splitting: fracturing of a stone along planes of weakness such as micro cracks or clay/silt layers, in case where the structural elements are orientated vertically. For instance, a column may split into several parts along bedding planes if the load above it is too high. (ICOMOS, 2008)

Staining, chromatic alteration: localized pigmentation of the surface is correlated to the presence of certain natural components of the material (concentration of pyrite in the marbles) both to the presence of foreign material (water, oxidation products of metallic materials, organic materials, paints etc.) (Bugini-Folli, 2008). It is a kind of discolouration of limited extent and generally of unattractive appearance. (ICOMOS, 2008)

Stakeholder: is anyone who is affected by or has an interest or stake in a particular issue. Examples of stakeholders include members of national, regional, local agencies, governmental/state bodies, business leaders and industry representatives, representatives from non- profit groups or other citizen organizations. All end-users could also be considered stakeholders, but not all stakeholders are end-users.

3 DESCRIPTION OF THE SITES AND THE REGION WHERE THEY ARE LOCATED

This section is devoted to the description of the sites selected as test beds for the demonstration activities to evaluate the effectiveness of the HERACLES approach/system enabling an assessment/awareness situation, building and area information and decision support system for the full implementation of diagnosis, monitoring, remediation and crisis management services, through the integration of multi-source data. The methodologies and analysis will take into account 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). This Section is organised in two parts, each one providing a general description of the test beds then focusing on the assets that are specifically the object of the demonstration activities.

The HERACLES philosophy/strategy is **NOT** to focus only on **well-known centers/cities /monuments, but mainly** on "**minor" historic centers,** however representing the basic nature of the European Countries, not often greatly taken into account but constituting the essence of our **Countries**, our **Culture**, our **Identity**, our **Economy**, **were people lives, and works**.

In this respect, Gubbio 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 Crete, Knossos represents **all the important archaeological sites that face many problems deriving from extreme phenomena** due to climate change**,** and Koules fortress 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, the recent 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). CH in fact, is of paramount importance, representing a noteworthy factor for social identity and an economic value certainly not negligible, as stated also by OICD. Consequently, the HERACLES contribution could result very important and useful in this direction, too, through new solutions and systems improving the resilience of a vulnerable heritage at risk.

Moreover, HERACLES project will be a good example of GLOCAL, thinking GLOBAL, but acting LOCAL.

3.1 Gubbio

Gubbio is the capital of one of the largest Italian municipalities (the seventh for extension with its 524 square km) with a population of around 32.000 inhabitants.

The site on which the first settlement was built was carefully chosen by the ancient inhabitants: in fact, it is close to a river, providing the availability of water, it is protected from extreme weather events from the mountains around (mainly from NE). Furthermore, it dominates the valley, away from the swamps and easily defensible.

As demonstration of the importance of Gubbio for its territory and culture, it is important to mention that for its tradition dated back to about 1000 A.C. (i.e. *Festa dei Ceri* - Saint Ubaldo day) is to be inscribed in the list for the immaterial UNESCO Heritage, and the three *Ceri* are at present representing the symbol of Umbria, one of the 20 regions in which Italy is currently organised. In summary, Gubbio can **be 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, 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 a number of criteria for intervening in the historic centers. Until then, the oldest parts of a city could be demolished and reconstructed. The historical centers, after Gubbio Charter, will be 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 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"]*, <u>since it results very coherent with the DRS 11-2015 topic</u>.

The choice of Gubbio is thus linked also to its ability to message and to propose itself as an educative place, as a centre 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 city Walls, that, as appear nowadays, were built in approximately 1.500 years, through elevations, renovations and expansions. HERACLES activities will be mainly directed to the mitigation of the hydrogeological risk of the monumental part of the town constituted by the "Città Alta" and the 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 of increased deterioration due to climate change effects coupled with pollution, and present damaged parts that can lead to structural instability.

Here, the chosen test-beds are the <u>Town walls</u> and the <u>Consoli Palace</u>.

Concerning the economical aspects, currently, the territory is in strong economic difficulties for the crisis of different industrial sectors hitherto profitable (cement/concrete industry, electrical appliance industry; both civil and industrial prefabricated building sectors; ceramics industry; artistic handicraft; etc.) that in recent years left thousands of workers in unemployment insurance as well hundreds of people lost their jobs. At the same time, among young people, sharply rising unemployment/inactivity/NEET **(N**ot (engaged) in **E**ducation,

Employment or **T**raining) persons are observed. For all these reasons the average income is below the European average

At the same time, disadvantaged environmental and geographical conditions have a negative influence on the communication routes network, since the territory is mountainous and hilly, far away from the principal road network and railways, it is vast with consequently very extended with high maintenance road networks costs. Furthermore, the settlement density is low and not homogeneous.

Among the most obvious effects of the crisis in this area, emigration is starting again, mostly towards other European countries, a phenomenon which was not observed for over 40 years and that now is involving young people with a medium-high level of education.

The sector presenting growth potential in the short and medium term is Tourism and its satellite activities. Main attractions for Gubbio tourism are cultural and artistic heritage, religious and natural heritage of the area, artistic handicraft and gastronomic heritage. The progression of this sector, strongly depends on a correct preservation and development of cultural/natural heritage of Gubbio and its area.

3.1.1 *Town Walls*

The first settlement is documented from pre-history (middle Paleolithic). Then, around 1500 B.C., first Indo-European colonists settled permanently and Gubbio became the capital for these populations called "Umbrians". Gubbio was an important centre during Roman domination too, and was the first town to establish alliance with Rome (from Cicero - *Pro Balbo*, XX 46-47; XXI, 48), obtaining the Roman citizenship, and becoming a *Municipium*. The Roman city on the slopes of Ingino mountain was built according to the usual square Roman land (*centuriazione romana*) and archaeological findings testify continuity till the IV cent. A.C., during seven centuries of peace and prosperity. With the fall of Roman Empire, Gubbio was occupied by Eruli population and destroyed by Toti, the king of the Goths. As a consequence, the settlements in the plain were abandoned to move on the mountain where the defence was easier. The current appearance of the old town of Gubbio began to form after three centuries of Barbarian populations raids (Heruli, Goths), of real invasions (Normans, Ungarians, Saracens) and alternate dominations (Longobards and Byzantines).

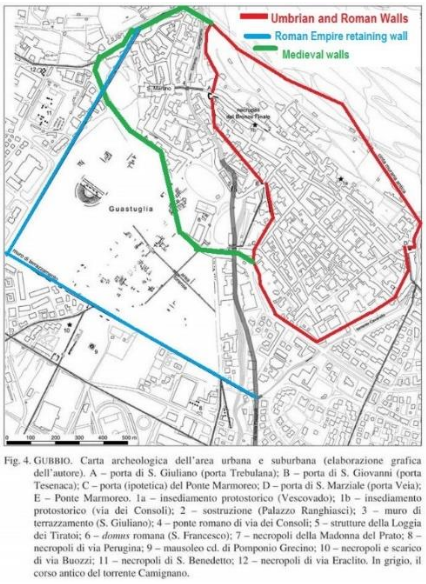


Figure 1 - track of town walls in Gubbio

Figure 2- the town plant in middle age

Then, Gubbio was characterized by a prosperous and peaceful period from 1262 to 1631. During this time, in the Middle Ages, Gubbio became an important and independent municipality (*Libero Comune*), which conferred it the present planimetry and structure of the town, very well conserved and considered as an example of typical Middle Ages town. During this phase an urban expansion took place, and the Cathedral and the Town Hall, symbols of the religious and political power, moved on the most protected slopes of the mountain. Later on, during the Montefeltro domination, Renaissance buildings were realised. The town Walls had been built since Umbrian age. Only during Middle Ages they reached the length of 3 kilometres and a height of more than 12 metres because had to protect the city against invasions, sieges and enemies raids.

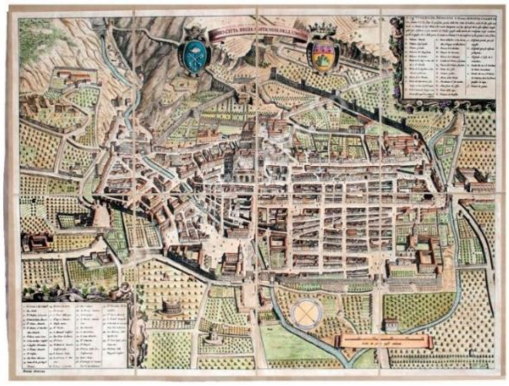


Figure 3- the town plan in 17th century

Figure 4- the town walls today

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 door of the town. This door was at the entrance of the city, in the lowest part of the main square (now *Piazza 40 Martiri*), still visible in Figure 3, in the South west side, where the road leading to Perugia begins. The "*Marmorea*" door was demolished together with 50 metres 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 which slopes the city has been built. These interventions were performed mainly to remove the thousands of cubic meters of soil carried there by rains, since it was intensifying the load on the Walls and increasing the aquifer water levels.

The first intervention was made over thirty years ago, removing the soil accumulated upstream of the walls and pushing on them. A 6 metres concrete retaining wall was built, with post-tensioned cables placed far 4 metres from the ancient structures and finally creating new slopes uphill (see Figure 5). For its position on the map see Figure 15 (section 4) on risk -zone 2 Cassero.

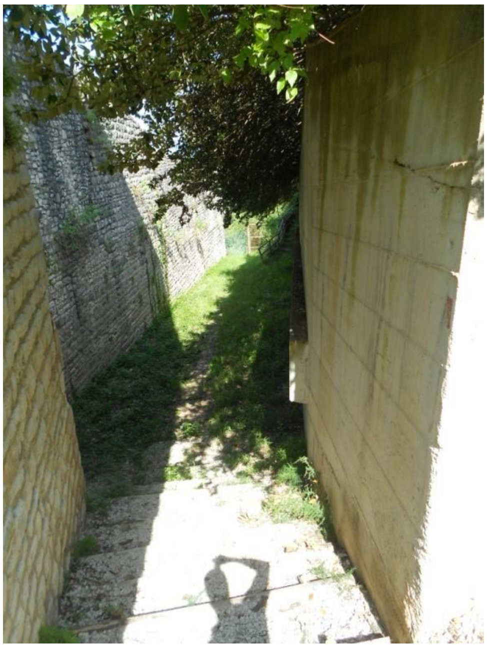


Figure 5 - the retaining concrete wall (1st intervention)

The second intervention was made eight years ago. This was divided in two parts. The first one concerned the part of the Walls between S. Ubaldo and S. Girolamo doors for about 125 m. For its position on the map see Figure 15 (section 4) on risk, zone 4,5,6.

The soil slipped against the Walls over last centuries was removed and it was used to make rammed-earth wall or "retaining/reinforced earth wall" (about 3 metres upstream of, and parallel to the Walls); the hollows present in the collapsed areas were filled; the external facades were restored (eradication of plants, roots and weeds shrubs using pesticides, without affecting the existing binder; treatment with anti-mould and anti-moss; surface cleaning of the stones with low-pressure water cleaner; filling of the joints and cracks of the stones with mortar). Finally, a resin has been used to protect all the surfaces (see Figures 6, 7, 8, 9, 10).

Figures 6-7 - town Walls: lower part - the slope BEFORE and AFTER the intervention (notice the position of the road sign)

Figures 8-9 - town Walls: upper part - the slope BEFORE and DURING the intervention

Figure 10 - town Walls: upper part - the slope AFTER intervention with a clear vison of the retaining/reinforced earth wall

3.1.2 *Palazzo dei Consoli*

At the end of the Middle Ages the *Liberi Comuni* period ended and during the following three centuries Gubbio was dominated in sequence by the Montefeltro, Medici and Della Rovere Families. In this period were built the most important monuments: the complex of the "Consoli Palace", the Podestà Palace (the actual Town Hall) and the "Piazza Grande" among them (Figure. 11).

Figure 11: A view of the Consoli Palace complex, in the high part of the town

The Consoli Palace was built between 1332 and 1349 and designed by Angelo da Orvieto, on the project of Matteo Gattapone architect from Gubbio. The Palace has a rectangular shape, and a very articulated distribution of volumes. This building has a foundation system on two levels (Figure. 12).

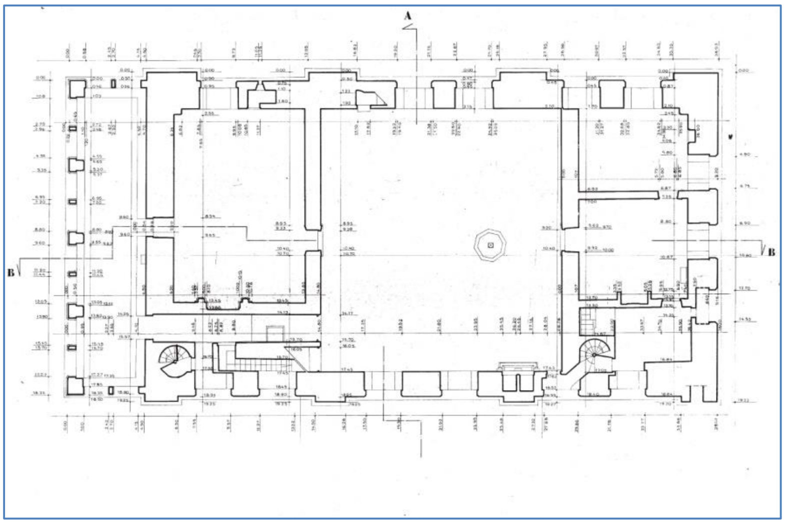


Figure 12: Consoli Palace plan

The facade overlooking the square is made of ashlar stone. In its highest part six windows with round centre in pairs, divided by pilasters, are present, while the battlements is supported by small pointed arches. The lower part has two mullioned windows positioned on the two sides of the Gothic style portal, decorated with a XVI-century fresco in the lunette. The entryway is through a fan-shaped staircase. On the façade is still present an iron cage which in the past was used to expose thieves and criminals to the public shaming (see Figure 13).

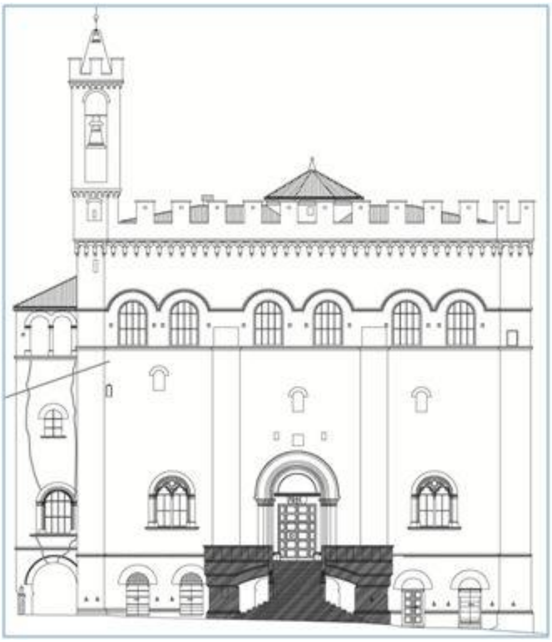


Figure 13: Consoli Palace façade

The portal leads to an internal hall with a barrel vault named "the *Arengo*" that during the Communal age was used for meetings and assembly of citizens for the government of the city (Figure 14).

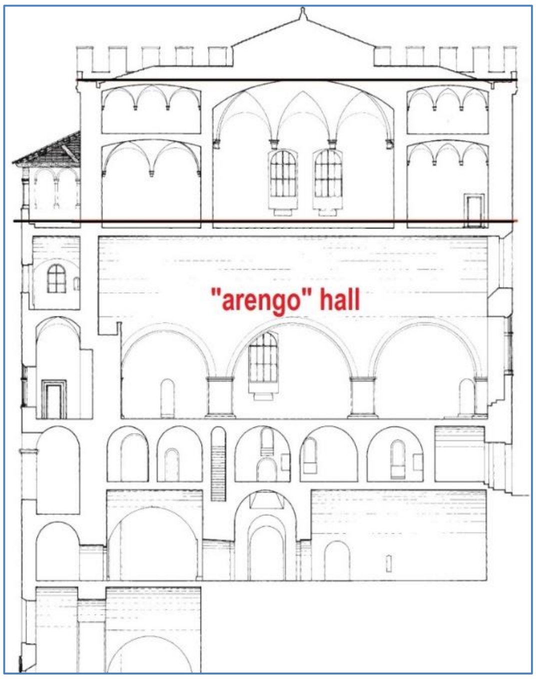


Figure 14: Consoli Palace: section plan

The palace was the first building to have running water, used to power the beautiful fountain located inside the building. Since 1901, the building hosts the town museum, presenting art gallery, ceramics section, archaeological and oriental collection, and collection section on Italian *Risorgimento* (*Risorgimento* is the period leading to the unification of Italy). In the ex chapel of the Palace, the *Tavole Eugubine* are conserved. They represent a unique and precious document allowing the interpretation of the language of the ancient Umbrians population.

In the tower is placed the famous big bell (*campanone*) that since 1380 marks with its sound (*sonate)* very few and special events during the years.

Since XIX century until now, many restorations were made such as: the re-building of the main stairs; reinforcement interventions with anti-seismic techniques after the earthquakes of the early 80s, particularly that one of 1984; the cleaning of the façade and interior walls; optimization of the museum lighting and plumbing, as well as the restoration of the wooden external portals and doors.

3.2 HERAKLION

Heraklion is the largest city and the administrative capital of the island of Crete. It is the fourth largest city in Greece. According to the results of the 2011 census, the population of the Heraklion urban area was 225.574 inhabitants. It extends over an area of 684.3 km^2.

The city of Heraklion is the largest urban centre in Crete (the fourth largest municipality in Greece) and the economic centre of the island. Heraklion is one of the most popular touristic destinations in the country and in the Mediterrean area. Its population was increased in the last two decades (1981-2001) by approximately 30% and it is projected to increase by a further 20% by the year 2021. Heraklion is also a well-established science research centre in Europe given that two major academic Institutions in Greece (the University of Crete and Technological Educational Institute of Crete), and one of the largest research centres in Greece (Foundation of Research and Technology Hellas- FORTH) are located within its region.

Heraklion is a central hub with an international airport, "Nikos Kazantzakis", second International airport in Greece, first in charter flights. The Heraklion port is the second in activity in Greece. Moreover, the port comprising a marina, fishing & commercial piers and repair zone, is a significant commercial hub handling large numbers of passengers and goods to all over Greece and abroad. Within the last years, the port of Heraklion received an increasing number of cruise visits, enhancing thus notably the local economy.

Here, the chosen test beds are the Minoan Knossos Palace and the Venetian coastal monument (sea fortress of "Koules"). This area combines in a whole the life of a capital of a region with its economy, its environment and its culture. They are both part of the historic touristic routes of the city with thousands of visitors on a daily basis (actually Knossos is the second most visited site in Greece after the Acropolis of Athens).

Although globalisation, tourism and economic growth have inevitably changed the way of life in Crete, especially in the large urban centres, to a modern and cosmopolitan style, the Cretans still preserve the bonds with their rich folk traditions and cultural heritage.

There is also an exceptional artistic production in traditional sectors such as pottery, embroidery, jewellery etc, that take inspiration from the cultural heritage values of the area.

The most dynamic sector of the Cretan economy is tourism**;** the excellent climate of the island, the beautiful landscape and above all, the exceptional archaeological sites and historical monuments, along with the remarkable tourist resorts, attract as many as 3.000.000 visitors every year.

The financial activities of the Municipality of Heraklion are mainly concentrated in the secondary and tertiary sectors, while significantly limited but progressively engaging with the primary sector.

Heraklion has the largest share of industrial activity in Crete. More than 60% of the industrial units of Crete are located around the city. The tertiary sector is based on the number of employees, first place in the economy (80%). Dominant position in the tertiary sector hold the sectors of retail -trade and restaurant - hotel.

The concentration of the units are located within the connective tissue of the residential areas of Heraklion. Most hotels operate on an annual basis and serve not only tourists but also those who travel for business or other reasons.

As a result of the economic crisis, data indicated that business activity was significantly decreased in Heraklion within the last 3 years, continuing the downward trend that has been shown in the year 2013. During 2014 a number of 1.048 businesses were started and 1.831 were shut down (-783 difference), while in the previous year (2013) the number of businesses that were initiated and closed were 1.491 and 1.615 respectively (-124 difference). During the last year, a positive sign was presented only in the touristic industry, in which the number of enterprises that were created was higher than the ones that were shut down (+ 59), although it is important to highlight the very strong factor of seasonality in terms of employment within the touristic business activity (71.78%). On the other hand, in the manufacturing sector the reduction is very high; 112 companies were created in contrast to 467 closed (difference -355).

3.2.1 *Knossos*

The Minoan Palace of Knossos, is a spectacular Bronze-Age citadel and represented the ceremonial, economic, social and political centre of the **first civilization of the Mediterranean basin**, namely the Minoan civilization. Also known as the Palace of Minos, as a citadel, **is considered the Europe's oldest city**. It was continuously inhabited from the Neolithic period (7000-3000 B.C.) until Roman times. It is located in the S.E. of the city of Heraklion and is the largest and the most glorious of the all Minoan Palaces in Crete, covering an area of 22000 sqm. Around 2000 B.C. a large building, the Old Palace, was erected, which was destroyed around 1700 B.C., but immediately rebuilt (New Palace), following an architectural plan in which around a Central Court (oriented N-S) and a court to the W, four major wings with hundreds of rooms are settled.

The Palace was excavated partly by M. Kalokairinos and fully by sir A. Evans between 1900 and 1905. The need for preservation and restoration of the monument was obvious for Sir A. Evans from the first years of the excavation. Since 1905, most of its parts were sheltered, and in some cases restored. With the restoration Sir A. Evans reconstructed entire floors of the monument with reinforced concrete. He restored the frescos, copies of which were placed in the restored sites and he constructed columns and pillars with concrete. After the World War II large scale restoration works were made under the directors of the Ephorate N. Platon and S. Alexiou, but they were restricted only to the preservation of the ancient walls, the restoration of the floors and the protection of sectors with shelters. During the ‘90s the Ministry of Culture, recognizing the problems that the monument was facing, took measures for its preservation and restoration. Under the authority of the Ephorate of Antiquities a great part of the concrete slabs of Evans’ restoration was conserved, and paths for the visitors were created, which reduced the wear of the monument and gave the visitors a more complete view of it. In the period of 2000–2008 a conservation project of the Palace was included in the 3rd C.S.F (Community Structural Funds). For its protection and restoration a NSRF (National Strategic Reference Framework) Project begun in 2010 and finished 2015, concerning the restoration and conservation of the monument. Indeed, a complete programme of conservation and promotion of the site was launched: conservation of masonry, gypsum stones and limestones, ancient coatings and plaster, copies of frescoes, columns and wood imitations, conservation of the Minoan pithoi, and replacement of Evans's lightly-arched roofs.

3.2.2 *Rocca a Mare -Koules*

The Sea Fortress of "Koules" is located in the port of Heraklion and constitutes a characteristic type of the Venetian military architecture. Similar fortifications can be found in all major cities in Crete (Rethymnon, Chania) as well as in other locations in the Mediterranean basin (Cyprus). In fact, **an important sector of CH in Greece and in Europe is that one on the coastal area throughout the Mediterranean (cities, ports, lighthouses, fortress and other monuments) that face the risk of hazards from climatic change, such as significant impact from the sea** (sea level rising, increasing intensity of extreme weather phenomena combined with the air and land associated hazards, increased salinity accelerating corrosion and deterioration of materials and structures, etc).

The Venetian Sea-Fortress is an emblematic monument for the city of Heraklion. Better known as Koules ("Su Kulesi"), the Ottoman name, which prevailed over its original one, Castello a Mare or Rocca a Mare. It is situated at the edge of the NW breakwater of the Venetian harbour. The large limestones used for its construction come partly from the Hellenistic fortifications of the city. In the past, at the same place was a rectangular beacon-tower, called by the Venetians, Castellum Communis. The tower was destroyed by the earthquake of 1508 and since 1523 it was decided that a larger fortress, built according to the bastion-system, had to replace it. The shape of the fortress is roughly quadrangular, with a semi-circle bastion at the SE side. Its outer walls are inclined and the main entrance is situated to the West, giving way to the Venetian fortified mole. On the western, southern and north-eastern façade, the marble emblem of Venice (i.e. the lion of St. Marco) was embedded. On the ground floor, to the left of the main corridor, there are barrel-vaulted rooms which hosted barracks, warehouses, prison cells and water-tanks. Light and air came into the rooms through the roof. All around the building there were openings for the cannons. A staircase and a ramp for the cannons lead to the upper terrace, around which there were other cannon-openings, barracks, a mill and a beacon. The surrounding walls ended up in a straight parapet, protecting the inner corridor. The battlements were added during the period of the Ottoman occupation.

The first attempts of restoration started in 1959 by the curator of antiquities Stylianos Alexiou. More work has been done by M. Borboudakis during the period 1972-75, according to the approved study suggested by A. Lampakis to make the fortress accessible to the public. No additional work had been executed during the following years, resulting in the decay of the monument. The binding mortar of the masonry has been badly weathered and the balusters, although recent restored, were almost ready to collapse. Salt black hard crusts were covering part of the walls, sea and rain water were entering from the broken skylights at the roofs of the galleries. All the iron elements used in the monument were heavily corroded.

During the first decade of 2000, the Greek Ministry of Culture, anticipating the problems that the monument was facing, decided to take new measures for its protection and safeguarding. Under the direction of the Ephorate of Antiquities a National Strategic Reference Framework

Project concerning the Restoration and Conservation of the Venetian Fortress (Koules), took place (2011-2016). In the conservation program the main concern was related to the static and reinforcement aspects of the monument. In order to achieve the desired result, previous interventions to masonries, both indoors and outdoors, have been removed, the lions' relieves have been consolidated and conserved, and the old frames of the cannon openings at the ground floor have been replaced with stainless ones. Restoration works aimed to the cleaning and protection of the stone surfaces from hard salt crusts and biodeterioration signs, where it was possible without losses of the material. In addition, the three lions' emblems on the facades of the monument were cleaned and consolidated in order to achieve compactness.

It has to be mentioned that during the restoration program (2009), the School of Mineral Resources Engineering of Technical University of Crete had performed analysis of stone masonry identifying four types of sedimentary stones:

a) breciated fossiliferous limestones,
b) microbreciated limestone,
c) calcarenites sandstones, and
d) bioclastic/biomicritic fossiliferous limestone.

The continuous exposure to marine aerosol of the fortress has produced severe weathering of the building stone (biocalcarenite), which is a porous material susceptible to the action of soluble salts and environmental conditions. The same problem concerns the materials used for restoration works.

4 DIFFERENT RISKS AND RELATED IMPACTS ON THE SITES

Variations in climate parameters connected with Climate Change trigger risks and consequent impacts on CH assets. In the following paragraphs, the major risks affecting the HERACLES test beds and their relative consequences are described, with the aim to hypothesize and plan effective mitigation actions.

4.1 Gubbio: risks/hazards & technical aspects

Gubbio is a medieval town with a very significant cultural heritage, which 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 of 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 material 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 are worsening in the last years due to a higher concentration of CO_2, associated with more intense rainfalls, that producing acid rains, are 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 selected sites for HERACLES demonstration activities, i.e 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.

4.1.1 Town Walls

The first test area identified in Gubbio is the monumental part of the town, constituing the “High Town” and 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.

The part of the urban walls exposed to the maximum risk is located on the slopes of Ingino mountain in N/NE direction. The area nowadays is mostly interested by olive plantations, while in the past was also used by wood-cutters 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 historic 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 the World War II. In fact, in the past, only 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 metres 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 the increase of 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 occurred over the last centuries.

According to this scenario, the activities of the HERACLES project will be directed to the mitigation of the hydrogeological risk on that area. The Walls suffer mainly from torrential rains and humidity characterizing the soil surrounding the area and closely connected with the mountain natural area. The heavy rains increase the push on the Walls in two ways: the first one is through the washout producing and transporting rubbles, 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 of 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.

An other 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 the stresses on the surface of the stone and leads to a heterogeneous stone-binder system behaviour.

The HERACLES activities for this scenario, will address to quality of the mortars used and their properties. Furthermore, mortars with improved characteristics will be designed.

The Walls areas to focus on, are shown in the following photo (Figure 15):

Legenda:

i. Zone 1 ("*Forte di Parco Ranghiasci*");
ii. Zone 2 ("*Cassero*");
iii. Between zone 3 ("*Torre*") and zone 4 ("*Porta S. Ubaldo*")
iv. Between zone 4 and zone 5 ("*Bughetto*")

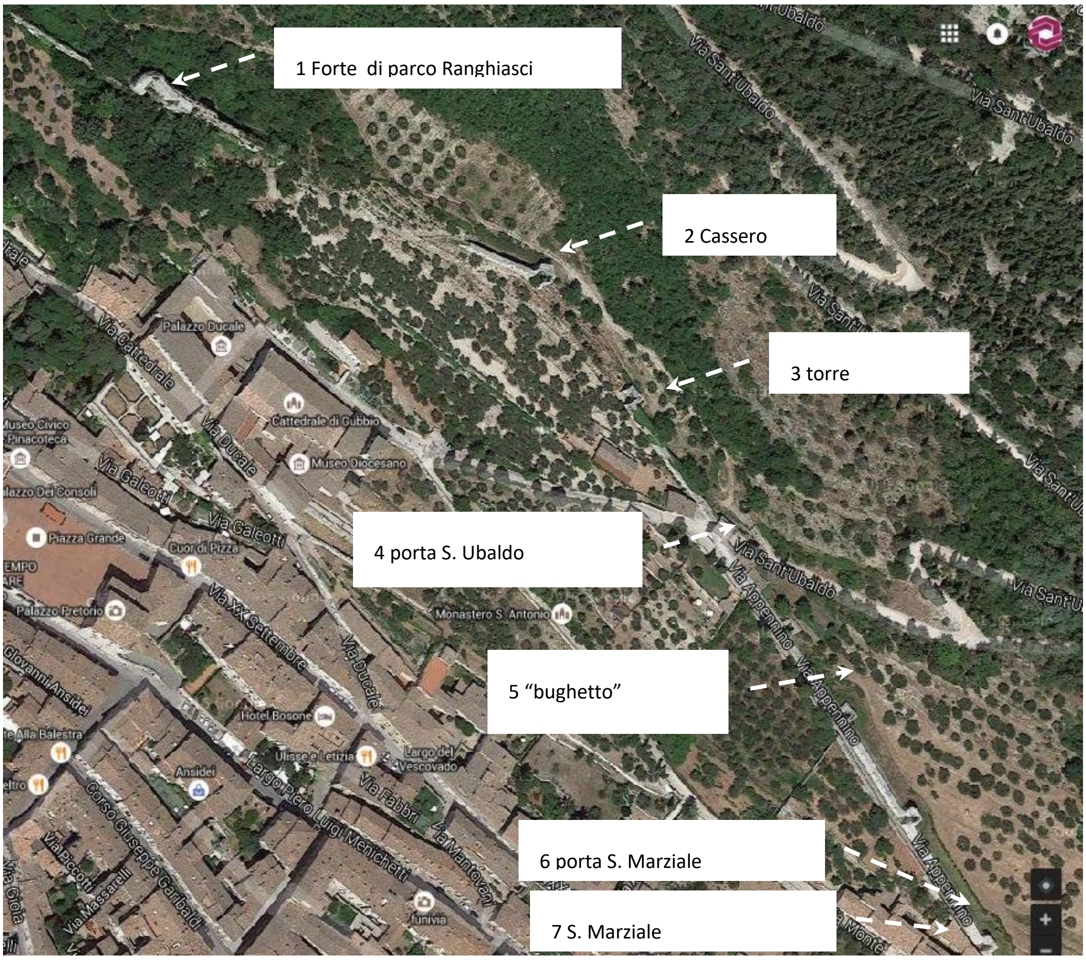


Figure 15: Identification of the studied zones on the satellite image of the area

In the following subsections, an overview of the main problems occurred in the last years are presented and described

4.1.1.1 Atmospheric moisture change and intense rainfall and flooding related

The atmospheric moisture change is the main hazard affecting the town Walls since its major consequence are intense rainfalls that leads to flooding. These can affect the masonry itself due to erosion of the mortar or cracking of the system stone/mortar or to an increase of the aquifer levels that leads to a higher pressure on the walls, creating structural instability.

Physical changes to porous building materials and finishes due to rising damp can be observed.

Only during the last three years there has been at least three events of intense rainfalls: June/2013, May/2016 and August/2016 with many damages to private and public buildings/structures.

The lower part of the town Walls in the west side of the city surrounds a car parking (called “*Seminario*”) that in the last years has been continuously flooded. The two photos below show such situation. The town Walls not clearly visible, are on the left side, behind the trees curtain.

Figure 16 a), b) - car parking "Seminario" June 2013 - before flooding and after flooding

In M**ay 2016 an hailstorm occurred so violently that the roads and the roof**s **looked like after a snow fall/storm.** Of course, it produced also an important temperature excursion.

Figure 17 - May 2016, heilstorm in Piazza 40 Martiri (where "Porta Marmorea" was placed in the past)

4.1.1.2 Damages derived by faulty or inadequate water disposal systems after an extreme events

Historic rain water disposal systems are not capable of handling heavy rains and often are difficult to access, maintain, and repair. This can produce an increasing load on the Walls and in the last four centuries many events occurred regarding collapses and landslides in the upper part of the old town, affecting the Walls and attributable to this situation. In the map below the occurred events are reported with the indication of the period/year (Figure 18).

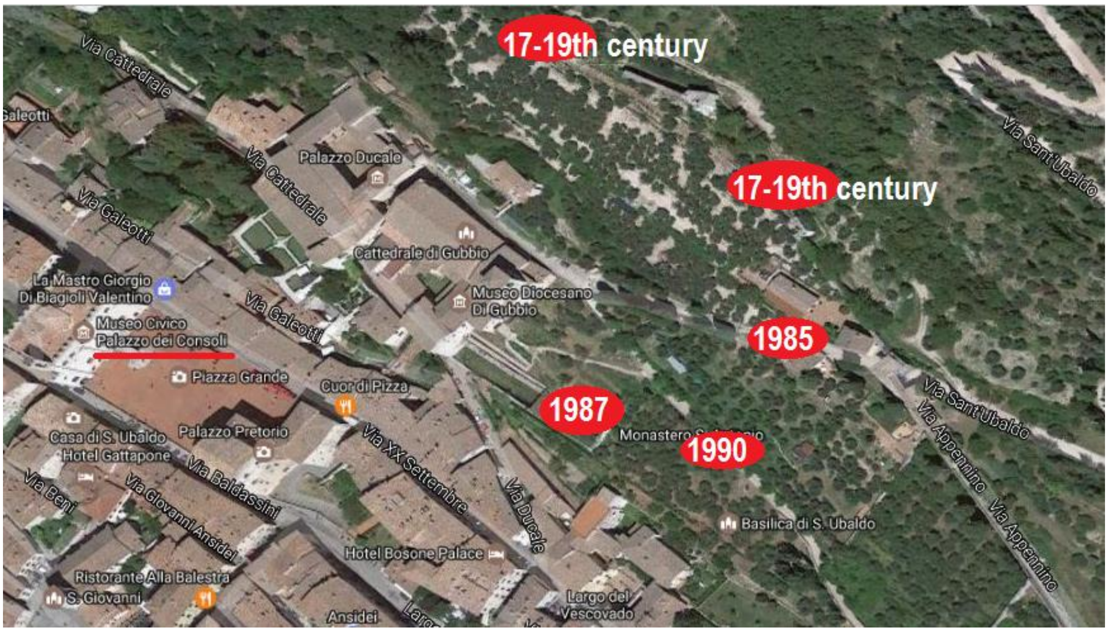


Figure 18: Map with the indication of the occurred events and indication of the period/year.

Between XVII and XIX century, over 130 metres of town walls collapsed probably for the increased load due to the upstream accumulation of rubble and soil and also to the increased level of aquifer that creates an additional load on the Walls. The interested zones are indicated in Figures 19, 20, 21.

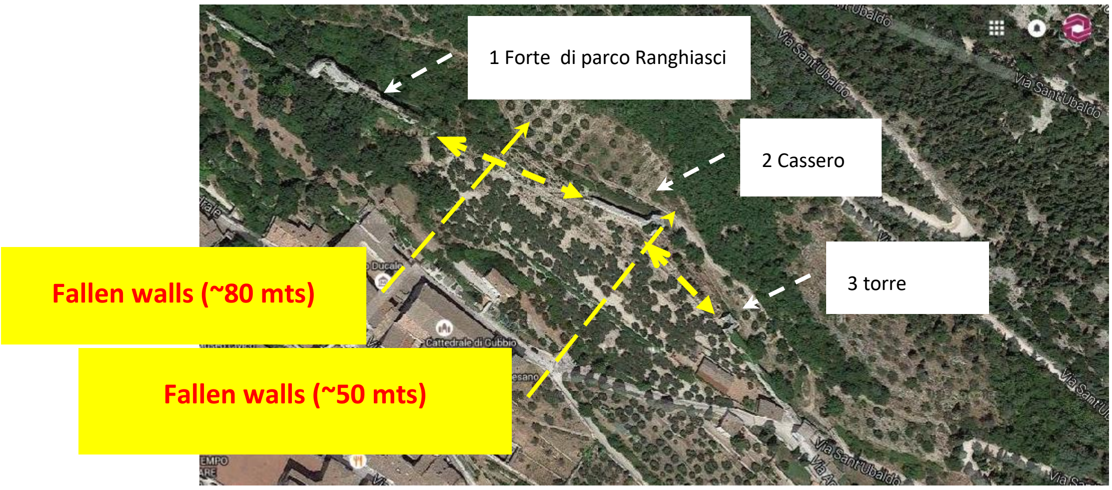


Figure 19 - Map with the indication of the collapsed town walls areas

Figure 20 - Photo of the areas where parts of the town walls, collapsed (between the zones 1-2-3 as indicated in Fig 15)

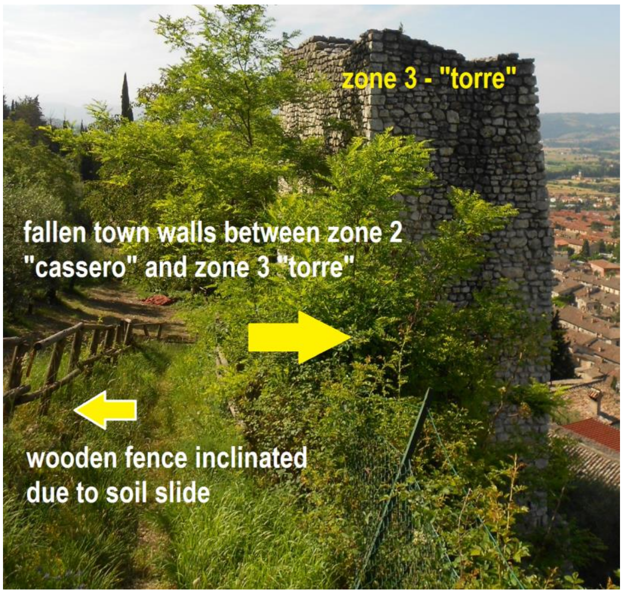


Figure 21: zone 3 (as referred to Fig.15) – zone were walls collapsed and bended fence due to soil pushing

Also **medieval terracing** are integrated parts of the town Walls. During last decades, in the northern side of the town, many episodes of collapses of these terracing occurred. For these events only low-quality photos are available, because are stop-motion images taken from the VHS broadcast news by local TV. Nevertheless, they are useful to clearly illustrate the problems created by the hazards induced by climate change in this area.

The first recorded event was in 1985 when around 15 meters of terracing walls collapsed. This terracing was acting as retaining walls, since XIV century

Figure 22 – 1985 collapsed terracing, with the landslide, in the zone 4 ("Porta S. Ubaldo"), view from below

Figure 23– 1985 collapsed terracing - after the removal of the collapsed material- view from above

Figure 24 - 1985 collapsed terracing, after the removal of the collapsed material, view from below

In 1987, 100 meters downstream with respect to the landslide above (Figures 22-24), a chasm opened in the *Duomo* garden, due to a variation of ground water flowing. The hole created after that event, had a depth of more than 30 meters, a diameter up to 5 meters and a volume consisting in hundreds of cubic meters. After many interventions to reinforce, the final solution was to use the occurred cavity to build the existing elevator, that now joins the Consoli Palace level with the Duomo and town Walls level. In Figure 25 the section of the pit is reported, as represented in the initial technical survey produced after the event.

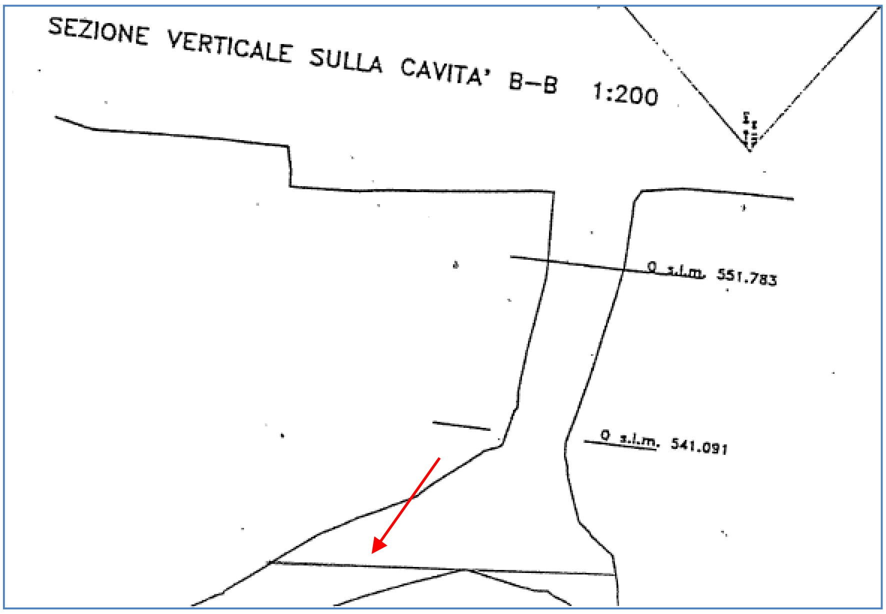


Figure 25 – 1987 Chasm in Duomo - vertical section of the pit after the collapse. The red arrow indicates the similar point of reference as in Fig. 26

In Figure 26, an impressive view of the pit with an operator inside, is shown. He stands over the pyramid created by the fallen gravel (The red arrow indicates the operator position in both 25 and 26 figures.

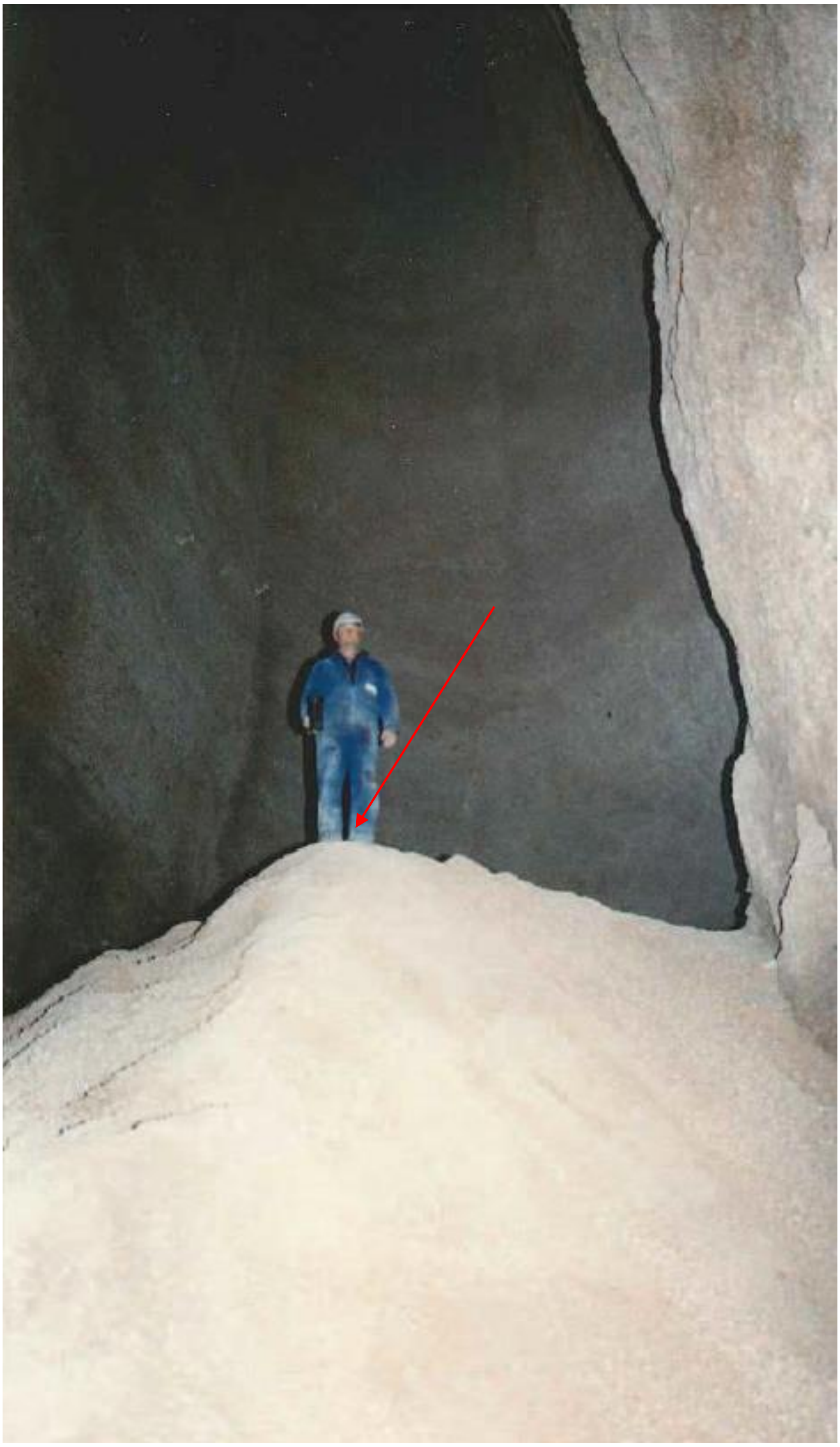


Figure 26 - 1987 Chasm in Duomo – an operator inside the pit after the collapse. The red arrow indicates the similar point of reference as in Fig. 25

After 1990 there were a series of terracing wall collapses in *via del Monte*, few meters far from the previous sites. The first one occurred in the upper part of *via del Monte* (close to and over the Duomo garden) (Figure 27)

Figure 27 - Walls collapse upstream via del Monte

The second one occurred few years later, always in *via del Monte* with a single chasm, downwards with respect to the previous one (Figure 28)

Figure 28 - Chasm in *via del Monte*

The chosen solution was to stop the landslide avoiding the rain water circulation inside the soil nearby, by the use of a covering (see Figure 29), waiting for a definitive intervention.

Figure 29 – covering of the chasm to prevent further possible negative effects induced by rainfall

Unfortunately, this system was not useful, and did not prevent few months later the collapse of dozens of meters of wall (including the covering itself) (see Figure 30 and 31).

Figures 30-31 - collapse of the medieval terracing under the covering and extending for a greater area with respect to the former problem evidenced by the chasm – just below *via del Monte* (view from below- east side)

Figure 32 - collapse of the medieval terracing under the covering and extending for a greater area with respect to the former problem evidenced by the chasm – just below *via del Monte* (view from above- west side)

4.1.1.3 Subsoil instability: ground heave, subsidence , landslide

The recent flooding has resulted in subsidence throughout the Walls neighbourhood.

Furthermore, during decades a consistent soil slide accumulated rubbles upstream, that is now pushing against the Walls.

In Zone 1 ("*Forte di Parco Ranghiasci*") the soil upstream is 6-8 meters higher than the ground level downstream. The ancient aqueduct acted like a retaining wall, limiting the pushing (see Figure 33).

Figure 33- zone 1 - ancient aqueduct retaining wall

To clarify this phenomenon, the following figures (from Fig 34 to Fig 36) and relative explanations have to be considered.

In Figure 34 (a merge of three photos) in a same vision, the upstream (left side) and downstream (right side) levels, are shown

It can be noticed how high is the difference in height between them, entailing that around 8 meters of soil on the upstream slope are pushing on the Walls.

Furthermore, the passage indicated by the yellow arrow is a breach in the wall due to a landslide. On the right side a concrete retaining wall built during the '80s, can be seen.

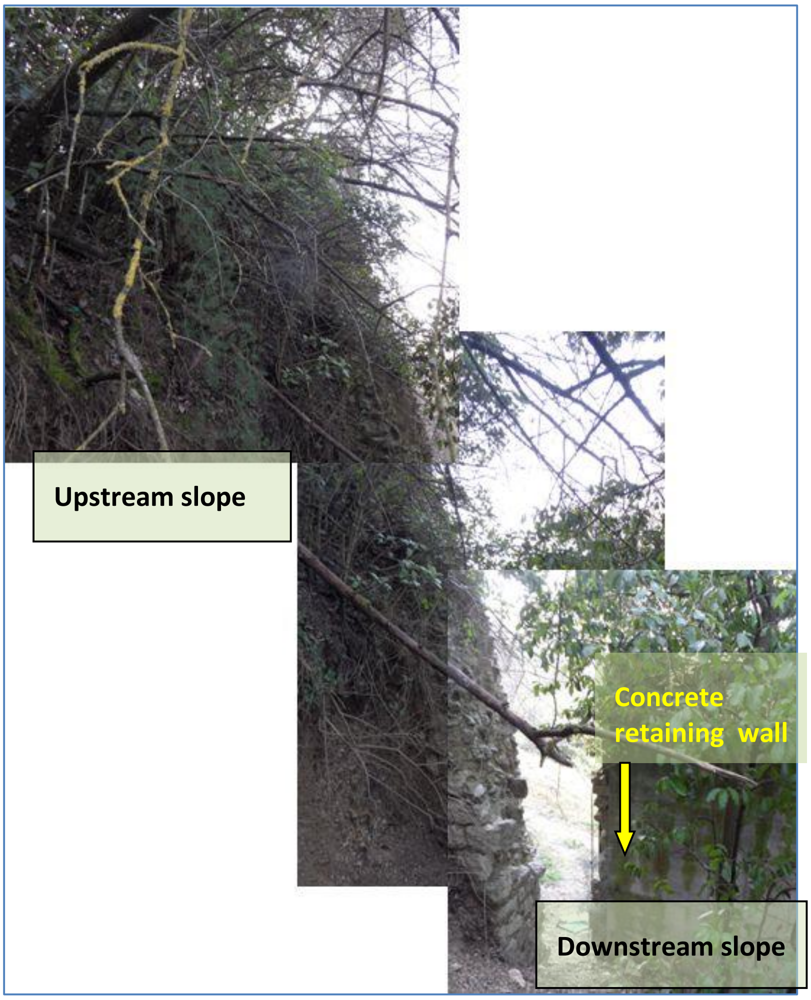


Figure 34 – town walls – below zone 1: soil level difference upstream-downstream

As well, in Figures 35 and 36, the same opening on the walls is shown, as it appears from the two different Walls sides (upstream and downstream). It is possible to see the great difference in height with respect to the ground level, upstream and downstream. Upstream, the opening results at ground level, meanwhile downstream, it is at an height of almost 6 meters from the ground level. It means that from the mountain side, at least 6 meters of soil are pushing on the Walls. The opening is indicated by a red circle. The downstream ground level is indicated by a red arrow.

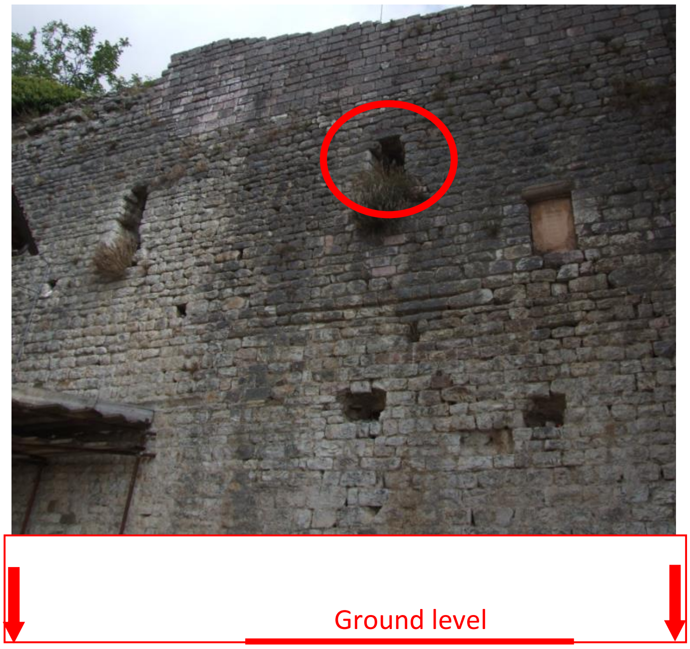


Figure 35: zone 4 (as in Fig. 15): Walls downstream side - notice the opening at around 6 metres from the ground level downstream.

Figure 36: zone 4 (as in Fig. 15): Walls upstream side -same opening of Fig. 35: note that the same opening has on that side a completely different level with respect to the ground level upstream. (the opening is the same in both figures)

Between zones 2-3-4 (as indicated in Fig 15) there are many evidences of landslides consequences, such as the tilting and damage of various objects like a flagpole and a wooden fence (Figures 37, 38, 39).

Figure 37 - tilted flagpole

Figure 38- zone 3-4: bended fence

Figure 39- zone 3-4: ben bended/broken fence

4.1.1.4 Erosion of inorganic materials due to flood waters

The erosive action due to flood waters, the so called "rainfall erosion", have different phases: the "run-off" and the "excavation".

The run-off is the erosive action, producing the removal of the stone material carried by rainwater flowing in sloping rocks or on building and/or architectural structures, such as the Town Walls or the Consoli Palace. It differs from other erosive actions because the rain waters are not confined in a groove so they exert their action on the whole surface, disorderly, degrading it. The amount of run-off action is related to the volume of water, to its force, to the slope of the surface and the nature of the rocks and /or materials undergoing this phenomenon.

The excavation occurs when a masonry is constituted by different materials or when its geometrical characteristics can create zones easier than others to be attacked by rain waters. For instance, the possibility to have higher flow in a limited groove leads to a higher erosion. Concerning materials, in masonry the erosion is stronger for mortars than for stones.

The rainfall brings other issues such as:

- Hydrolysis: in this chemical process the water is responsible for the direct cleavage of internal links of the altered minerals pattern.
- Oxidation: the oxygen, causing this kind of alteration, is coming from the atmosphere and from rainwater.
- Dissolution: this alterative phenomenon comes from the abundance of rainfall. Rainwater contains in fact CO_2, and it can solubilise rocks such as carbonates or chalks, otherwise difficult to be altered by water.

In the following images (Figures 40, 41, 42) are shown examples of damages caused by erosion:

Figure 40 - zone 1 as indicated in Fig.15: effect of rainfall erosion on walls

Figure 41 - zone 1 as indicated in Fig.15: - rainfall erosion

Figure 42 - zone 3 as indicated in Fig.15: - rainfall erosion

4.1.1.5 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.

Figure 43- January 2017: Town walls during last 30 cm snow fall

Figure 44- January 2017: Town walls with snow and ice

4.1.1.6 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.

4.1.1.7 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 rainfalls and pollution. The dark patina or "black crusts" are related to the chemical degradation.

Figure 45: blackened stone rows on the Walls

Figure 46 a), b): blackened stone rows on the Walls

The photos above (Figures 45, 46) were taken in zone 5 ("*Bughetto*" or *via S. Ubaldo*), as indicated in Fig. 15. There are "rows" of stones that, unlike the others treated with similar cleaning systems, show dark patinas, hardly attributable to direct smog, since the car and motorbike traffic in this area is reduced to one or two vehicles per day.

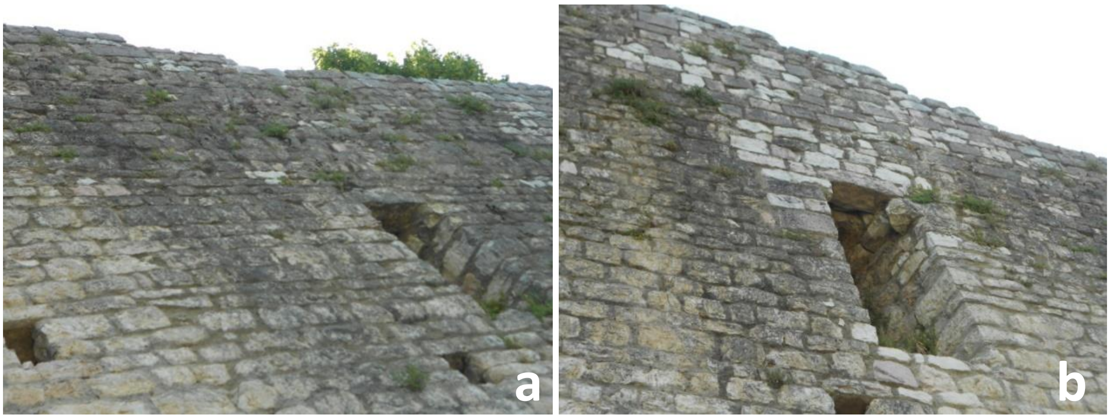


Figure 47 a), b): blackened stone areas on the Walls

Differential Blackening phenomena are even more evident in the following figure (Figure 47), taken between Zone 4 (*Porta S. Ubaldo*) and 5, as indicated in Figure 15. Blackened and not blackened areas are clearly visible, while subjected to the same climatic/environmental conditions.

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).

Travertine: The city Walls were also made with waste materials from Roman palaces and villas of the Roman *Urbe* in the valley that were used as a quarry. These porous stones deteriorated faster than those of limestone. The Climate Change may further accelerate this phenomenon leading to structural instability (Fig. 48).

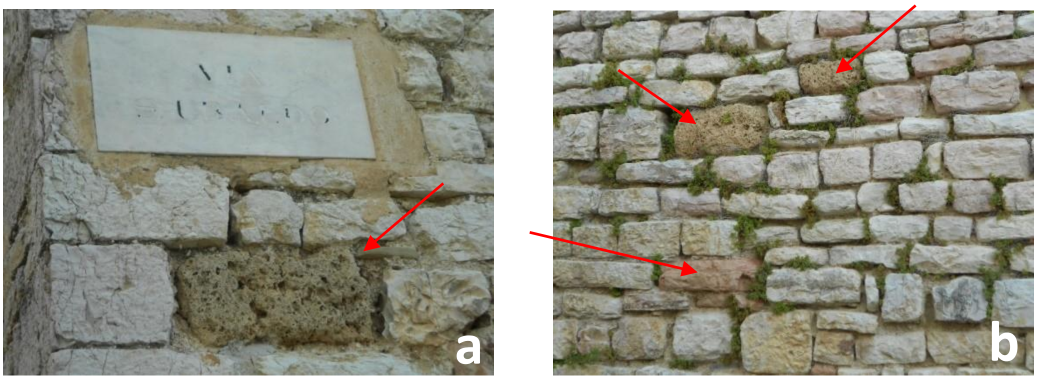


Figure 48 a), b): Travertine stones, evidenced with the red arrows

Sandstone (serena stone): during the time, the rainfall acidity, the air pollution, the cold and the biological agents action produced a visible material degradation such as erosion, peeling, flaking, cracking and discoloration on various artefacts and on the architectural sculptures of the Middle Ages and the Renaissance. These kind of stone is evidenced in Figure 49 with red arrows

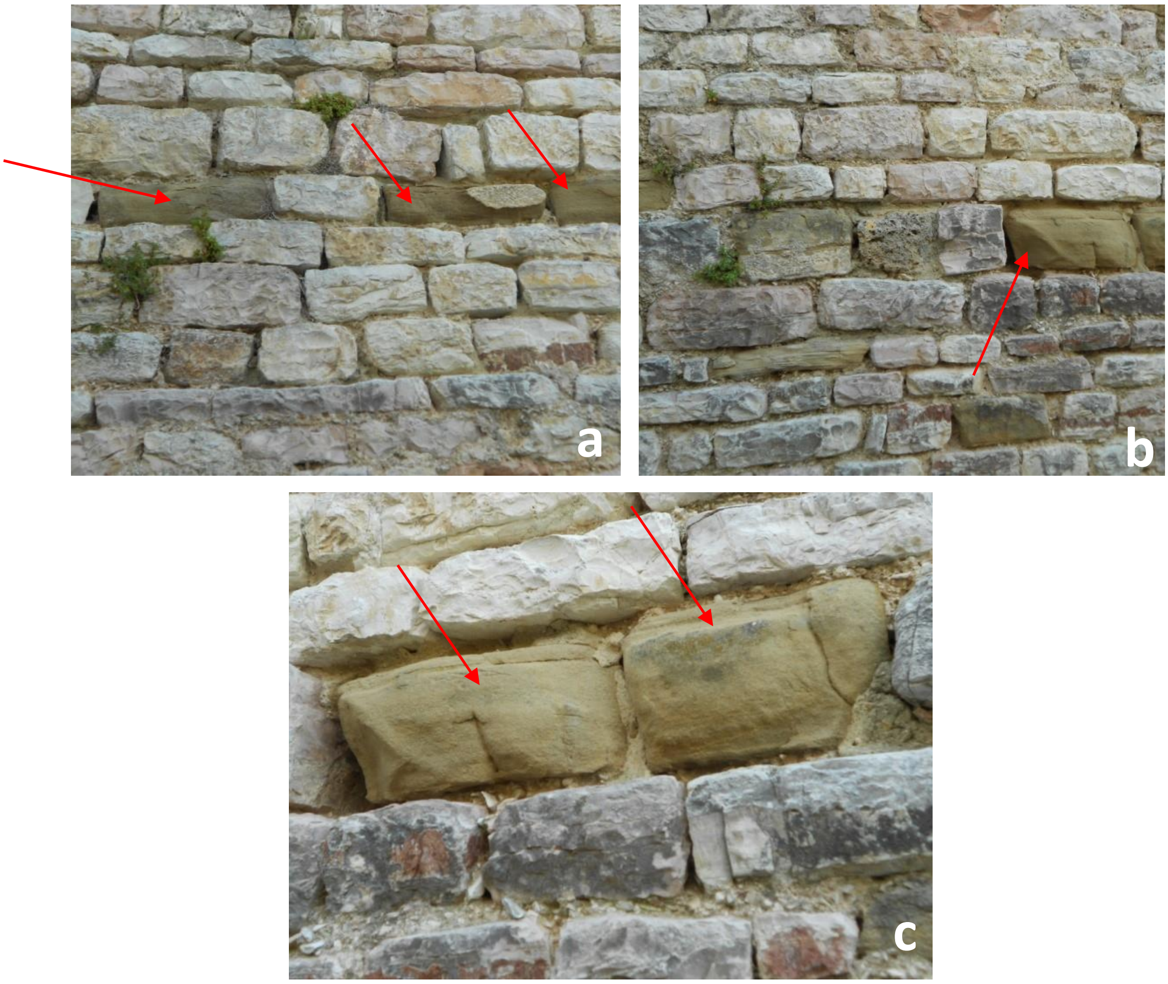


Figure 49 a), b), c): the presence of sandstone in the Walls, evidenced with the red arrows

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 particular 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 50 and 51).

Figure 50- Zone 1 - tower restored before 1990: the mortars used are decaying and flaking and part of the external face collapsed

Figure 51 - erosion due to rainfall and degradation of mortars

4.1.2 Consoli Palace

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 construction has the 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 metres. 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, in 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.

4.1.2.1 Atmospheric moisture change and intense rainfall and flooding related

The atmospheric moisture change is a hazard affecting the palace, enhanced by the intense rainfalls 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 kind of limestones were used in the construction, as already discussed in the section 4.1.1. 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, 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 (see Figures 52 and 53). 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").

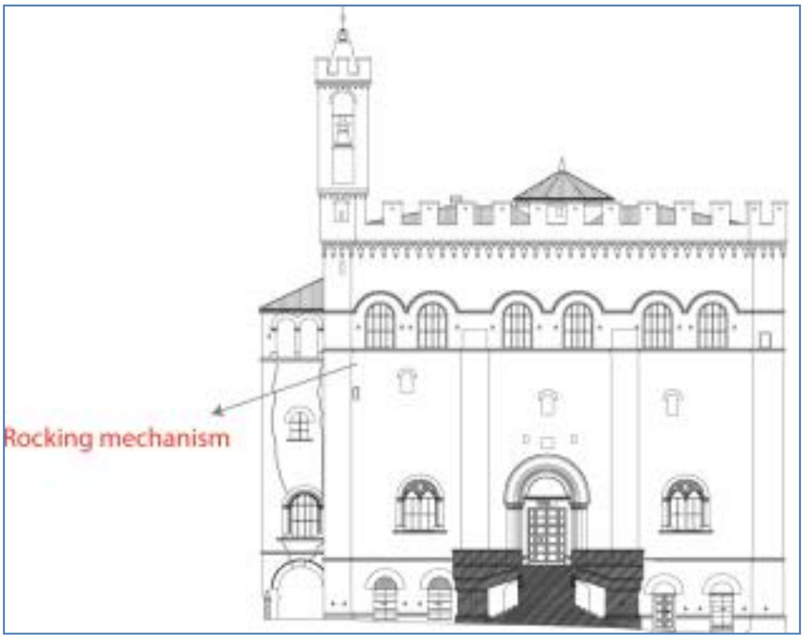


Figure 52- Rocking mechanism in Consoli Palace

Figure 53 - cracks in loggia due to rocking mechanism

4.1.2.2 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, easily intrudes into the cavities of the material. When the temperature is lowered to the freezing point, the water increases its volume due to the ice formation and will exert a considerable pressure inside the hollows, causing an 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 a stress in the material due to the succession (in short cycles) of expansion and contraction caused by the change of temperature. The increase of 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)

In Figure 54 it is possible to see a seasonal condition leading to thermal stress, freeze/thaw cycles and frost. The effect of the deriving physical erosive process, in terms of material loss, is evidenced in Figure 55.

Figure 54- situation of thermal stress and/or freeze-thaw/frost causing damage and deterioration of façades

Figure 55 – Consoli Palace- main stairs - freeze-thaw/frost damage causing thermoclasts and consequently loss of material as evidenced inside the red circle.

4.1.2.3 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.

4.1.2.4 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 figures (56-61). This phenomenon, concerning mainly limestone, was already discussed in Section 4.1.1.7: please refers that section.

Figure 56 - blackening of materials (Piazza Grande level)

Figure 57 – Consoli Palace-column of the loggia showing differential blackening (limestone).

Figure 58 - Consoli Palace- arch of the loggia showing differential blackening (limestone)

Figure 59 - Consoli Palace - black crusts on the façade, view from S-W side

Figure 60- Consoli Palace - black crusts on the façade, view from N-W side

Figure 61 - Consoli Palace - black crusts on the façade, view from N-E side

4.2 Heraklion: risks/hazards & technical aspects

4.2.1 Koules Fortress

The fortress of Koules, is located at the entrance of the Venetian port of Heraklion, facing the Cretan sea.

4.2.1.1 *Air pollution*

The fortress of Koules is surrounded by a number of major sources of pollution (see Figure 62). Specifically:

- the local airport of N. Kazantzakis is situated 2 km to the East
- the local installations of the Public Power Corporation are located 9 km to the West
- the Industrial Area of the city of Heraklion is found 4 km to the SE of the monument.

All the above contribute significantly to the air pollution load of the monument. According to statistics, during the summer period there are more than 150 arrivals and departures per day. Many of these take-offs follow the direction of the airstrip airport fortress burdening the atmosphere with air pollutants. Finally, smokestacks of the ships from the nearby port constitute an additional source of air pollutants.

Figure 62: Google map of the greater area of Heraklion city, in which the two monuments are located together with the major sources of pollution.

4.2.1.2 *Wave and coastal flooding*

The immediate contact of Koules with the sea makes the fortress vulnerable to salty northern winds, which they are often very severe, reaching 9, 10 or even 11 in the Beaufort climax/scale. Especially during the winter season high waves are often literally covering the monument (Figure 63).

Figure 63 a), b): Wave impact on Koules during winter

The fortress of Koules is affected by climate conditions coupled with the pollution which can initiate and accelerate deterioration mechanisms for both original and restoration materials. Geophysical measurements recently carried out, have revealed that caves at the foundations of the monument are present and repeated at regular intervals, showing that are made deliberately for the circulation of sea water under the construction. Unfortunately, in the past, these caves/tunnels have been considered as resulting from the foundation erosion and for this reason were filled with concrete in order to stabilize the structure. As a result, the appearance of water through the monument derived and now this phenomenon is noticeable especially at rooms 13-14 (see map of the structure in Figure 70).

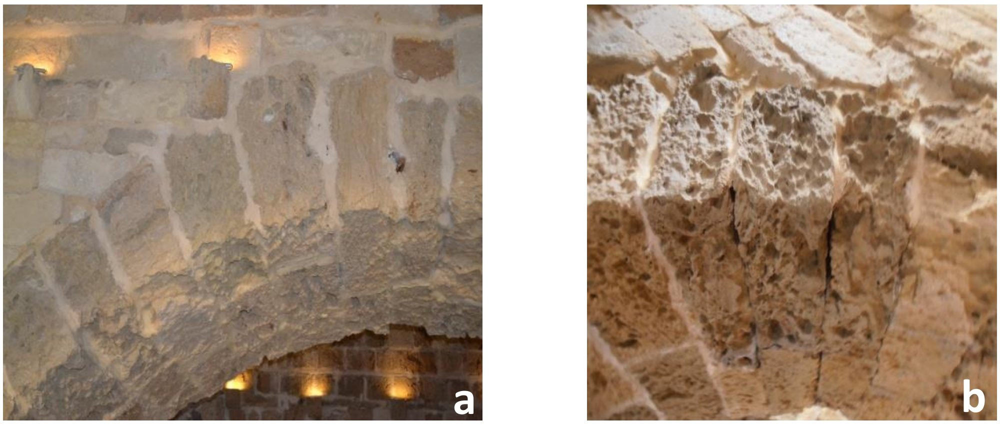
4.2.1.3 *Moisture and salt crusts*

Crusts of salts and black hard encrustations are observed on the walls in several rooms at the interior of the monument. Similar black crusts have also been observed at the areas around the joints both internally and externally to the monument. These crusts are rough and inhomogeneous and appear aggressive to the materials (see Figure 64 a) and b))

Figure 64 a) and b): Black crusts and salt efflorescence

4.2.1.4 *Weathering of stone materials and structural issues*

The cumulative effect of the weathering factor at the monument is unambiguous, since it has been acting for more than five centuries. Macroscopic investigation indicated that the deterioration of the stone, along with the detachment of the grain aggregates, proceeds to selective pitting, resulting to the formation of deep interconnected cavities. The stone appears to have suffered an irregular loss of material, which follows the alveolar weathering pattern (see Fig 65, a,b).



Figures 65 a) and b): Alveolar weathering patterns

Furthermore, a number of cracks have been detected around the monument and their restoration is important. These cracks are located at "Sperone"(Figure 68), at the room next to it (Figure 69, room 26) and at the right side of the main entrance. On the external wall of the "Sperone" the gap was filled with small stones ("stone stitching") (Figure 66). The same procedure was realized on the wall of the main entrance of the fortress (Figure 67).

Figure 66: Crack outside the "sperone"

Figure 67: Crack next to main entrance

Figure 68: Crack inside the "sperone"

Figure 69: Crack at the room (26) next to "sperone"

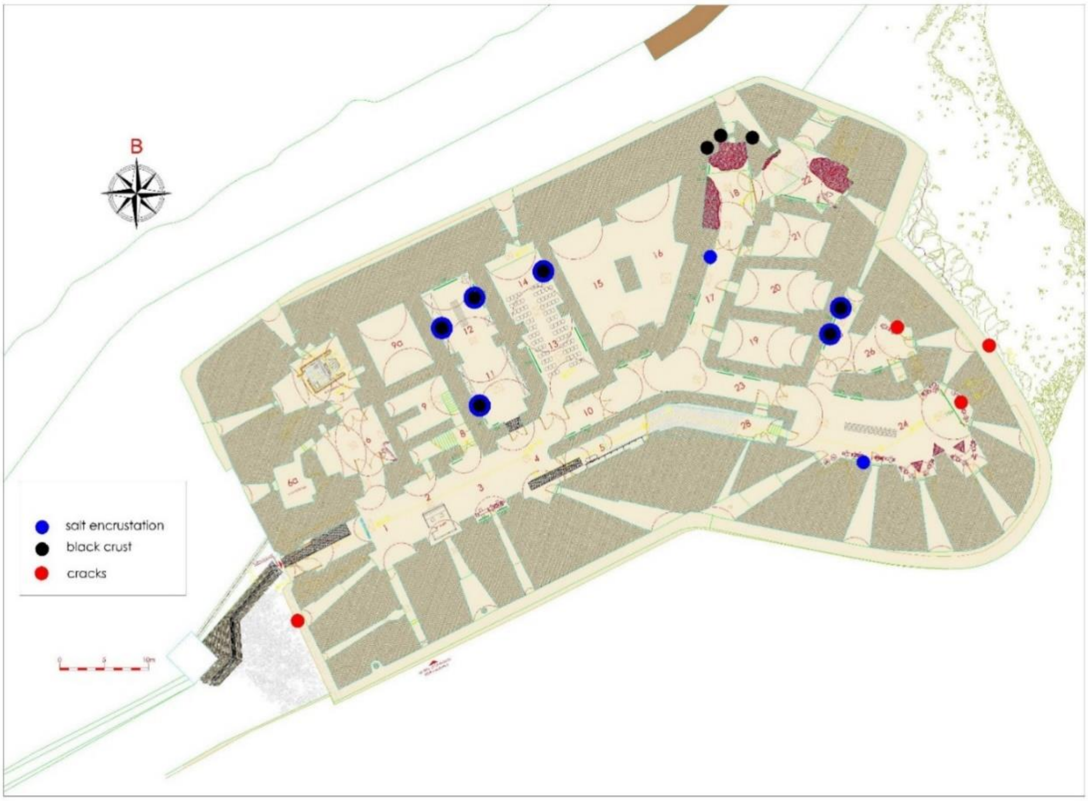


Figure 70: Plan of the Venetian fortress of Koules located at the port of Heraklion

4.2.2 Knossos Palace

Generally, the Palace of Knossos (see Figures 71,72,73) had suffered extensive damage due to mechanical and biological factors, combined with the local microclimate and the structure of the walls. The main reasons for its damage are (a) the direct exposure to sunlight, rain, wind and atmospheric pollution, (b) the relative humidity and temperature changes, and the (c) extensive use of reinforced concrete for its restoration.

Figure 71: West Court and West Facade of the Knossos Palace

Figure 72: South Propylon of the Knossos Palace

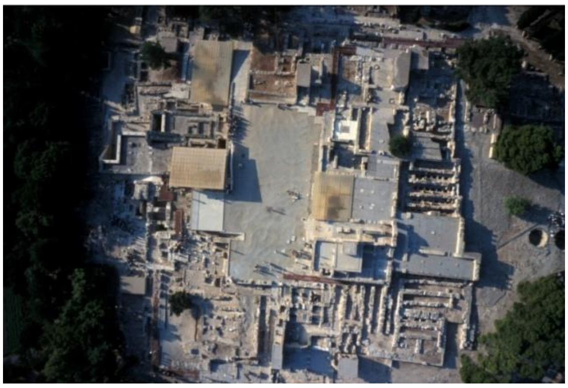


Figure 73: Aerial Photo of Knossos Site

4.2.2.1 The masonry (ancient and restored)

The Minoan walls were constructed of rough and carved limestone and gypsum stones. The joints were filled with mortar of clay. The walls were coated with clay and lime plaster in order to create a surface for the fresco decorations. Different cement mortars had been used during Evans's restoration (1900-1930), and later, after World War II, during different conservation works (1950-1970, 1980s) as filler for the ancient walls. Since 2000, a complete conservation program of the Minoan walls and of the of Evans's restoration has been launched. The cement mortar, used in the earlier interventions, was removed in order to conserve the stone walls. The joints were cleaned, consolidated and filled with new, compatible material, known as "Theran mortar", whose ingredients include Theran soil, quarry sand, slaked lime and icon pigments. The major risks of the masonry are the cracks in the ancient and the restored masonry.

4.2.2.2 Reinforced concrete

The need for preservation and restoration of the Palace was obvious for A. Evans from the first years of the excavation. Since 1905, most of its parts were sheltered, and some restored. For the restoration, Evans reconstructed entire floors of the monument with reinforced concrete. Recently, the conservation of Evans' reconstruction is considered necessary because it has become part of the history of the restoration and a monument in its own right. During the '90s a great number of the concrete slabs of Evans' restoration were conserved, without replacing the slabs, but with the conservation of the iron girders.

4.2.2.3 Moisture and temperature circles, rainfall

Corrosion of the iron girders used in Evans's reconstruction (Figures 74, 75), cracking (figures 74), degradation, deformation of reinforced concrete elements (Figures 75, 76), humidity (Figure 77), are the major threats for the Palace. A static control of the monument is needed, for planning static reinforcement. Groundwater and generally moisture affect the monument.

The moisture monitoring is also necessary, since the humidity penetrate throw the jointing mortar inside the walls and creates efflorescence salts in ancient and restored masonry and roofs. The Minoan walls were coated with clay and lime plaster in order to create a surface for fresco decoration. The main causes of their damage are the exposure in unroofed area, with high levels of humidity, and the use of cement mortar in previous restorations. After the analysis of the composition of the plasters the appropriate materials and methods will be selected for their conservation. Major risks are the loss of cohesion of the materials.

Figures 74 and 75: Light well and Corridor of the “Queen’s Megaron". Corrosion of the iron gilders used in Evans’s reconstruction

Figures 76,77,78,79,80: Corridor with the fresco of the “Prince with the Lilies”, “Magazines with the Giant Pithoi” "South House", “East-West Corridor”. Photos show typical problems such as cracking, deformation of reinforced concrete elements and humidity.