The deterioration mechanisms of building materials and innovative ways to conserve them
Case study:the Medieval Town of Rhodes

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Abstract

Abstract

Over the years, buildings made by stone and other porous materials suffer physical and chemical damages through absorbing water while exposed to weathering. Deterioration then occurs due to various intrinsic and extrinsic factors and urban environmental damage is very extensive, altering material's form. A representative example of such case is the Medieval Town of Rhodes which suffers from loss of its aesthetic value owing to the disintegration of its building materials with extended architectural surfaces deteriorating from salt erosion and grain detachment. Today, the Rhodian sandstone shows intense damage in most buildings through alveolar weathering and coordinated actions are needed for its preservation.

This paper highlights the need for a new conservation management plan based specific for Rhodes. The new conservation strategy should focus on the planning process of preservation of cultural heritage but also on a precise characterisation and mapping of decay patterns with an innovative approach to identify, describe and classify conservation problems. The physical and chemical properties of the building materials used within the conservation area of Rhodes are firstly investigated. A representative range of historic buildings are documented and studied to identify the common damages and propose either traditional or innovative consolidation treatments according to an extended literature review. This research gives an overview of a suitable method to assess deterioration patterns of stone and mortar.

Discussing organic and inorganic consolidating products traditionally used to regain the mechanical properties of decayed materials, will produce the basis for a cohesive conservation plan for the historic fabric of Rhodes. Many innovative techniques from other countries have been studied in depth to discuss solutions for the building fabric of Rhodes and finally a cohesive conservation management is proposed.

Introduction

Research aim and objectives of study

This study addresses issues of conservation of building materials and its importance to heritage with reference to urban sites, like Rhodes looking at material selections for architectural projects, their potentialities and limitations. Main objective is the study of a variety of deterioration patterns found in selected surveyed urban buildings, looking at degradation causes with the view of planning suitable interventions. This is examined through the interactions between environmental conditions, physical properties and structural factors, which will lead to recommendations on how best to deal with them. This indication of material performance can then produce a platform for objective decision-making on materials compatible with the original fabric.

The conclusion of this research is the analysis of the properties of innovative products for historic building repair, estimating through literature their future compatibility or even possible failure.

In the present study, preservation of stones and mortars weathered by salt crystallisation is in depth examined. The novelty of this research is to examine selected innovative materials in several case studies in order to update a philosophy and practice of conservation and consolidation in the Medieval Town of Rhodes and perhaps similar sites in the Mediterranean.

Research methodology

The methodology employed in this research project begins with an in-depth literature review to gain knowledge of deterioration processes of building materials and understand the need for using compatible materials in the historic fabric to propose effective solutions to conserve them. In order to conduct a comprehensive view on the subject a variety of scientific papers and books have been studied.

The next phase of the study involved gathering information about the historical development of Rhodes and in particular background research on the conservation techniques applied through all these years from archives and historical maps. An analysis of the building materials used in the Medieval Town of Rhodes is then discussed focusing on their physical and chemical characterisation. Moreover, the identification of the decay mechanisms causing similar patterns is being investigated to assess the main types of deterioration found in this area.

8 buildings were chosen according to location, history and, environmental factors so that they represent the problem. Thus, a visual survey of the sandstone masonry buildings with dimensioned drawings and sketches of the facade and notes on possible effects of decay patterns is employed to document and describe the diagnosis of deterioration. The case studies are classified according to several factors that lead to the deterioration of porous materials inside the conservation area and are likely to suffer from the same decay mechanisms. The chosen criteria put the theoretical research undertaken into context and can ultimately provide answers about the rate of deterioration of these materials.

The interpretation of the findings allow recommendations to be made regarding the consolidation treatment of the traditional materials and generally on urban town scale while proposing the suitable repair techniques in each case. Through categorising and collecting data from different case studies a new coherent management plan of historic preservation is attempted concerning not only the consolidation but also the restoration philosophy in the Medieval Town of Rhodes.

The final stage of the study recommends new innovative consolidating products for sandstone and restoration mortars in historic buildings while comparing it with traditional building techniques. The discussion identifies their properties, checks their compatibility, suggests patterns of decay that might present in the future and evaluate how to minimise the acceleration of materials decay.

In conclusion, this study explores a material's compatibility and suitability with critical thinking on different conservation approaches to generate principles for conservation materials that can be used not only for the Medieval Town of Rhodes but also to other Mediterranean cities that suffer from similar deterioration.

The vulnerability of historic buildings

Preservation in historic cities- A growing concern

Heritage structures constitute the physical continuity with the past associated with specific events and people at that time. The urban structure of a historic city is either homogeneous or static as it has witnessed changes by human and natural processes during its development. [1] ′′***Historic buildings provide the authenticity, the credibility, the sense of community, the sense of history that bind people in a fast- moving, 24/7 ever- changing world. They ground us. They provide a sense of self, a sense of identity in this creative age that we are moving into.***′′[2]

Buildings in historic surroundings are also subject to several decaying processes, accelerated by aggressive environmental factors that affect their durability and preservation. 3 To preserve the historic character of a city an effective conservation management plan should include measures to control or reverse these processes. [4]

Although the conservation of built fabric historic sites dates back to the mid-17th century, the etymology of "historic preservation" has not crystallised until the 19 th century when this term was put into practice.[5] Nowadays people are aware of the importance of cultural heritage and they become more and more conscious of preserving built heritage. In many places, governments follow the guidelines of Venice Chapter recognising the retention of historic spaces as a cultural necessity that they need to take responsibility to safeguard them for next generations.[4]

The growing concern for preservation in historic cities has lead to innovative ways to ensure its future transmission. Many organisations for example propose a holistic conservation plan or make applications of these ways with successful results. Three examples in two countries, two in Greece and one in Scotland, are studied to reflect their perspective to conservation and as a model of solutions to my selected case study.

Another dimension is economy and due to the severe economic crisis that today Greece faces, its historic heritage is endangered and thus, radical approaches or innovative techniques with low cost application must be considered. A project showing a way forward is ''HERMES'' (HERitage Management E System), a Digital Heritage Collection of Historic Buildings(Figure 1) that was awarded by Europe Nostra for its innovation element to ''promulgate the value of digitization in the collection and maintenance of intelligence about Europe's architectural heritage''. [6] Its main objective is monitoring the building stock of Hermoupolis to assess their vulnerability and propose a decision-making model according to the need of intervention in each case. This multi-variable model is based on a database and evaluates historic building's pathology and architectural quality in correspondence with the building's history, position within the city, general condition, present and past purpose, ownership and the social impact. The final outcome is a platform that unites historic buildings in a point system while reflecting the necessity and hierarchy of interventions that must be implemented to save the maximum historic fabric with the minimum funds.[7]

Athens has a similar approach to ''HERMES'' regarding the preservation of cultural and architectural heritage with the publication of the journal ''MONUMENTA''(Figure 2). This is a non-profit organization, founded in 2006, for the protection and efficient management of the natural and architectural heritage of Greece and Cyprus. Basic prerequisite for the protection of the architectural heritage of Athens is the precise documentation in the form of analytical and critical reports to evaluate its current situation. [8] They focus on buildings of the 19th and 20th century in Athens with the broad aim to be applied to the rest of Greece.

In Scotland a regional scheme was set up to record and evaluate properties of architectural or historic merit at risk or under threat of demolition. [9] The Buildings at Risk Register (BARR) has been in operation since 1990 and is managed by the Royal Commission on the Ancient and Historical Monuments of Scotland reporting to Historic Scotland and local planning authorities annually. Due to the growing concern that a significant percentage of listed buildings within a conservation area is prone to extensive damages and abandonment for many years their main responsibility is to identify and monitor their condition.[10]

Figure 1: The Digital Heritage Collection of Historic Buildings of HERMES project

Figure 2: MONUMENTA’S logo

The adherent need for integrative thinking in decay of building materials

Figure 3: NOAH'S ARK logo

Figure 4: Deterioration of Rhodian sandstone and its architectural features

Degradation processes affect architectural surfaces threatening the cultural heritage and their knowledge and analysis of their mechanisms is a priority. [11]

The majority of heritage buildings are made by traditional building materials, especially stone, and are an integral part of our cultural patrimony threatened in particular by several environmental factors, enhanced by the growing population and industrialisation recently. [12] The environmental factors along with the physical, chemical, biological properties of each material exacerbate the effect under severe circumstances, like current urban environment and the rapid climate change. According to EC NOAH'S ARK project(Figure 3) for example, the anticipated impact of climate on materials such as carbonate stone, limestone and marble will result in major surface loss due to the yearly concentration of carbon dioxide and the increased salt crystallisation.[12] The atmospheric pollution alters both the aesthetical aspect and the physical–chemical properties of the materials leaving the outdoor build cultural heritage at risk. [13]

Moreover, inappropriate repairs like the extensive application of incompatible, impermeable materials, especially the highly cementious ones, through the passing years damaged significantly and irreversibly the historic fabric aesthetically and even more their structural performance.. As many unsuitable consolidation treatments have accelerated decay, a systematic and scientific study of stone consolidants is primary issue.

Within the aspect of stone degradation in the urban fabric, the most vulnerable features are firstly the architectural decorative elements such as parapets, balustrades and cornices and then follows the delamination of stone at windows mullions and the deterioration of ashlar stone or plasterwork.

The multi-disciplinary research field of stone degradation has triggered new environmental regulations and societal concerns for developing innovative and compatible materials and techniques.[14] Today scientists have improved their knowledge on deterioration processes of building materials and many innovations in building industry has been implemented like nanomaterials and silica based ones.[15] Both the traditional and the innovative products have drawbacks and a more comprehensive research is required to achieve the needed efficacy between consolidant and original material.

We must cite Schueremans interpretation of compatibility as "using materials that do not have negative consequences on the authentic materials".[16] Thus, in order to minimise the rate of decay an interdisciplinary research is needed to ensure this does not happen.[17] Especially, the stone consolidation needs integrated consideration and a theoretical position before selecting the most suitable treatment and testing it to the original structure.[15] As Kant mentioned, ***''Application without theory is blind, whereas theory without application is mere intellectual play"*** .

Lastly, innovative building materials and technologies are one of the fundamental forces that formulate the building history. Conservationists before selecting suitable treatments must take into account the nature of materials, their physical and chemical properties of each product, their structural properties, their interaction with other materials, their anticipated durability for a given situation, cost, maintenance requirements and their aesthetic aspect of the result [14].

Building materials at risk

Figure 5: Decay due to mechanical damage leading to loss of compact material

Figure 6: Hard mortar favours moisture entrapment in the sandstone rather than the mortar

Decay is a natural process that results in the degradation of materials response to changing conditions and can alter either slow or fast the physical, chemical and mechanical properties(Figure 5) of the materials. Decay often arises from misunderstandings related to the use of hard mortars(Figure 6) which are incompatible with the stone and the wrongful application of reagents within the stone to protect it together the humid polluted environment.[18] This decay process has really become a vital problem since the Industrial Revolution at late 18th century.[14]

Natural stone, timber and lime are the primary building materials that were used traditionally for a range of buildings, from chivalric churches and castles to simple residences. These materials have been used for centuries and they constitute part of the memory and the culture of each surrounding. Before the advent of manufactured materials and the Industrial Revolution, building materials were limited to locally sourced ones mainly for transport reasons, becoming a key-indicator to local distinctiveness.[14] Developed over many centuries, the knowledge about craft construction techniques was handed from master to apprentice, often through families, so that craftsman evolved with intimate understanding of how materials behaved, and hence how they should be conserved and repaired. [18] Then, due to changes in building technology from the beginning of the 20th century and the rapid advances in manufacturing and materials development, this passing path of knowledge was over resulting in loss of important skills.

The use of stone in building emanates from the ancient times as one of the most widely used material.[19] Although it is remarkably resilient and probably the most durable material, it faces severe deterioration due to [20] weathering, the effect of wind-borne particles abrading the surface of the stone, or constant wetting and drying cycles.

Figure 7: Hard mortar favours moisture entrapment in the sandstone rather than the mortar. Example from the Medieval Town of Rhodes

Figure 8: Disruption of the stone masonry near the windows from example in the Medieval Town of Rhodes

The deterioration of stone masonry has become a worldwide problem since the Industrial Revolution increased the levels of acidic gases in the air.[18] As stone is exposed to outdoor conditions the main cause of its deterioration is moisture entrapment in its core and polluting gases.[21] A common effect of acid oxides is disaggregation that leads to surface recession. Stone in polluted urban environment is prone to alveolar weathering processes due to excessive fluctuations in temperature and crystallization of water-soluble salts inside the porous network that lead to hampering its cohesion and mechanical properties(Figure 7,8).[22]

As the chemistry of stone deterioration processes is complex and stone consolidation is often an irreversible intervention, an effective solution of its successful application should be the ultimate goal. Therefore, the consolidation treatment either with traditional materials or innovative products should, on the one hand provide mechanical efficacy and on the other hand prevent any physical or visual alteration of the building.[23]

Case study: Medieval Town of Rhodes

Figure 9: The geographical position of Rhodes in Greece

Figure 10: Map of Rhodes

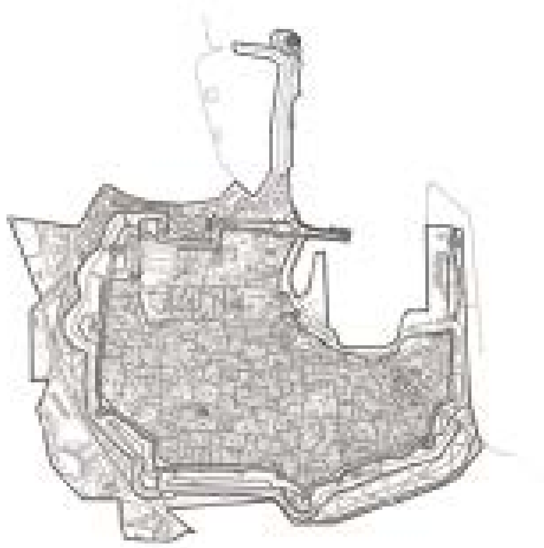


Figure 11: Map of the Medieval Town of Rhodes

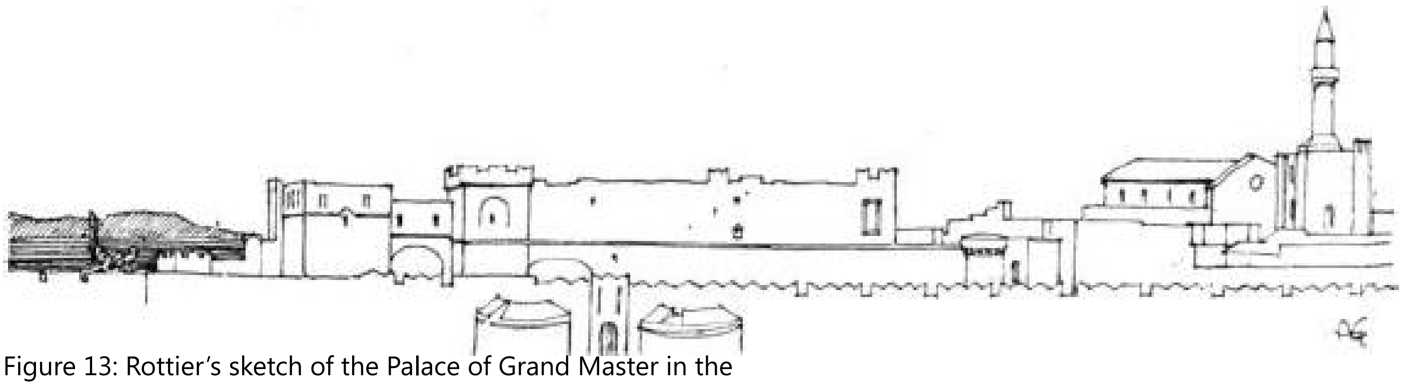
All monuments and buildings in the Medieval town of Rhodes are constructed of the local Rhodian sandstone. Today, this porous stone shows considerable damage in most buildings, particularly through intense alveolar weathering. Owing to Rhode's marine environment, salt efflorescence and moisture entrapment in the stone's high pore spaces have been recognized as the main weathering process liable to the deterioration of building materials.

Today the Ministry of Culture in Greece and the Greek Ephorate of Byzantine Monuments in the Medieval town of Rhodes make continuous efforts to adequately maintain and restore the historic buildings within the conservation area but more co-ordinated actions and research should be made.

Location and study boundary

Rhodes is situated on the southeastern part of Greece in the Aegean region(Figure 9) and is the largest island in the Dodecanese. Rhodes(Figure 10), one of the most well-preserved medieval cities(Figure 11) in the world among the 951 World Heritage Sites of UNESCO, is an impeccable historical surrounding(Figure 12), which has suffered a succession of cultural influences, evidence of whose are a range of monuments , such as the early Christian churches, the Early Byzantine fortress, ancient docks, the medieval castle(Figure 13), the towers, the chivalric buildings and housing of 'tongues' on Knights Street, mosques, many of them almost intact over time. The town of Rhodes is one of the most typical examples of continuous living in the same area, an area known for its natural beauty and at the same time demonstrates a strategic geographical position, integrated into one of the most characteristic areas of the Mediterranean, ancient crossroads of maritime routes between the Aegean and the Near East Coast.[24]

Figure 12: Cultural routes along the medieval town highlight its significance



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The historical development of the Medieval Town of Rhodes

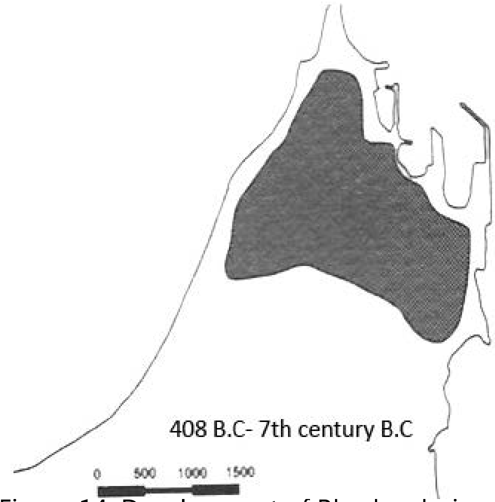


Figure 14: Development of Rhodes during the Hellenistic period

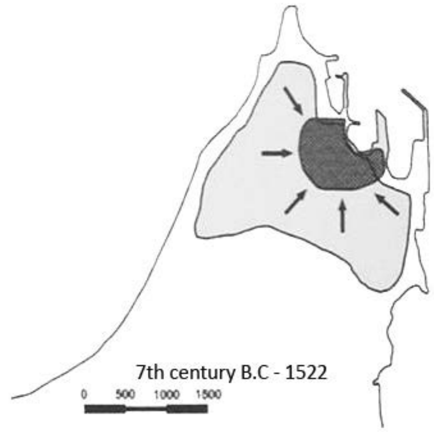


Figure 15: Development of Rhodes during the Byzantine and Knight period

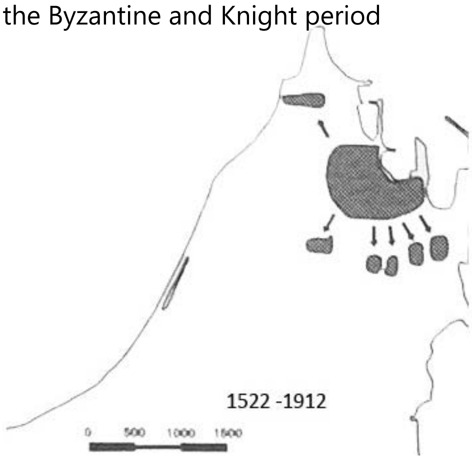


Figure 16: Development of Rhodes during the Ottoman dominance

During the Hellenistic period(Figure 14)became one of the most organized cities with a Hippodamian town planning system that is still readable nowadays. When in 408 BC the town of Rhodes was founded in the northeastern end of the island from the merger of the three oldest cities (Ialyssos, Kamiros and Lindos), into one governing and residential center.[25] During the Byzantine period, it became reduced in size but it maintained its strategic location in the Mediterranean. It consisted of the Byzantine castle, the chivalric monuments and the fortified town, known later at the Knight reign as the Collachium[1](Figure 155).[26] The Order of Knights of St. John arrived in 1309 and remained until the Ottoman conquest in 1522, bringing back the of ancient times and restructuring the landscape both architecturally and financially. The medieval town, became a financial and cultural center in the southeastern Mediterranean with its port to be considered as a safe stop for merchants and pilgrims on the journey of the Holy Land.[27] When Rhodes became part of the Ottoman empire in 1522 (Figure 16), this architecturally and socially advanced city became a simple province of the Ottoman empire for almost four centuries until 1912, when the city was handed over to the Italians. The Italian occupancy was a fertile period of scientific and archaeological research, restoration of monuments and urban interventions to protect the area of the Medieval Town(Figure 17).

1.The northern part of the Medieval Town is called Collachium (Κολλάκιο) and is surrounded with Byzantine walls and consisted exclusively of residences for the Knights and administration and military buildings. At the highest end of northwestern Collachium the Palace of the Grand Master is built representing the impressive Gothic Provencal architecture.

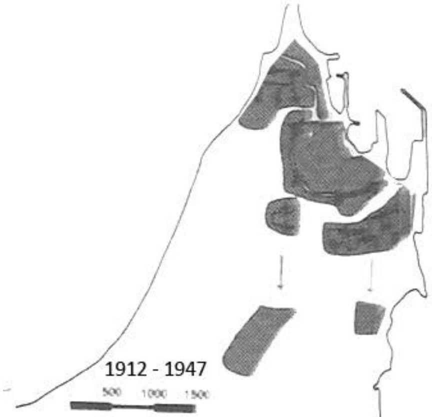


Figure 17: Development of Rhodes under theItalians

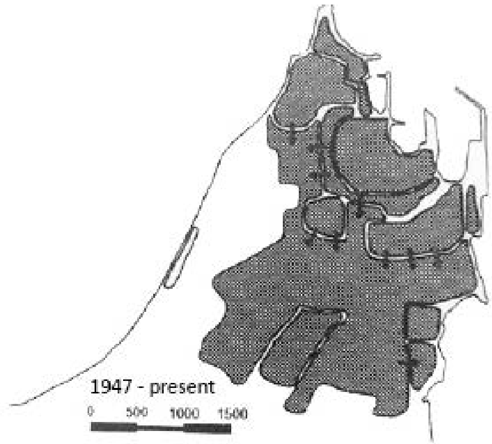
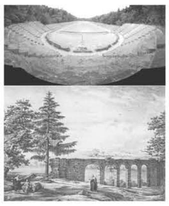


Figure 18: Development of Rhodes after 1947

The incorporation of the Dodecanese into Greece in 1947(Figure 18) found the medieval city in ruins due to bombardment in World War II. The first concern of the Greek government was, the preservation of the historical character of the area with the necessary restoration works and the maintenance of tourism infrastructure (Figure 19). Then, when in 1988 the Medieval Town of Rhodes was established as a World Heritage Town by UNESCO[28], the Greek government made coordinated efforts to secure the archaeological surrounding of Rhodes through urban conservation plans and restoration works across the town(Figure 20).

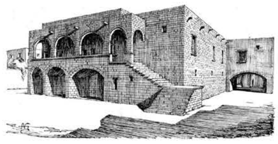

Figure 19: Current image of the city with baths and mosques

408 b.c	Establishment of the city of Rhodes Hippodamian planning town system
164	Integration of Rhodes in the Roman Empire of islands
330	Integration in the eastern part of the Roman Empire
1309-1522	Hospitallier period Expansion and erection of fortifications Construction of important public buildings: the master palace, hospital, churches - Gothic and Renaissance Architecture Division of the city into two zone
1522-1912	Ottoman period reconstruction of majestic mosques of pure Ottoman architecture
1912-1945	Italian period a master plan to revive and expand the city of Rhodes aiming to restoration of monuments and urban interventions
1960	Declaration of a historical monumental complex
1988	Inclusion in the list of UNESCO World Cultural Heritage
1990 until today	Need for new residential areas and improvement of existing conditions and networks in town


Ancient stadium and aqueduct

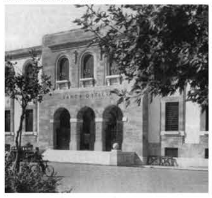

Temple of Apollo


Castellania, Court of Justice during the Hospitallier period


Tongue of Auvergne


Photograph of Apollwniou Street in 1911, a typical street in the medieval town


Engravure of the harbour in 1850


Photograph of the commercial centre in 1947


The central bank of Italy in the New Town of Rhodes

Figure 20: The historical development of Rhodes

Figure 21: The stages of urban development of the Medieval Town of Rhodes

Micro-climatic and environmental conditions in Rhodes

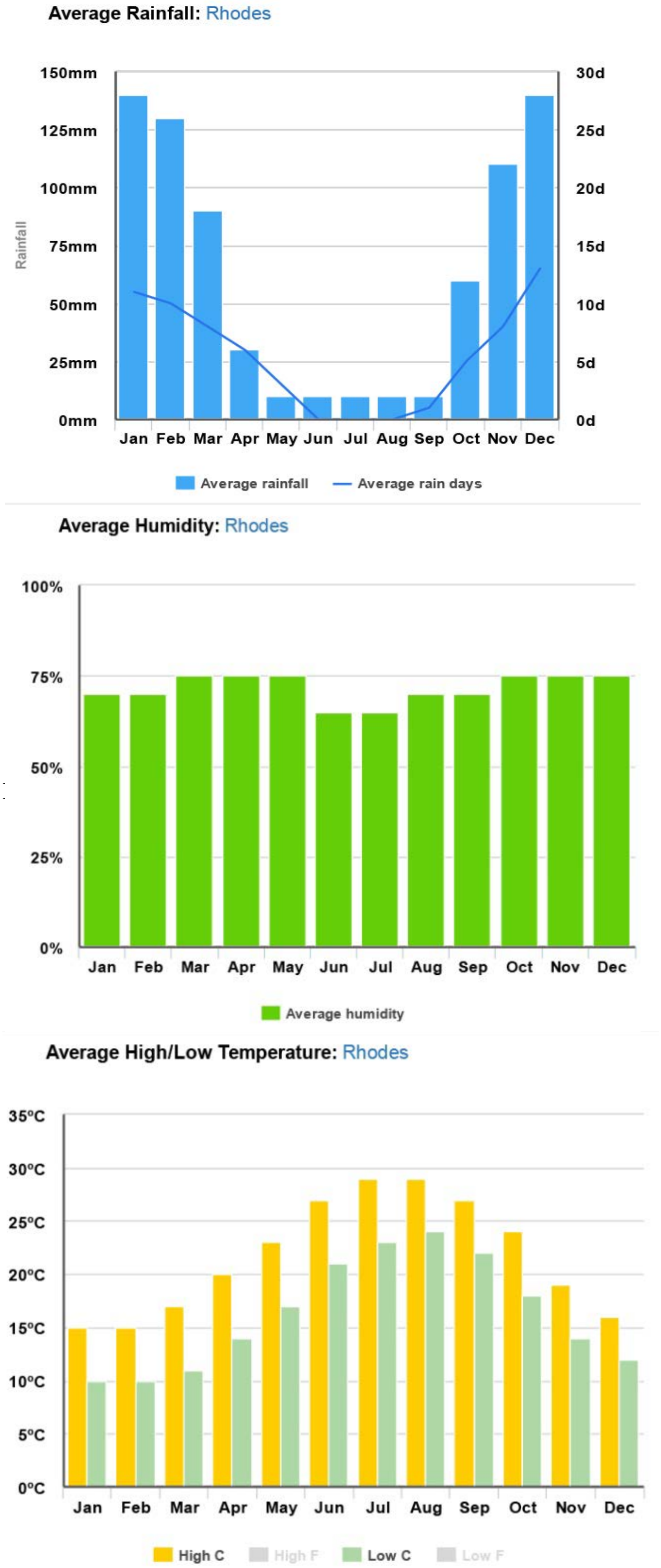


Figure 22: Charts showing the average rainfall, humidity levels and temperature in Rhodes

Hot Mediterranean dry-summer,
subtropical climate

Mild
with moderate seasonality

Summer
dry and hot

Winter
rainy with moderate temperatures

The alveolar weathering of the sandstone in the Medival Town of Rhodes is the main deterioration pattern seen around the conservation area and its increasing significantly by the damp climate and the micro-climatic conditions in Rhodes. Therefore, a brief description of the climate in Rhodes is thought necessary to evaluate the environmental performance of the porous stone. The climate of Rhodes is characterized as a typical Mediterranean climate with mild winters and very hot summers defined by high levels of moisture (70%) and adequate rainfall lasting from early November to late February.[29]

On average, Rhodes is exposed to high sunlight over 200 days a year while reaching high temperatures especially in July and August with maximum temperature of 31°C. At night the temperature drops below 20°C due to the increased levels of humidity temperature. From May to October the climate remains very hot with the average high 28°C and the temperatures often exceed by 5 degrees in the average temperature of the rest of Greece. Fairly strong and frequently winds (43%) characterize the mild but wet winter

Materials and methods of construction

Traditional building materials in Rhodes

Construction system of masonry

exposed ashlar

Building stone

highly porous calcareous sandstone, low strength

Cement and mortar

lime mortar
kourasani(κουρασάνι)
patelia(πατελιά),type of grey aluminous earth

Figure 23: Rhodian sandstone

In order to propose solutions for conserving historic buildings, it is essential to understand the local building methods and materials, the Rhodian sandstone and all kinds of mortar.

Local sandstone

The main building material of the masonry in the Medieval Town of Rhodes is a local sandstone characterised as a highly porous calcareous stone with low strength prone to alveolar weathering and deterioration(Figure 23).[31] It is a fossilifereous bio-calcarenite with a mean open porosity usually higher than 30 % and mainly contains a cement of calcium carbonate known as calcite, grains of quartz, feldspars, and muscovite as minor components. The Rhodian calcareous sandstone derived from ancient structural relics such as Byzantine fortifications and constructions of the early period of Knights, and it was the primary building material for the whole medieval town.[32] Regarding the construction of the houses, the foundations were constructed by blocks of porous sandstone cast in lime mortar infilled with small wedges and ceramic tiles because the stones there were rubble. The ground walls are load-bearing and support vaults and are 100mm thick tapering to 30-40cm at the upper floors. The blocks are generally well-hewn, and laid in the pseudo-isodomic system with courses approximately 19-22cm height and narrow joints. [33] Construction differed according to each conqueror. For instance, during the Knight period, the horizontal and vertical joints are straight, dressed with the help of a ruler to provide clean external surfaces. Although the Ottoman craftsmen continued building according to customary ashlar construction system, they used to fill the less regular joints with a thin layer of lime mortar in recess to avoid moisture concentration.

Porosity = volume of pore space/bulk volume

Cement and mortar

Figure 24: Patela mortar in historic building of Rhodes

Figure 25: Kourasani mortar used as a coating material on the Suleyman mosque in Rhodes

It should be noted that three types of mortar, patelia (πατελιά)(Figure 24), kourasani(κουρασάνι)(Figure 25) and lime mortar, are the most common in the Medieval Town of Rhodes. Lime mortar is only used on the ground floor inside and outside whereas patelia and kourasani are used outdoors to cover the wooden roof and the exteriors walls respectively. Small shells (i.e. potsherds) are embedded into the plaster of the outer surface to strengthen the plastering and reduce cracking their characteristic texture and appearance.[31] Patelia is a local mortar that consists of grey aluminous earth, is used nowadays to cover flat wooden roofs, spreading over the boards in a layer 20-30 cm thick. A thin layer is applied every autumn, soaked and compacted with a roller, and then it dissolves by the rain covering all the capillaries and possible cracks that occurred in summer and making the surface watertight.[32] Ceramic powder mixed with lime in a ratio of 1:3 produces the well-known strong watertight mortar kourasani. This kind of mortar can be characterized as lime mortar without hydraulic constituents. It consists of a mixture of ground tile and lime, and frequently used as an insulating material for water-shedding of the domes and flat roofs. The aggregate is natural, principally limestone, but containing a significant quantity (up to 30%) of quartz and other minerals that are fragments of eruptive rocks and broken brick.[31]

Deterioration patterns of stone

The necessity of mapping decay patterns of building materials

Interpretation of the spatial complexity of deterioration characteristics is pivotal to decay studies and conservation efforts. Documenting the condition of the building materials used in the historic fabric should lead to identification of the decay patterns and its causes and finally to the application of effective preservation to postpone failure. The photographs and drawings made on situ are the primary notes provided me the essential evidence of the building's prior condition.

This survey should follow the principles of Venice Charter whereas ''***in all works of preservation, restoration or excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs".***[4]

Deterioration patterns are the visible imprint of environment factors on materials, fingerprints of the past that can identify the cause of the current damage. They depend on the type and severity of extrinsic elements and on the type of substrate and its properties. The survey aims to provide relevant information about the variations of the Rhodian sandstone with a systematic observation on situ and analytical investigation that will produce a diagnosis to induce the adequate conservation actions. Description and evaluation of the deterioration mechanisms will identify historic and environmental damage, and will lead to a holistic conservation strategy based suitable conservation remedies and assess their future performance.

The possible causes of decay

Figure 26: Salt erosion seen on the porous Rhodian sandstone together with structural cracks on the masonry


Figure 27: Biological colonisation and plants on the facade

Sandstone decay can be attributed to the nature of the material(substrates, surface roughness, porosity and mineralogical nature[33,34], the marine environment and the climate of the island. The micro-climatic conditions of the city such as temperature, rising humidity from the ground, sun exposure, frequency and velocity of wind. Climate is one of the greatest factor affecting building materials[4] and especially, the mild climate of Rhodes favours the high levels of humidity benefiting the dampness.

In porous sandstone, atmospheric humidity along with moisture from the ground can enhance the concentration of weathering agents, letting water penetrate the core. This together with temperature fluctuation can favour the movement of soluble salts inside the masonry. All in all, the destructive effect of moisture in buildings:

- Penetration of moisture through the stone masonry
- Cracks on the stone surface caused by swelling and shrinkage
- Salt erosion (Figure 26)
- Development of fungi, moss and algal growth(Figure 27)
- Chemical corrosion of the materials [35]

Salt crystallisation is among the most harmful abiotic fast-acting decay mechanisms, on porous stones.[4] If the stone show high water penetrability, then water can migrate inside the layers of stone until salt crystallises in the places where water vapours. Hence hen the proper evaporation of moisture is not achieved inside the stone, water penetrates deep into the masonry exacerbating the rate of dampness leading to mould growth. It is related to acidic gases in the atmosphere, as well as thermal expansion due to constant wetting and drying cycles.

The rate of decay by salt crystallisation depends on the a)type of salt, b)temperature, c)relative humidity, d) pore size, e)pore density and f)frequency of wetting and drying cycles. [4] Ultimately, these causes can lead to slow carbonation under the surface, impoundment of moisture and loss of mechanical strength of the porous stone(Figure 28).

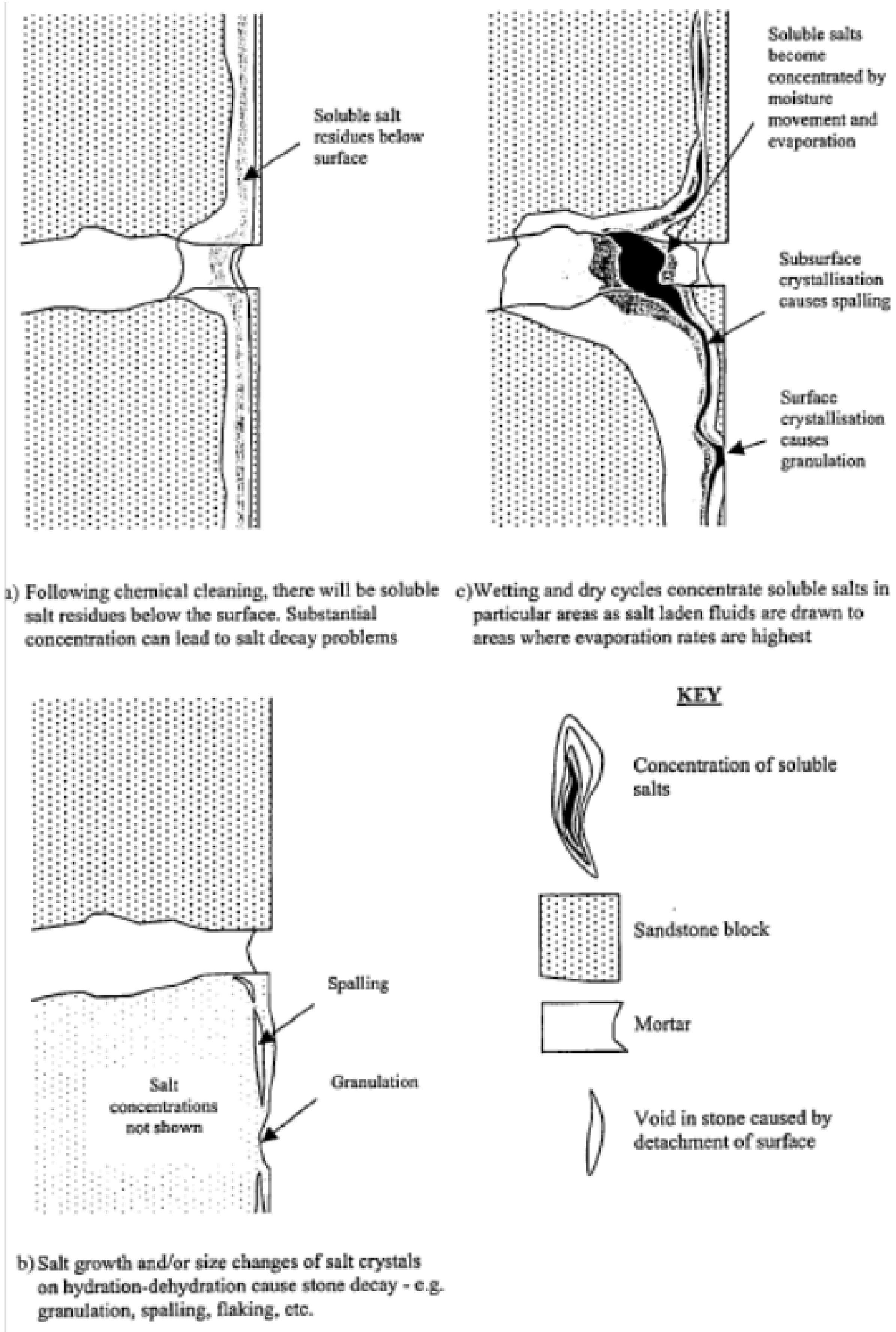


Figure 28: The effect of salt erosion on a porous sandstone

Figure 29: Dissolution of stone components due to salt erosion and transformation of CaCO3

Figure 30: The abandonment and lack of maintenance exacerbate the decay of stone due to vegetative mechanisms

Chemical effects can derive from the combination of sulphate salts and hydrated calcium silicates produced by the modern cement mortars that was used from Italians as a repair mortar.

Air pollution is a crucial factor for the performance of building stones. Generally all stones are composed by a matrix of calcium carbonate is susceptible to degradation when it interacts with acid gases from the environment and stimulates the transformation of CaCO3 of the stone(Figure 29).[36] Whereas acid rain begin the dissolution of the cement components, the sand grains lose their coherence and the layer below the surface becomes a weakened layer liable to deterioration.[4]

Part of the aggressive urban environment is also smoke as the main responsible of surface soiling that deteriorates the visual appearance of the material by creating a thin black layer.

Materials with high porosity like the Rhodian sandstone usually show very high level of bioreceptivity, i.e. the ability to develop living organisms on the surface [37], especially bacteria and algal growth [38,39], and it may be further exacerbated by deterioration mechanisms affected by certain environmental factors. Under the deterioration due to vegetative organisms the effect of bacteria, moss and algae is also considered(Figure 30). Water entrapment inside the masonry can act as a carrying agent of several biological compounds leading a local deterioration of stone. The common microorganisms that are seen on the surface of Rhodian sandstone is moss, as a sign of continuously wet masonry, algae when stone is saturated during the winter. Besides the superficial effects only some fragmentation is to be expected if plant roots have penetrated into the gaps but no actual structural failure. We have to mention though the appearance of certain bacteria on the stone surface that can dissolve the silicate cement of sandstone due to organic acids, loosening that way the quartz grains.[11]

Lastly, human neglect can cause premature building decay. Previous interventions with destructive cement repairs during the Italian period have affected negatively the aesthetic and structural function of the building. Keeping all that in mind while considering the lack proper maintenance or inadequate restoration strategies, we can see how complex deterioration of the fabric can be and its potential to affect architectural, cultural, historical and archaeological value of the site.

Mapping the decay patterns

Figure 31: View of Thiseos Street

Figure 32: View of Pythagora Street

Figure 33: View of Archiepiskopou Eythymiou Street

Selection of case studies

A representative number of sandstone buildings were chosen from locations along the Medieval Town of Rhodes in two areas, the Juderia settlement and the Burgo. 7 complex of sandstone buildings were selected to document deterioration patterns and compare the results, focusing efficiently on 4 only streets (Figure 31,32,33) and aiming to produce relevant observations for the whole area(Figure 34). The buildings present similar properties with their facades being constructed approximately during the same period using the same building material. Although these streets exhibit different characteristics, they are representative of the whole condition in the conservation area and can be pointed out as key indicators of deterioration.

In order to select the buildings some parameters had to be thought like their position in the centre of the city or close to the sea and their ownership. The buildings near the centre of the conservation area found on better state and the sandstone showed slower rate of deterioration, whereas on the other hand, those nearby the harbour were extensively damaged from the solubles salt. It was important to include buildings of public property and also to private inhabitants to discuss different aspects of conservation treatment. They had also to be listed in the conservation area and show obvious signs of deterioration of building materials.

The evaluation of the condition of the selected building focused on facades only to get an overview of their preservation inside the conservation area. Moreover, this analysis allows for explicit recommendation to be made according to various factors and finally produce an overall statement of cultural significance. A thorough analysis of their distribution around the city will be beneficial to classify their causes and effects to make a comprehensive plan based on an innovative method that will be discussed on a next chapter.[40]

1.


2.


3.


4.


Figure 34: Location of surveyed case studies

5.


6.


7.


Overview of case studies

This study focuses on residential buildings in the historical city centre of Rhodes aiming to provide an overview of the diversity and the nature of deterioration patterns and generate tangible data to construct a cohesive document. Two settlements are surveyed and compared to the same parameters to conduct an efficient conclusion about the causes and the impact of the deterioration patterns.

Juderia settlement

The Juderia settlement presents clearly distortion of its historic and aesthetic character due to many interventions during the Knight, the Italian, the Turkish and lastly Greek period and can be characterised as the most extensive bombarded space in the whole conservation area. This almost deserted area does not follow the Hippodamian system as it occurs within the conservation area, but in the contrary it is seen narrow streets with arches and high walls on either side(Figure 35). The majority of buildings in Juderia dates back the second period of the Knights (1481-1522), where exposed ashlar masonry combined with local materials (mostly sandstone in grey-beige colour) was the prevailing building technique of that period. The common type of house is a 2-storey residence with rooms on the floor covered with a flat wooden roof whereas the ground floor is a vaulted warehouse with a direct entrance from the street(Figure 36,38). While these houses present a strong main facade with ornate decorations, no large openings now exist to provide the necessary protection from public eyes according to the Turkish religion. This also is justified by the fact that the courtyards are always put into the back of house and sometimes an external staircase leads to the first floor.

It must be mentioned that the buildings in this area are of big interest of the Greek Ephorate to restore them to accommodate increasing number of university students. Their quest is to change the social and spatial introversity by using the existing derelict building stock and strengthening the residence towards urban rehabilitisation(Figure 37).

Figure 35: Built-unbuilt space in Juderia settlement

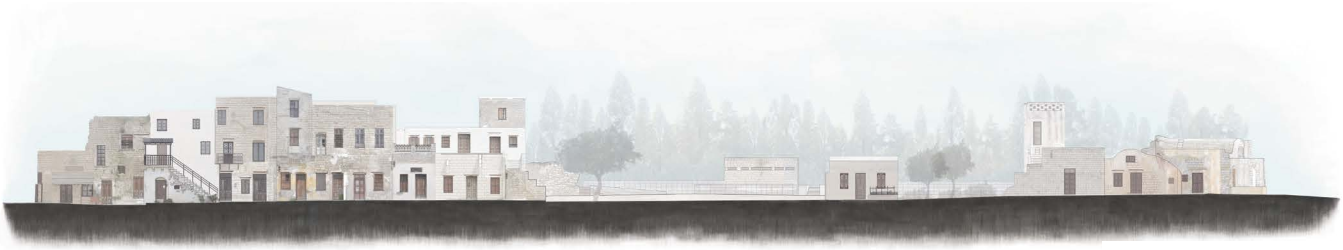


Figure 36: The main facade of Thiseos Street from the side of the Alchadef Park

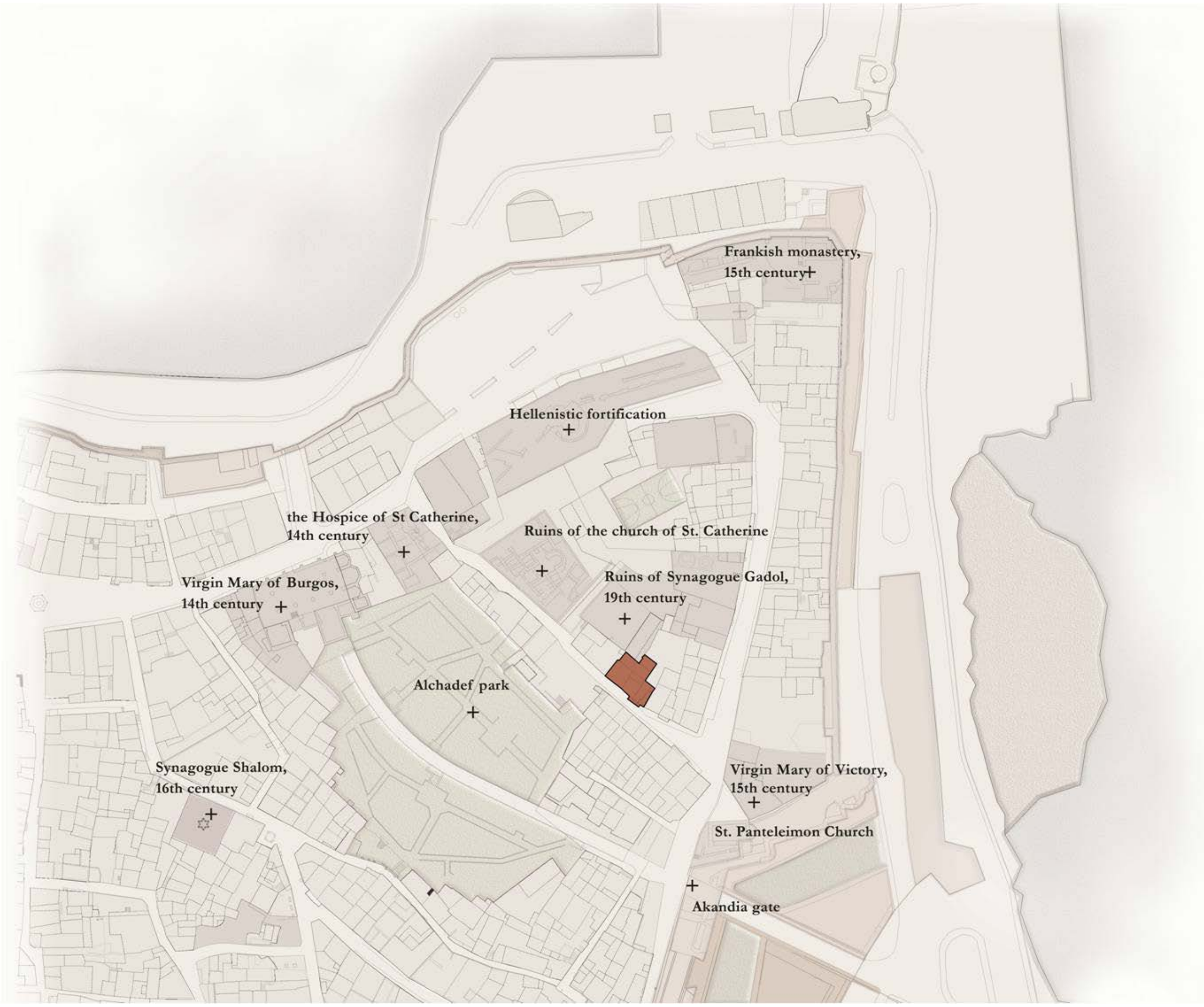


Figure 37: The cultural and architectural value of Juderia settlement

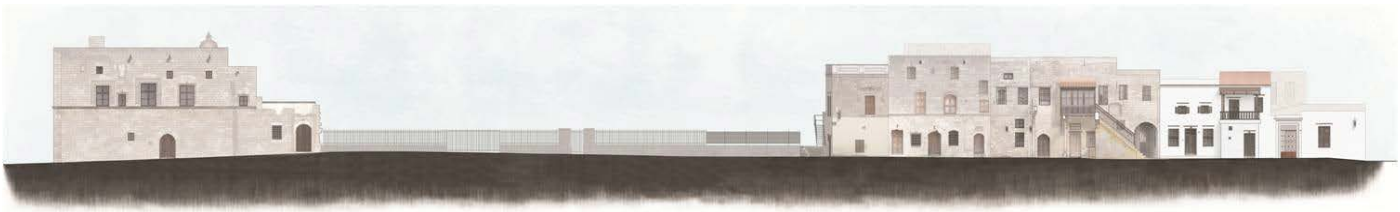


Figure 38: The main facade of Thiseos Street from the side of the archaeological site

CASE STUDY 1: THISEOS 19

Figure 39: Photograph of Thiseos Street at early 19 century showing the existing sachnisi

Figure 40: Main facade of case study showing all the architectural phases of interventions

Figure 41: Position in the Juderia settlement

Location

This building is situated in Thiseos Street at the north-eastern edge of the commercial centre next to the medieval fortifications and close to the commercial harbour(Figure 41). Due to its vicinity to the sea the alveolar weathering pattern is more obvious on extended architectural surfaces.

Cultural and heritage value

Its position next to the Hospice of St. Catherine, a masterpiece of Knight architecture of 15th century, the Hellenistic fortified ruins and the Jewish synagogue Kachal Salom highlights even more its significant cultural heritage and need for preserving it.

Architectural features

It was originally built as a two-storey residence in a T shape for a single-family extended on two floors, a typical example of the architecture of houses constructed in the 15th and 16th centuries in the medieval town of Rhodes(Figure 40). The property consists of two restored vaulted spaces on the ground whereas the first floor has horizontal roof with a new internal low height floor. This room on the first floor was used as a living room and its floor was decorated with pebbles from seashores(Figure 41).

A survey of the building found that the load bearing walls were made of sandstone and lime mortar. More specifically, the masonry is almost 90-100cm thick on the ground floor reducing to almost 30cm in the first floor. The walls were made of two leaves of sandstones whose cavity is filled with pebbles and the covering of the flat roof is a water repellent local argillaceous mortar called patelia.

Vacancy-Occupancy

Nowadays although this complex of houses has been restored in the last decade from the Greek Ephorate of Rhodes only the ground floor is occupied by a single-family leaving the upper floor abandoned for years. This property belongs to the public after the Italian period and the current residents pay low rent to live there.


Figure 42: Biological growth in the stone masonry


Figure 43: The impermeable cement mortar from the Italians


Figure 44: Honeycombing pattern due to different properties of stones

History of interventions

The original form of the building extended on the first floor to the back but on 1959 due to a strong earthquake the building was damaged severely and the rear roof fell along with a part of the walls. The Turkish occupants had earlier altered the main facade by creating large wooden sachnisi openings looking to the street, a typical 19th century feature of a Turkish house. During the Italian period the use of cement mortar for re-pointing joints caused irreversible problems for the porous sandstone. They also moved the sachnisi to slightly next to the previous position but they created more holes in the stone masonry affected its preservation and stability. The second internal floor is an addition from the final phase that occurred probably at the turn of the 20th century. Also from the texture and colour of the stones on the right part of the main facade we can assume that this part dates probably from 20th century. The ground floor was restored to be viable but the abandonment of the upper floor raises problems for its current residents.

Defects

The main facade has serious rising damp at the ground level and severe bedding almost 10cm declination at the upper parts. The salt erosion along with the biological growth(Figure 42) that almost is embedded in the stone masonry affect negatively the aesthetics of the building by salt erosion. Accumulation of deteriorated stones is observed on the basis of the masonry and near the water goods. The impermeable cement mortar(Figure 43) from the Italian period combined with the low porosity sandstone creates the honeycombing pattern(Figure 44) on the whole facade(Figure 45).

Focusing on a representative 1x1m section(Figure 46) we observe many cavities and micro-fissures on the stone surface along with black crust transforming the outermost layers of the stone and leaving a friable zone underneath susceptible to moisture entrapment. Although the cracks and the fissures are not so important as the previous effects they must be mentioned as they attract moisture into the core of the stone and degrade it easier.

Impact

The survey highlights the effect of the position nearby the harbour, the humidity and the previous interventions as l elements that need to be reconsidered to find an effective solution.

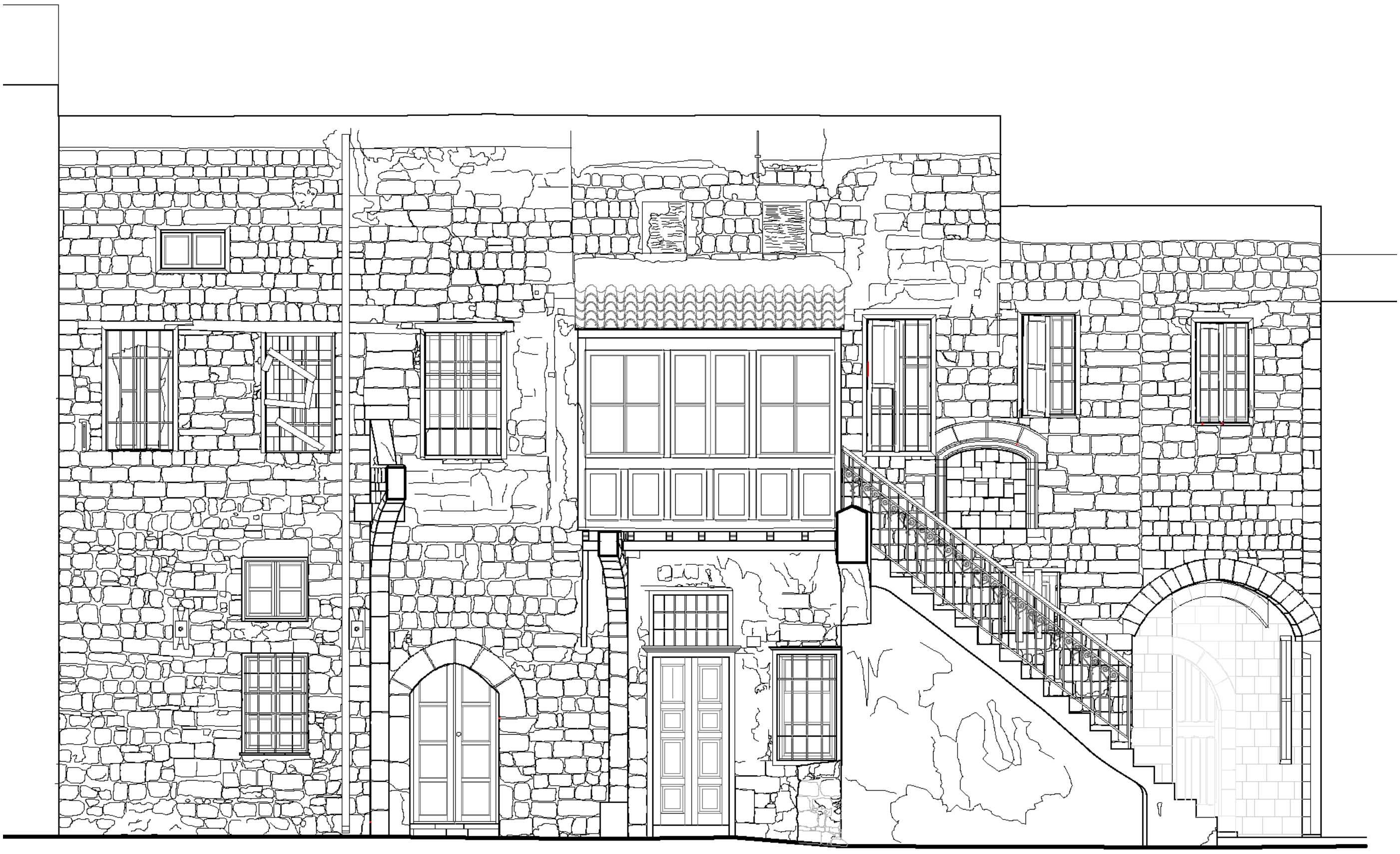


Figure 45: Documentation and mapping of the main facade

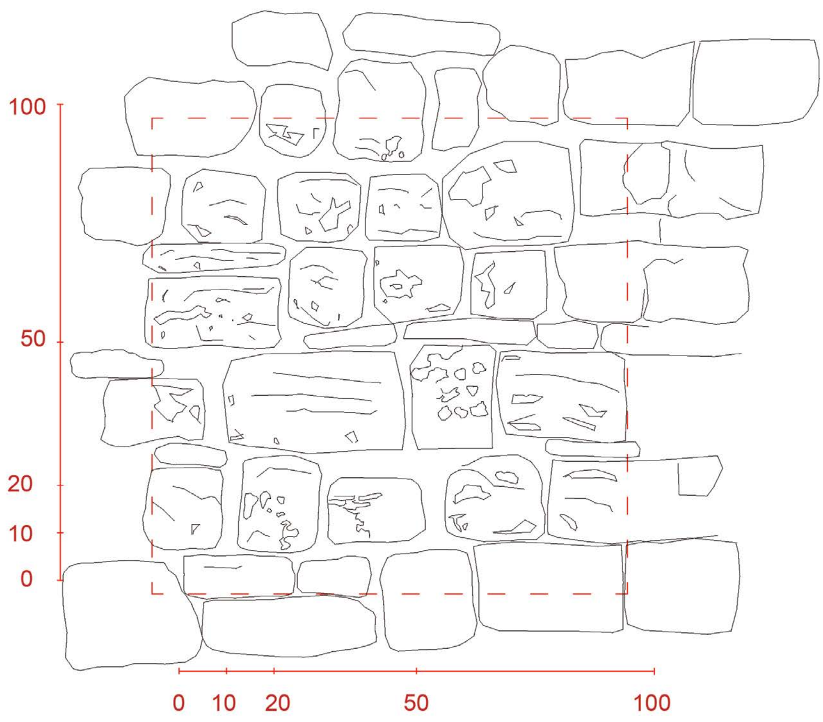


Figure 46: Representative section of the facade showing the deterioration of stone

CASE STUDY 2: THISEOS 32-34-38


Figure 47: The street facade of the complex


Figure 48: Disruption of the stone masonry due to salt erosion along with decay of mortar


Figure 49: Position in the Juderia settlement

This example consists of three buildings constructed at the same period, approximately the 15th century, and present similar architectural features. It therefore seemed appropriate to study them as a complex rather than individual buildings due to homogeneity of deterioration patterns and the same extrinsic factors affecting their aesthetic and structural performance(Figure 47).

Location

This compound is located opposite the previous case study. Its location next to a large plateau in front of the park and in contact with the archaeological sites adds to their key position in the urban historic surrounding(Figure 49).

Cultural and heritage value

The outstanding historical value of this complex in the Jewish Quarter, an area which now shows signs of depopulation, was made clear not only by photographs but also by depictions from international painters. Its architectural significance as typical examples of surviving domestic architecture dates back to 15th century when the Jews inhabited in the area.

Architectural features

The complex extends on three levels with internal wooden staircase, slightly decayed leading to the upper floors. All ground floor spaces are covered with vaults and present lighting and ventilation problems. All the buildings have flat roofs covered with the local mortar patelia(πατελιά) except of one with a pitched roof . The load bearing structure is made of Rhodian sandstone, which on the ground floor has a thickness of 60cm, almost 110 cm and on the first floor reduces to only 25cm. The floor on the right side is constructed with wooden planks indoors and pebbles in the outdoors spaces while the left section has been restored with ceramic tiles, a contemporary intervention.

The facades preserve some of the original historic features including decorative cornices, projecting eaves and water spouts of the Hospitaller period that show high quality craftsmanship of the chivalrous architecture of that period.

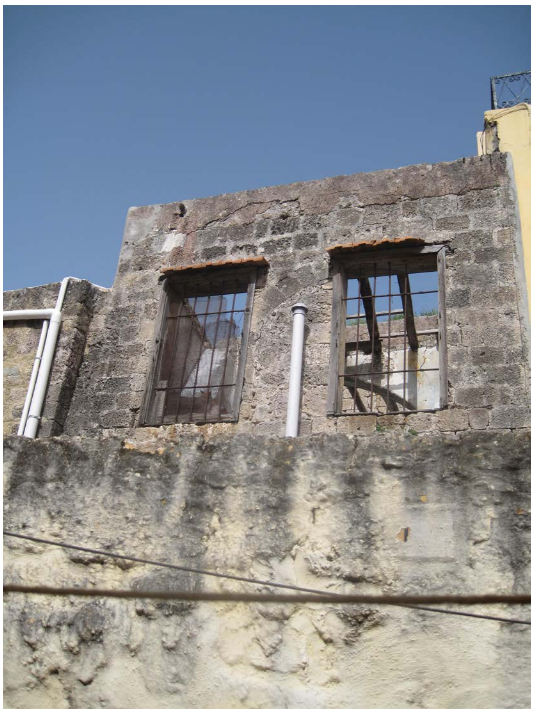


Figure 50: The roof in the back of the building has collapsed revealing 3 wooden beams

Figure 51: The extensive use of cement on the ground floor damaged irreversibly the structure of the masonry and the stone itself

Vacancy-Occupancy

Nowadays these buildings are public property and only the ground floor of the right building is occupied by a family. They are currently restoring part of the buildings because in Spring 2015 the floor collapsed causing major problems to the structure.

History of interventions

This complex of buildings provides evidence of the historic urban layout and the changes it underwent over time. It provides physical evidence of the significant changes that followed the earthquake of 1959 when the backside of the buildings collapsed leaving the masonry dismantled(Figure 50). Later interventions by subsequent owners, including the demolition of the timber balcony on the facade, the addition of a lath wall and the strengthening of the vaults with cement mortar have changed significantly the character of the buildings.

Defects

The extensive use of cement to strengthen the vaults is almost irreversible(Figure 51). As seen in Section 4 on decay causes, the differential temperature variation between the hard cement mortar and the softer porous sandstone affects notably the structural and visual performance of the stone as it is now covered completely.

Looking through the section of the stones we can conclude that the humidity have a negative effect on the sandstone in general in this area leading to the chemical dissolution of the stone and peeling of the surface layers. This in turn accelerates weathering and superficial losses enhanced with cracks formed on the keystones from compressive forces. Moreover, algal growth observed at capillary level of the masonry, in sections not exposed to sunlight cause fragmentation and bigger voids on the stone and the mortar(Figure 48).

Impact

The abandonment and lack of proper maintenance all these years speeded the process of the decay and in addition to the wrong human interventions(incorrectly contained forces due to cement in the vaults) led to major structural problems. Keeping in mind its location next to the harbour and the effect of the soluble salts on the low strength stone we understand the rate of decay in this complex.

Figure 52: Documentation and mapping of the main facade

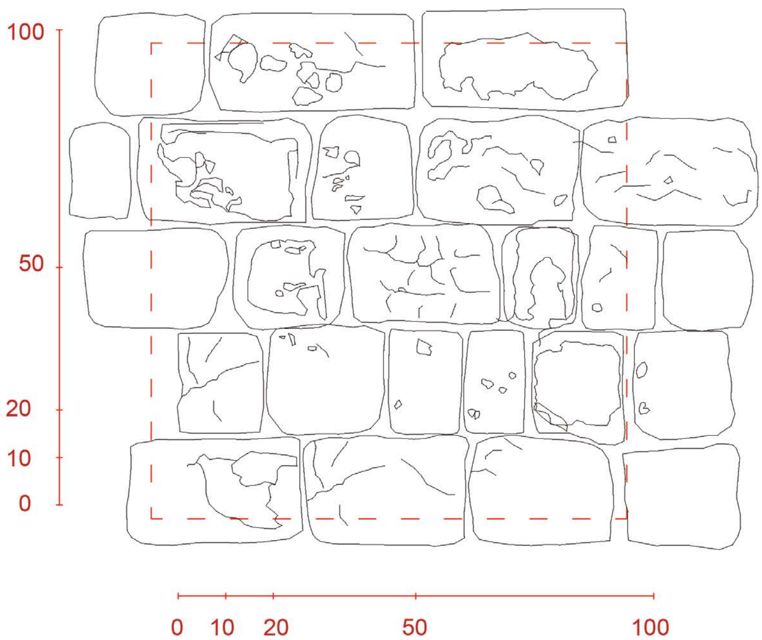


Figure 53: Representative section of the facade showing the deterioration of stone

CASE STUDY 3: KISTHINIOU 44

Figure 54: The ground floor of the building facing the street

Figure 55: The facade of the two storey building wchich extend on the first floor in the back of the property

Figure 56: Position in the Juderia settlement

Location

This building is located on the same block as the previous case study but on the Kisthiniou street which connects the two 14th century gates of the Medieval Town of Rhodes(Figure 56).

Cultural and heritage value

This building is not so important in architectural terms as the other case studies but its position in a such historic building block and outstanding cultural environment makes it invaluable.

Architectural features

It consists actually of two small narrow-fonted buildings, one storey and two-storey buildings with courtyard respectively, as we observe from the two doors on the facade(Figure 54,55). More specifically, the first door leads to a single vaulted space, previously used as storage area, and the second door to two spaces with an internal staircase going up to the first floor where the actual living spaces are accomodated.

Vacancy-Occupancy

After the Italian period it is a public property and currently being used as a traditonal workshop of Byzantine icons.

Figure 57: The blocked arched window

Figure 58: Replacement with new window frames

History of interventions

There are not seen many intervention on the main facade except ftom the blocked arched window(Figure 57) on the left during the Turkish period in an attempt to transform it to a a residence. Other than that, only the replacement of the window frames by the Greeks could be mentioned(Figure 58) which altering the aesthetic chracter of the building.

Defects

On the upper part of the bonding masonry the absence of the kourasani mortar is obvious and is probably the cause for the deterioration of the sandstone blocks. The necessary protection from the moisture is not provided and that is the reason why all the stones int he upper three rows are showing such rate of decay. Although, this building is close to the sea it is not seen the extensive deterioration of stone in the form of honeycombing and salt erosion may be due to the fact it was used a sandstone with better porosity from the same quarry.

The general condition(Figure 59) of the building is good with no major required except from the immediately conslidation treatment or even removal of the upper part of the masonry(Figure 60). Owing to its occupation throught the years it shows minimal signs of damage and abandonment facilitating more the selection of the adequate repair strategy.

Impact

Although now it is not showing destructive signs of decay on the main facade, co-ordinated actions must be taken to protect it from further future damage maybe with the application of a new coat of kourasani or Lithomex as we have previously discussed about restoration mortars on Section 6.

Figure 59: Documentation and mapping of the main facade

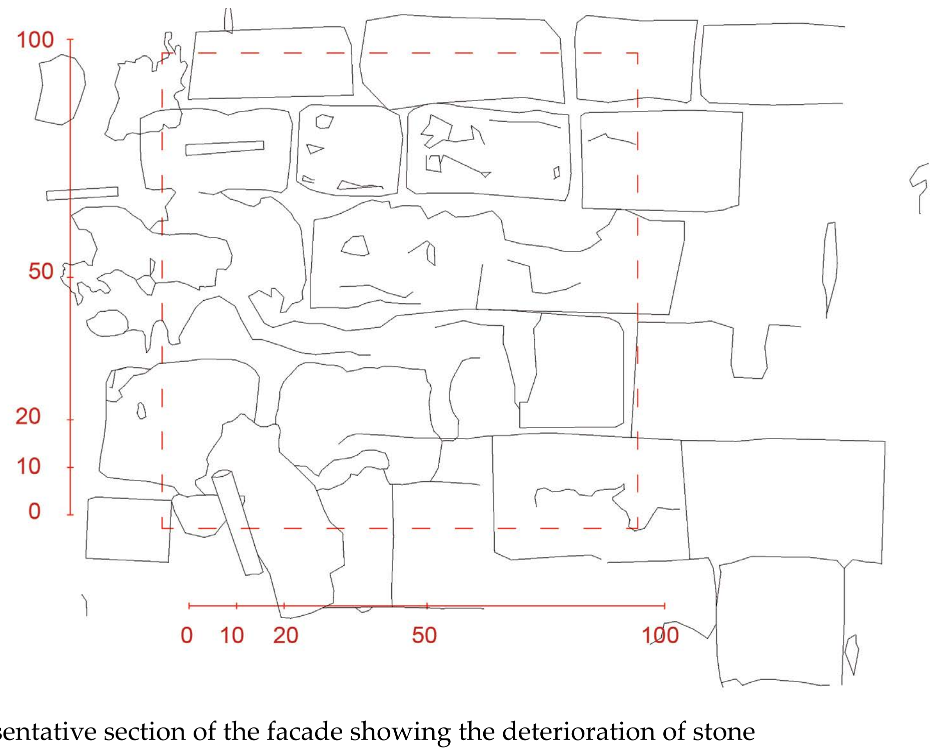


Figure 60: Representative section of the facade showing the deterioration of stone

CASE STUDY 4: KISTHINIOU 19

Figure 61: The main facade on Kisthiniou Street

Figure 62: The restoration of the right part of the building with new sandstones

Figure 63: Position in the Juderia settlement

Location

This building is situated in Kisthiniou Street next to the eastern fortifications close to the St. Pantelehmon, the Jewish elementary school and the Hellenistic ruins(Figure 63). Its location far away from the centre contributes to the slower deteroration from air pollution.

Cultural and heritage value

Being part of the Juderia settlement and the impeccable surrounding of the Jewish Quarter are the basic factors for its cultural significance. The architectural features do not contribute to the character of the area as it is only a 15th typical house of the Jewish community.

Architectural features

It is a traditional house with three supporting walls and a patio in the backyard, both traditional features of Jewish residential architecture in the Medieval Town of Rhodes. The property consists of one vaulted space and a rectangular space adjacent to it(Figure 61).

The building is constructed by the local sandstone in isodomic building system and the use of lime mortar for pointing(Figure 62). A visual survey on a representative section showed that the stones range between 19 to 22 cm and the masonry is almost 80cm thick on the ground floor. Owing to its abandonment and no possible access no observations can be made for the cavity walls.

Vacancy-Occupancy

This building is currently vacant just like the majority of the historic buildings in that area because when Jews left from the island after the World War II, they abandonded their houses for many years. Although it is public property, it has not been maintained from the Greek Ephorate due to lack of financial resources.

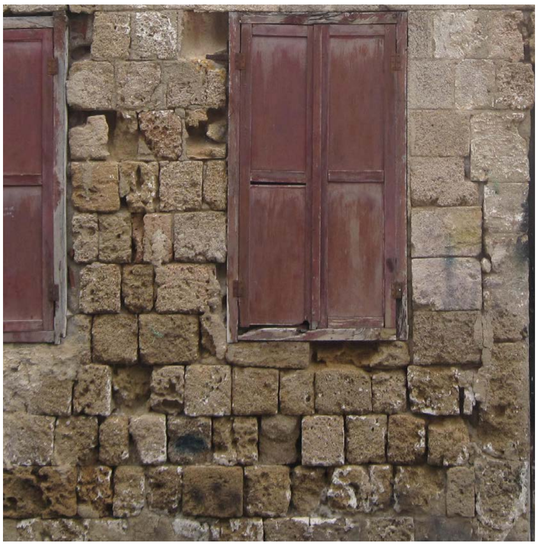


Figure 64: Loss of mortar on the joints and serious deterioration on the sandstone due to solubles salt

Figure 65: The use of brick on the main facade alters the visual appearance of the building

Figure 66: Salt efflorescence and black crust on the stone masonry due to poor rainwater goods

History of interventions

The visual condition of the facade suggests that the right part of the building has been unsuccessfully restored with the application of unsuitable new stones destructing the older stones which are weaker. Also, a different material, brick, was also used for extending the wall higher altering the architectural character of the building(Figure 64).

Defects

The building condition could be described poor because it experiences significant structural failure on the facade, particularly at the window's edges, and widespread effect of honeycombing of sandstone. The visual evidence of abandonment and deterioration include overgrown vegetation on the capillary level, smashed windows and black crust fromation near the rainwater goods(Figure 65). As it was mentioned in the Section 4 about the effect of putting porous stone in contact with less porous stone, here the more porous stone erode to a much greater depth than the new one(Figure 66).

Impact

The most destructive factor on the building is the soluble salts from the harbour and the wrong previous interventions with the allocation of unsuitable building materials, brick and new harder stones(Figure 67,68).

Figure 67: Documentation and mapping of the main facade

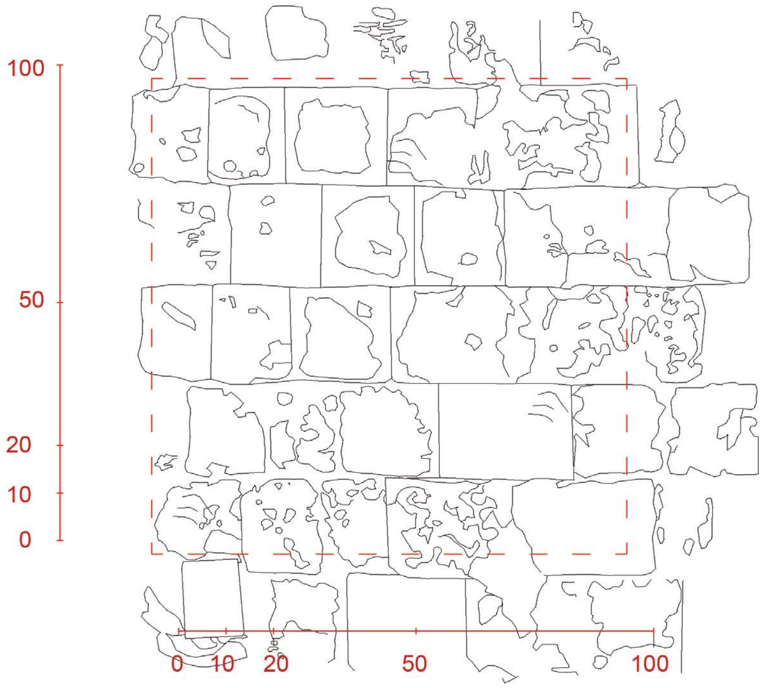


Figure 68: Representative section of the facade showing the deterioration of stone

Burgus settlement

The area between the Juderia settlement and the Collachium is called Burgus(Μπούργκο)[1] (Figure 69) and is the second example of my survey. It includes the commercial centre and the main residences within the conservationa area and the main axis of the Medieval Town, the Socratous street, where all the commercial and cultural functions are held. The surveyed area is located south to Socrates street with the dominant use of residence where the density is increased in the western part of town. On the other hand, the east side faces depopulation and a large number of buildings to be abandoned by inflating pressures of commercial activities and tourism. The poor living conditions led to the gradual abandonment of the medieval town by its inhabitants leaving the building stock

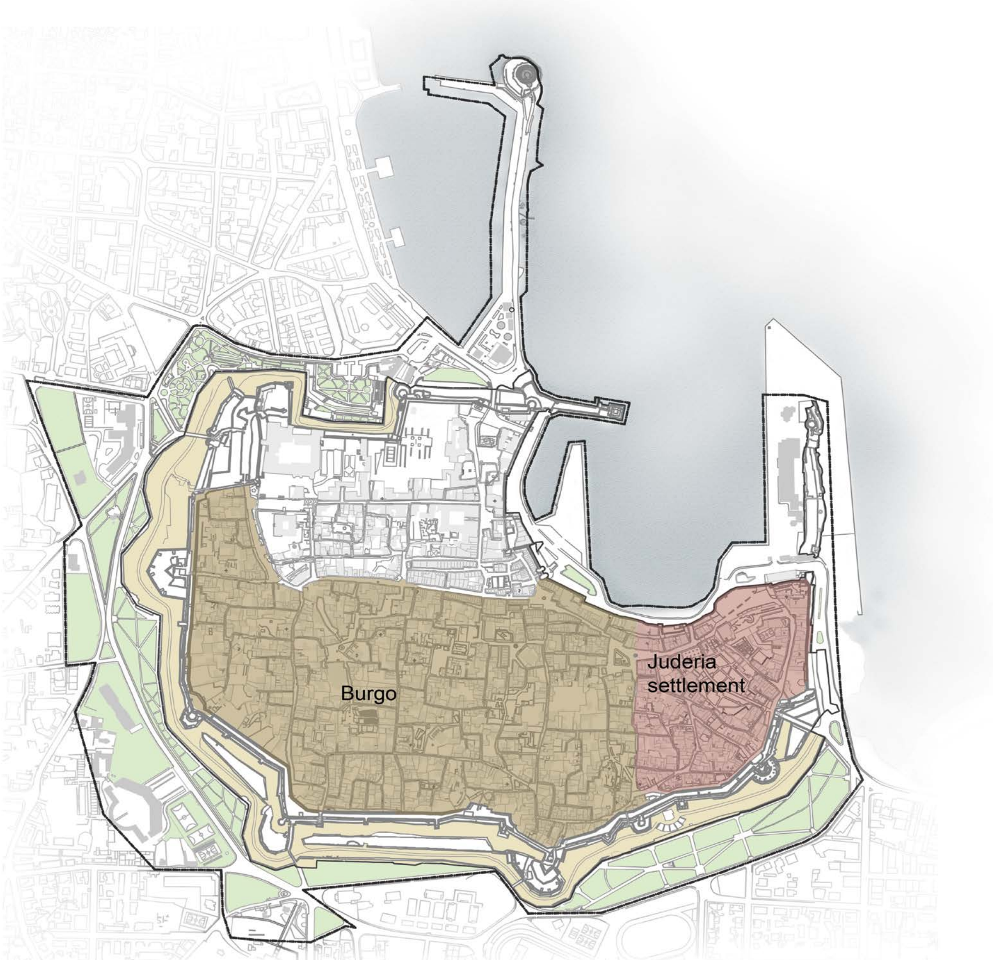


Figure 69: Depiction of Burgus settlement

1.Burgus (Μπούργκο) is a separate urban unit where Greeks and Latins lived during the Hospitallier period

CASE STUDY 5: PYTHAGORA 89-91

Figure 70: The main facade

Location

Situated in Pythagora Street, one of the most central streets(Figure 71) in the Medieval Town whose cultural value is characterized by traditional workshops and vernacular art. Being parallel to the cardo street, the most significant street during the Roman period and the ruins of the Byzantine fortifications opposite of the building add to its importance.

Cultural and heritage value

Its position on one of the most historic streets in the Medieval town and its own architectural significance, highlight its need for restoration and preservation to be enhanced again into the urban historic fabric.

Architectural features

The house probably belongs to the last period of building activity of the Hospitaller period(1480-1522). The original substance of this historic stone house consists of two rectangular narrow-fonted buildings with vault and one floor above with kitchen, living and sleeping spaces. The vaults are on the ground floor and they are constructed by hewn-blocks of local sandstone 18-22 cm wide and 25-35 cm long. The vaulted entrance(Figure 70) on the ground floor leads to an internal courtyard and a staircase going up to the first floor. The main facade has large windows with sculpted decorated mouldings, that overlook the street.

Vacancy-Occupancy

Today the building is not being used and has been left derelict for decades. It belongs to a private landlord but no further information could be discovered.

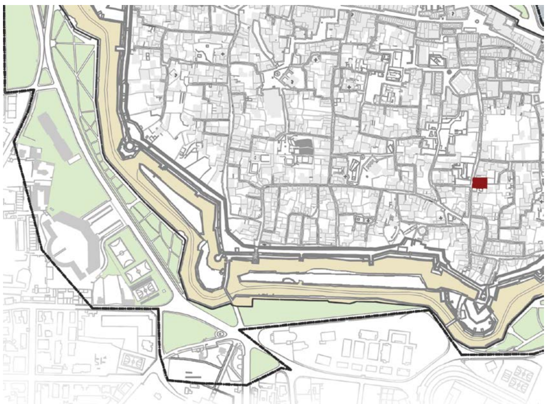


Figure 71: Depiction of Burgus settlement

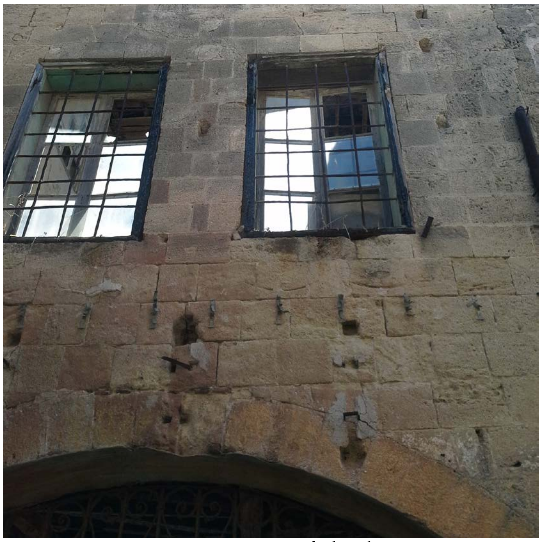


Figure 72: Deterioration of the keystone


Figure 73: Blocked arched windows


Figure 74: Use of cement for re-pointing and also for coating the surface of the facade

History of interventions

There are no much information given for that building but from a visual survey on the main facade we can conclude that the building has been restored to some extent by the Italians as it is seen from the blocked arched windows in the upper floor(Figure 72,73). Except of this intervention no major alterations has been obeserved on the structure or the visual appearance of the building.

Defects

The general state of the building is moderate with some elements like the windows being in a bad condition and the main structure facing problems as the roof has collapse leaving the bonding of the stone masonry unstable. However, the state of the sandstone is left almost intact probably because it is far away from the sea except on the point A in the Figure 74 where cement was used for repointing deteriorating these stone blocks and on point B where some stones on the keystone of the arch door has been damaged.

Impact

The survey of the building(Figure 75,76) showed a small percentage of deterioration on the ground floor where human interventions were applied and the signs of lack of maintenance became evident. Therefore, no major works are required for the conservation of the main facade.

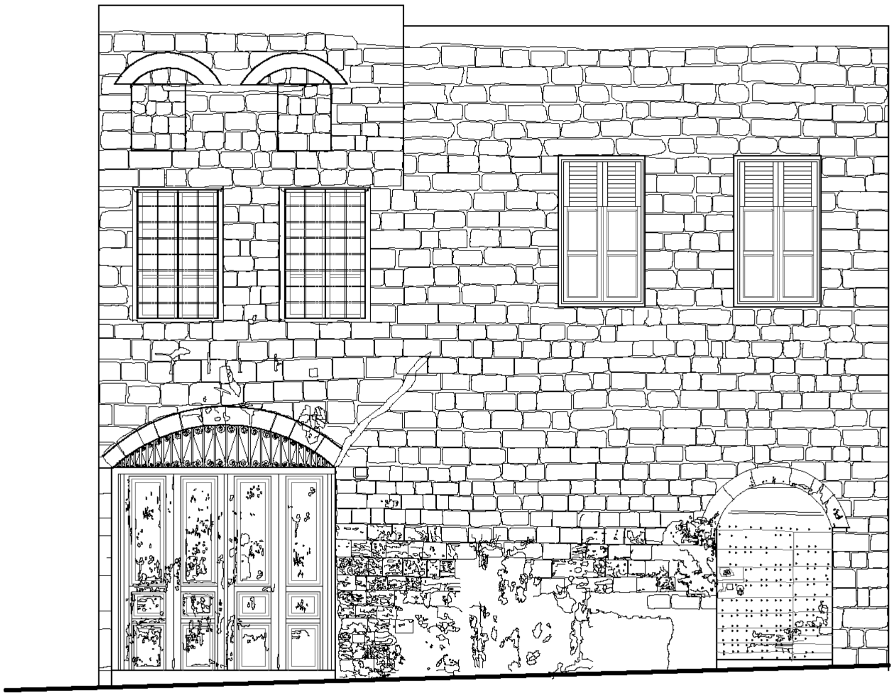


Figure 75: Documentation and mapping of the main facade

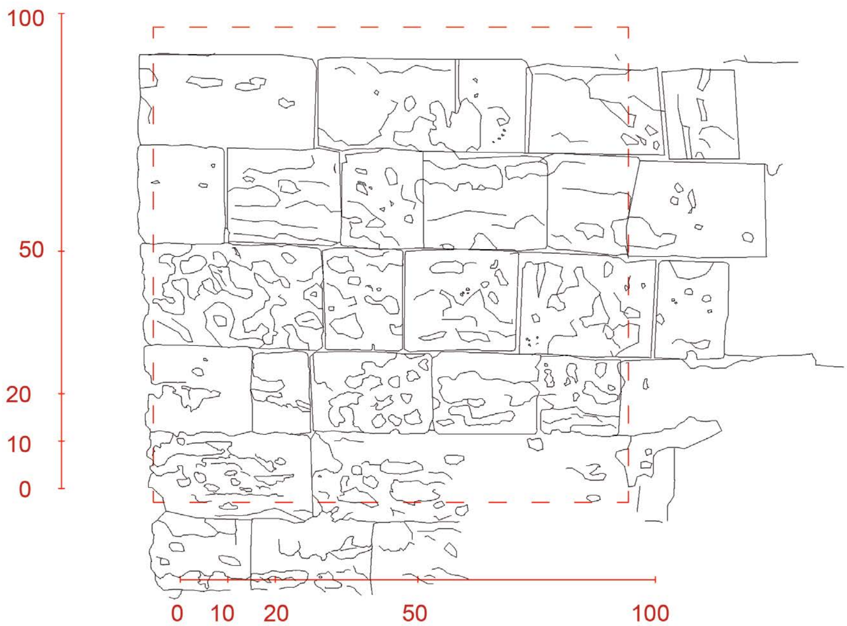


Figure 76: Representative section of the facade showing the deterioration of stone

CASE STUDY 6: PYTHAGORA 81-83

Figure 77: The main facade of the building

Location

This mid-15th century building is located in the same block with the previous building(Figure 78). Its position is very important for analysing the decay patterns as it is the only building on an open setting vulnerable to wind and rain.

Cultural and heritage value

The cultural heritage of this building is outstanding because it overlooks directly to the Byzantine ruins and may be connected with them. It is an impeccable example of Maltese architecture and adequate conservation treaments should be applied to restore its historical and architectural value.

Architectural features

This property consists of two rectangular buildings with their main entrance being from the central street(Figure 77). The arched doorway reveals that is from the first Hospitallier period because no ornamental features and decorated mouldings are observed on the facade. It is also completely made in solid natural stone, contained on the ground floor the service rooms and on the floor the main house units.

Vacancy-Occupancy

A private landlord owns this property and by seeing the boarded windows on the first floor and the railings on them, we can assume that the site was probably occupied a decade ago.


Figure 78: Location in Burgus settlement

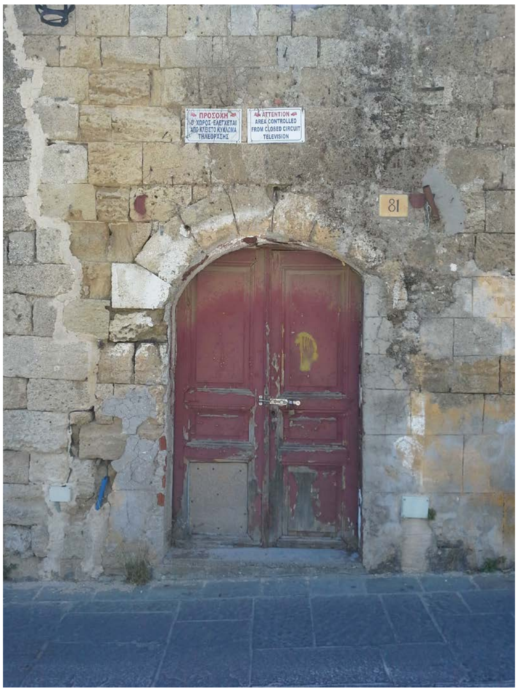


Figure 79: Deterioration of keystone of arched door and patina on the stone surface

Figure 80: Blocked window on the facade filled with rubble and the decayed lintel of the window

History of interventions

This building was always used as a house and storage for centuries. During the Knight period it was occupied by Greeks and then during the Ottoman period the Turkish inhabited for several decades until the Greeks became their last occupants. The visual survey on the main facade suggests that the central knighty window was blocked(Figure 79) to provide protection from the the public eyes according to Turkish religion and another one on the ground floor was opened for better sunlight and ventilation.

Defects

The building's condition is poor with the stone masonry experiencing destructive prooblems. The cracks on point A and B(Figure 74) look like a shear failure as the crack passes through the mortar to the stone endangering the bond between mortar and stone block. The horizontal timber lintels are bedding inside the stone masonry moving the loads to the stone blocks adjacent to the windows. The facade shows signs of dampness of the mild climate causing fragmentation and chipping of the stone blocks due to internal stress. The main weathering process for the stone deterioration that threatens its mechanical properties is carbon due to atmospheric pollution together with smoke causing surface soiling. The colour disfiguration, patina(Figure 80) and biological growth are not an actual threat to the historic fabric but only an aesthetic alteration of the building.

In a representative section(Figure 81) of the stone masonry, the stone pores suffer a pressure increase and as a result we see the effect of granular disintegration and consequent loss of material. The stone cavities on the stone surface and the superficial abrasion losses reveal the honeycombing pattern that damages the core of the stones.

Impact

The stability of the building is endangered from the plants growing beside the facade disrupting its structure with their roots. Its location in fornt of an open space and the air pollution from the carbon oxide of the cars are the main factors damaging the building and putting its stone blocks at risk.

Figure 81: Documentation and mapping of the main facade

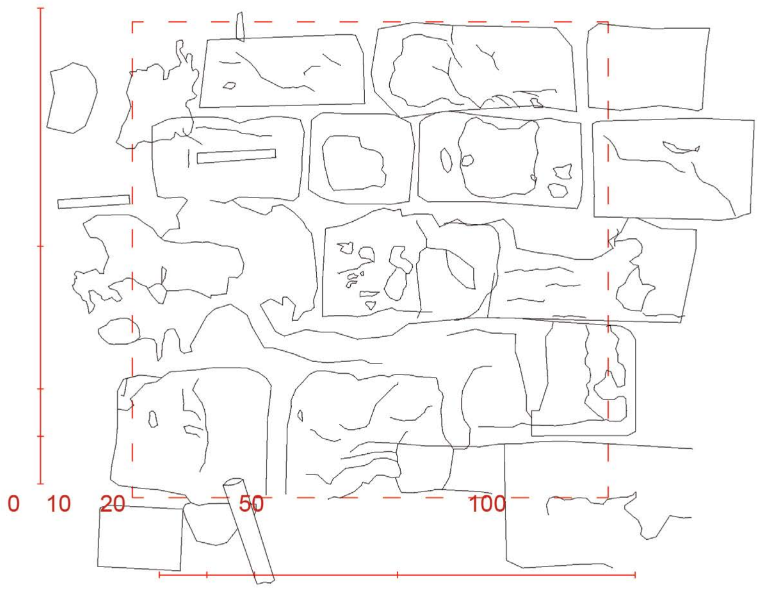


Figure 82: Representative section of the facade showing the deterioration of stone

CASE STUDY 7: ARCHIEPISKOPOU EUTHYMIOU 2

Figure 83: The building in the corner of the street and the enclosed sachnisi

Location

This building is located on the corner Archiepiskopoy Euthymiou Street with Pythagora Street at the southern part of the Medieval town(Figure 84) in a close vicinity to the fortifications and the gate of Koskinou(Κοσκινού).

Cultural and heritage value

This building is a representative example of Maltese architecture combined with the traditional cultural characteristics of Ottoman architecture and its contribution to the historic fabric of the medieval town is important to perceive the phases of architectural interventions through years.

Architectural features

Observing the main facade(Figure 83) with the two arched doorways we understand that is a 15th century probably from the first period of the Hospitallier period. This square building is extended to two storeys with the ground floor to be used as a storage and the upper floor as the actual residence for its inhabitants.

Vacancy-Occupancy

It is a private property that has left abandoned for decades now with no perspective to be occupied soon without the necessary interventions.

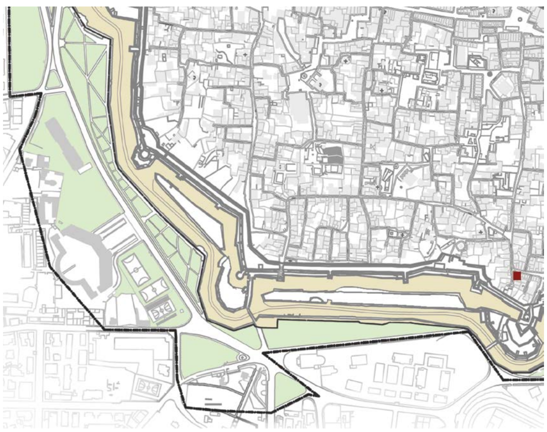


Figure 84: Location in the Burgus settlement

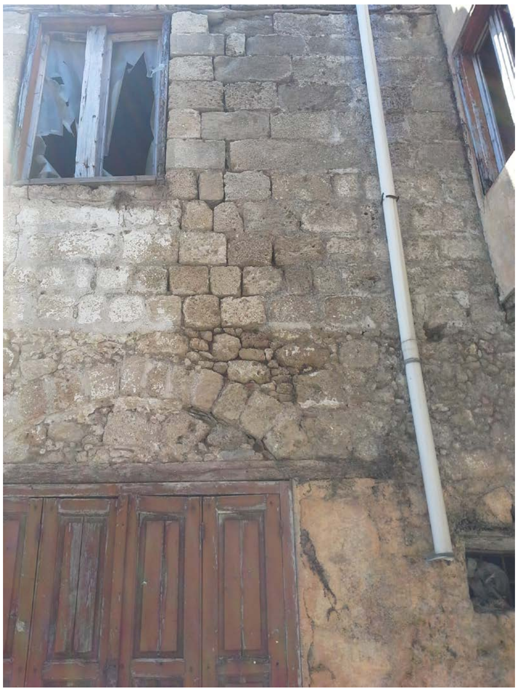


Figure 85: Arched doorway and loss of mortar in the joints

Figure 86: Voids in the structure due to the placement of sachnisi

History of interventions

The blocked doorway on the left and replacement with a typical 20th century door together with the placement of the timber framed sachnisi(σαχνισί)[1] covered with kourasani(κουρασάνι) are evidence from the interventions that took place in that building by the Italians and the Turks repsectively. Moreover, when the Turks added the sachnisi, they probably removed part of the masonry above the door and filled it with rubble affecting the visual apperance of the building(Figure 85).

Defects

The wooden beams inserted in the stone masonry have damaged the structure of the building(Figure 86) leaving some voids among stones. The building presents substantial evidence of deficiency in its structural performance on the upper floor, in particular at the stone blocks adjacent to the windows, and the rotten wooden beams of sachnisi and the decay odf the structural timber lintels. The ground floor seems to be in a good condition owing to the coating with kourasani protecting the sandstones from granular disintegration and case hardening happening on the upper parts of the masonry.(Figure 87,88)

The main cause of building's damage is human interventions affecting its stability together with aerosol pollutants from car's engines that create a thin black layer on the stone surface. Its position in the centre and not close to the sea contributes to the slower deterioration rate of the sandstone with minimal signs of salt erosion.

Impact

This building is a typical example of different architectural styles from all the civilisations found in Rhodes and its history must be protected at all costs. The application of a new coat of kourasani and a specified restoration mortar for repointing on the upper floor together with the replacement of deficient structural stones with new suitable ones re the main concern of the conservation strategy.

1.The enclosed balcony is seen traditionally on the main facades of buildings, in traditional Balkan and Asia Minor buildings. The timber framed space creates an additional living area on the upper floor and was used to control the entrance and the street in front of the house.

Figure 87: Documentation and mapping of the main facade

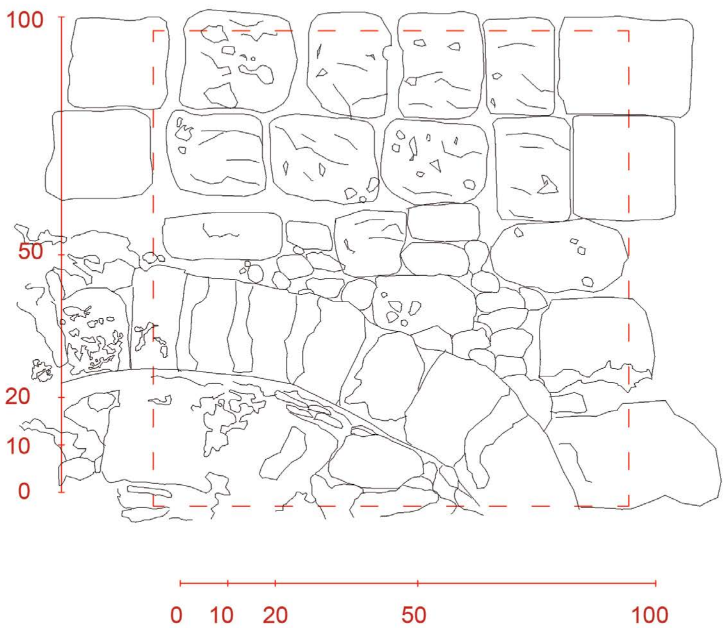


Figure 88: Representative section of the facade showing the deterioration of stone

Classification of decay features

The documentation of the spatially complex decay patterns on the case studies is followed by an assessment of the general state of each building. The criteria for the assessment depended on the state of their materials according to structural performance, visual appearance and physical properties, and environmental factors. Hence the basic parameters were classified into seven categories: 1)building itself, 2)building materials, 3)use, 4) built environment, 5) ownership, 6)vacancy and 7)previous interventions, as it seen on the Figure 89.

After all these parameters were considered and used to create a database for each building, then a new database was also developed to depict the decay patterns and their frequency of degradation.In order to investigate in more depth the distribution and the rate of deterioration of stone and mortar, one to one metre patches of the main facade were mapped. This method of mapping and classification thought to be the most suitable for this project as it can easily be applicable to a range of buildings.

An effective way to categorize the decay patterns that lead to loss of material, structural failure, insufficient coherence of material are the 1)mechanical effect, 2) thermal effect, 3)atmospheric effect and the living being effect. According to the Figure , the classes are divided several patterns of deformation, detachment, material loss, discoloration and biological colonisation.

With the combination of the two databases, the spatial distribution of the decay around the conservation area is depicted on.

STATE OF BUILDING	USE OF BUILDING	BUILDING MATERIALS	URBAN SURROUNDING
good	residential	type of stone	humidity
moderate	commercial	porosity	dampness of climate
poor	storage	type of mortar	position in the conservation area
	educational	hardness of mortar	air pollution
			vicinity to the sea

OWNERSHIP	VACANCY	WRONG INTERVENTIONS
public	yes	incompatibility of previous restoration works
private	no	unsuitable allocation of new stones
		unsuitable application of new mortar

Figure 89: The criteria for mapping and identifying the decay

Assessing deterioration patterns in building materials

Figure 90: Loss of the last layer of coating and disruption of masonry at the windows edges

Figure 91: Biological growth and serious water absorption at capillary level

By just wandering around the city inside the fortifications and looking at the buildings and their condition, anyone can realise the exorbitant rate of decay(Figure 90) that almost all buildings are facing. Within the scope of the present research and in correspondence with the previous chapter, an estimation of the effect of the deterioration causes is thoroughly examined.

Firstly, there will be a brief description of the observed deterioration patterns commonly seen in the historic fabric of the surveyed buildings.

The buildings affected by the micro-climatic conditions show severe decay on the stone masonry due to their proximity with the harbour and the orientation of their facade, mainly the visual appearance of the building materials. These aesthetic variations were depended on building materials defects, microbial growth and the extrinsic factors as humidity and irradiation.[41] One of the most intrusive defect is salt efflorescence, a white superficial layer of soluble salts mostly seen at water run-off zones like water leaching gutters results in extended recession of the stone layers.

The most serious capillary water absorption was observed at the ground level of the building(Figure 91).

The aesthetic issue is not the only one, since degradation processes may cause the loss of the original stony material. Biotic factors, especially microorganisms, are among the most common sources, affecting visual aspect and surface characteristics. Microbial growth and biological compounds may have positive effects on building materials, as for example biological cleaning, biodegradation of pollutants, bioconsolidation; but also negative ones, damaging exposed surfaces (i.e. biodeterioration).[42,43]

All calcareous sandstones are prone to deterioration due to their calcite composition facing Rhodian stone is much more vulnerable to extrinsic factors like salt spray, causing loss of material, loss of its sharpness, internal loosening and weakening of mechanical resistance.

Figure 92: Granular disintegration of sandstone

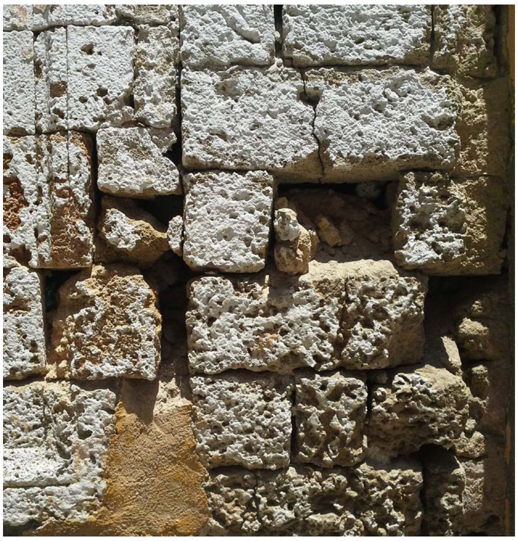


Figure 93: Honeycombing pattern

Figure 94: Case hardening of sandstone

The Rhodian highly porous calcareous sandstone shows signs of alveolar weathering pattern as the water flow in masonry leads to hard carbonate crust formation. The stone surfaces show advanced deterioration in the form of disintegrated stone granules on the lower courses under NaCI crystallisation circumstances.[32]

Porous stone in contact with less porous stone

Where porous stone is adjacent to a less porous stone, moisture movement is likely to be restricted downwards and the more porous stone may erode to a much greater depth than the surrounding one.

Another typical damage is blisters on sandstone surface caused by moisture entrapment., which produce thermal movement, and local eruptions that leave cavities.

Granular disintegration (Figure 92) results to loss of stone layers due to detachment of single mineral grains caused by soluble salts accumulation and sub-surface crystallisation of them.

Honeycombing (Figure 93) is a common phenomenon seen mostly in coastal locations that generates cavernous pitting leading to excessive deep holes in a honeycomb pattern.

In the form of contour scaling, fissures and thin cracks occur around joints leading to loss of stone surface around the joints while the stone underneath is likely to be deteriorated.

Case hardening (Figure 94) is most common decay effect on calcareous sandstone and after a prolonged period of slow deterioration affect even structural stability. More specifically, the dissolution of mineral elements and their reposition near the surface form a hardened superficial layer over the weakened stone interior.[44]

Figure 95: Loss of mortar in the joints

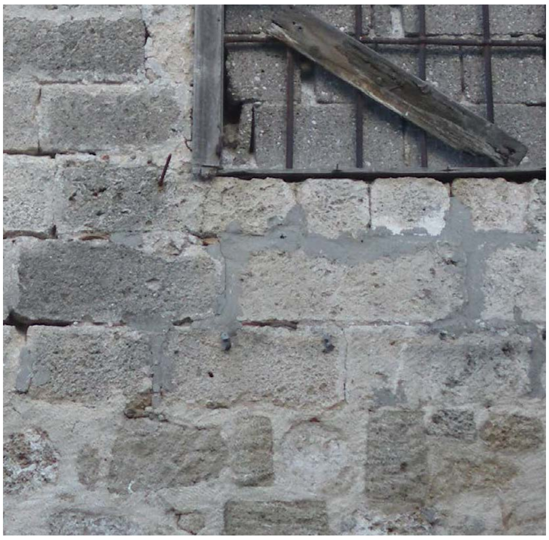


Figure 96: Hard cement mortar leading to moisture entrapment

Decay of mortar

The deterioration of the mortar is caused by the dissolution of the calcite, which leads to the accumulation and crystallization of the soluble salts and finally to the carbonation of the mortar(Figure 95).[45]

The joints in a stone masonry can be characterised ''as the pore's in one's skin" and if they are sealed by dense pointing mortar then the moisture can easily penetrate the stone and damage it ineversibly. When the decay has extended in much depth, then the disintegrated stones should be cut out and the ''holes" should be replaced with new one, just as the dentst removes the decayd tooth to prevent any more spread or infection. [46]

Hard cement mortars and its effect on the porous sandstone

Rhodian sandstone is a local biocalcarenite sandstone, which has high porosity and grain size that make it incompatible with hard cement mortars characterized by small grain sizes. Hence, re-pointing with such an inappropriately impermeable mortar will favour the decay of the adjacent more porous stone due to the moisture flowing from the less porous to the hard mortar accelerating the rate of decay. For instance, the joints that have been re-pointed with cement mortar fail as cement ages and trap moisture behind the impervious coating causing widespread water ingress(Figure 96).

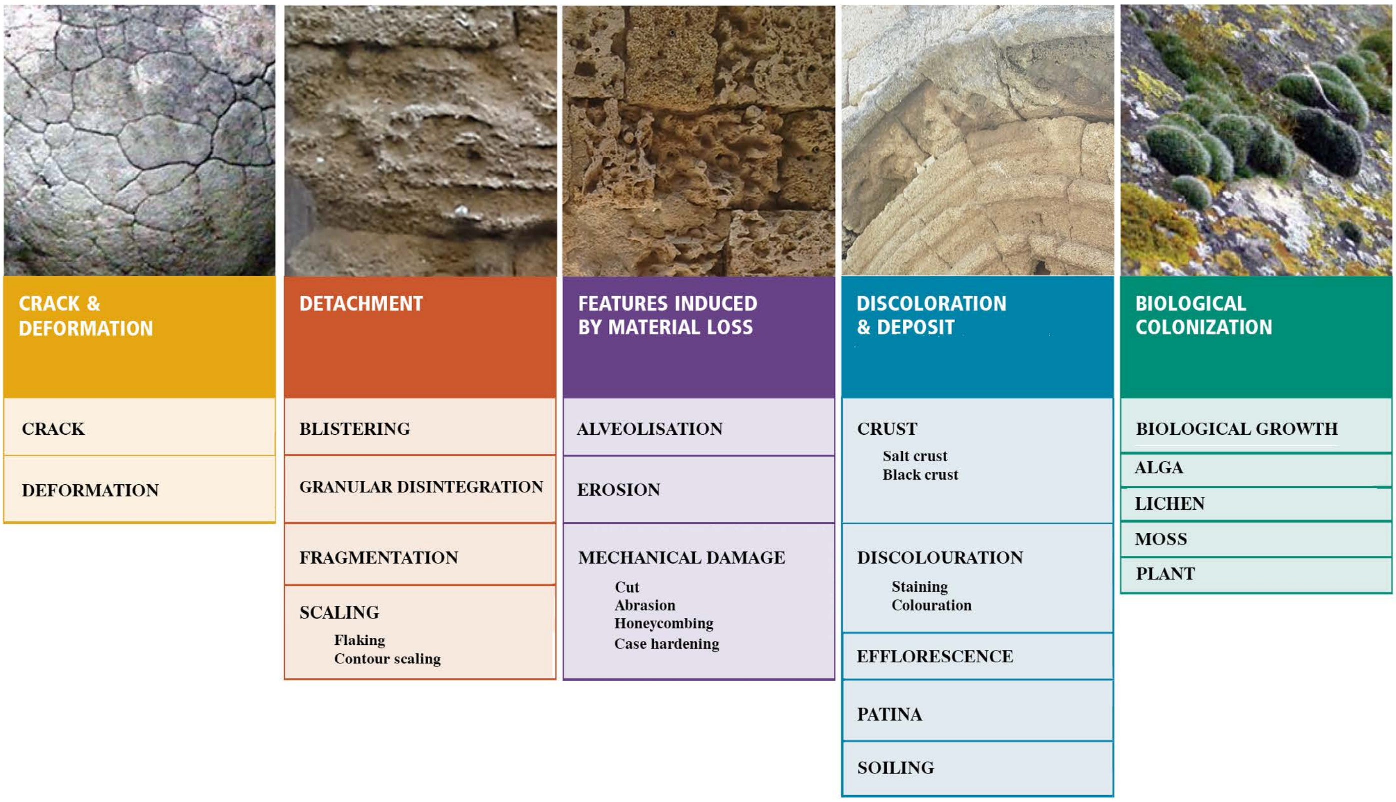


Figure 97: The deterioration patterns of Rhodian sandstone

Impact of decay on the urban built fabric

The next part of the research surveys in detail the decay properties in the case studies. Observing extensively all the facades on situ and examining the results from the two databases made it possible to apprehend the degree of deterioration and the elements that affect negatively the function of the building itself and the immediate surroundings. The main cause of decay observed in all buildings was the humidity at the capillary level increasing the rate of moisture inside the core of the stone.

The majority of the studied buildings present substantial evidence of deficiency in their structural performance leading to serious instability problems on their main facade, mainly at the stone blocks around the windows and the roof envelope, due to abandonment and lack of maintenance over the years. The main damage is loss of material, fragmentation of the stones and even collapse of some individual blocks of stones. The most extensive damages seen in the historic fabric are the disruption of the masonry, the back weathering of stone blocks adjacent to the windows, the decay of the timber lintels due to moisture and biological growth, intense cracking and blistering leaving cavities on the surface, deterioration of stone corners around the joint due to impermeable mortar and severe bedding at upper parts of the masonry.

Some others that displayed stable surfaces tended to slow deterioration with only a small number of individual blocks face extensive decay due to the hardness of the adjacent stones. [19] Severe damage is seen on the keystones and arches where stones with low strength and considerably high porosity were used. The corners of stonework are the most exposed locations of decay and the first places that facing evaporation and that’s the reason for being subject to wind-driven salt erosion. Almost 70% of the case studies demonstrates patterns of soiling, color disfiguration and black crust due to the aggressive marine environment. Although these types of decay change the visual appearance of the buildings and the architectural character of the whole area, they do not constitute an important threat to the actual fabric and can be considered as a second level decay processes.

In some cases, particularly on Kisthiniou Street and Thiseos Street it was observed an isolation of decay on stones that were placed afterwards in that position during restoration. In that case, the weaker stones located adjacent to hard stones showed extensive deterioration and sings of honeycombing due to their high porosity and their water absorption levels. These streets that belong to the Juderia settlement are the most defected from deterioration compared to the other two streets in Burgus settlement. This fact is justified by the two deterioration mechanims mentioned in Section 5 that they are thought to be the most destructive, the salt erosion and wrong interventions.

Compatible consolidation materials

Use of traditional mortars in built sandstone structures

It is known that the best repair strategy of historic buildings is the use of local materials compatible with the historic structure and thus, focusing on traditional techniques used in Rhodes is thought advisable.

Systematic applied research is needed to evaluate the compatibility of restoration mortars in simulating historic mortars. They must have microstructural and physico-chemical composition that is totally compatible with the historic structure. Accordingly the most feasible repair mortars are those using local raw materials while acquiring the necessary mechanical strength and preferably the same aesthetic effect, mechanical strength and durability. One feasible proposal is the use of the three traditional mortar types widely applied through the years in the Medieval Town. In particular, the upper part of walls and the covering of the roof are coated with the local hydraulic mortar, kourasani provide the necessary water shredding whereas on fall a coat of patelia will be applied.

However, as all building materials create major repair problems if they do not receive regular maintenance, coordinated efforts are needed to safeguard the future of them.[14]

Restoration mortars for the conservation of historic masonry

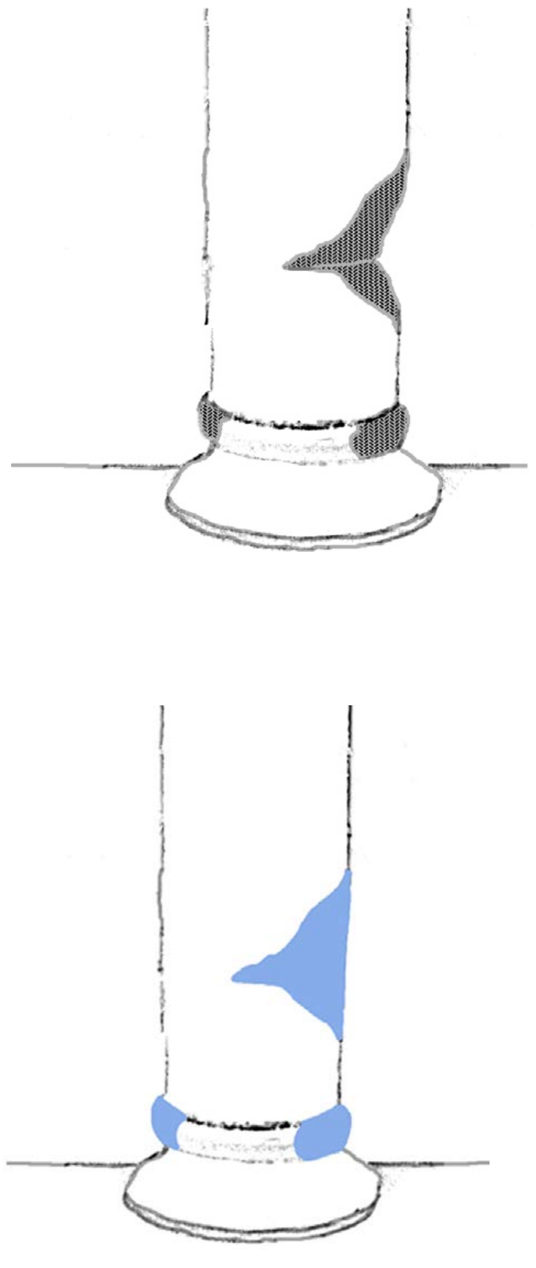


Figure 98: Sketch of a damaged column and a proposal of conservation with the application of a restoration mortar

It is known that hydraulic mortars have been in use to repair buildings since roman period. Then, in the 19th century cement mortars were established and used extensively during restoration of heritage buildings [47]. The recent generation of restoration masonry mortars tries to overcome the drawbacks of previous types, and especially the intrusive properties of Portland cement through the reintroduction of a lime based product that could satisfy the need of conservation works. The use of restorations mortars(Figure 98) has been applied in a worldwide scale for the conservation of numerous sandstone structures. Nevertheless, they are considered controversial because their performance is not evaluated enough and many questions are raised about their future compatibility with the original fabric.[48]

This type of mortar consists of formulated, dry materials with predetermined binder to aggregate ratios and sometimes additives to improve certain properties (workability, freeze or salt resistance). It is a moldable mortar that can be easily be prepared and applied on site while ''setting into place by its own adhesion to the substrate''.[47]

It is stated by many scientific articles that restoration mortars(Figure 91) should demonstrate a variety of positive characteristics from ease of application and low cost to long life expectancy of 30 years. [49,50]. In the context of Rhodes, the mortar should be adaptable to the condition and visual appearance of the stone and allows preserving as much of it.[50] Although the visual appearance of the mortar, texture and colour, does not play a significant role, it is essential for the coherent compatibility of the materials. Another advantage is to provide high breathability allowing a sufficient degree of vapour permeability and water transmission through the stone layers.

When selecting the restoration mortar, it is important to consider the physical and mechanical properties of the binder and aggregates along in terms of the interaction with the old mortar and compatibility with the stone. Every stone has different properties and requires a specialised restoration mortar mix to be designed.

Thus, these characteristics of stone should be obtained in relation to the mortar:a)surface feature, b) composition, c)mechanical strength, d)elasticity, e)porosity f)thermal expansion and g)water repellence.[51]

Moreover, several other factors can accelerate the damage process instead of arresting it. For example, the use of organic polymers in the mortar can be harmful or even cause biological growth on the stone [52].

Suffice is to refer to two experiments that has tested the efficacy of different restoration mortars as a stone repair material. The first one is the Lithomex manufactured in France, a anhydrous mixture of natural hydraulic lime and binder. It develops great comprehensive strength thanks to the early carbonation of calcium hydroxide but low sorptivity due to the presence of organic additives.[53] The other mortar is called Conserv from UK, a natural repair mortar applied mostly on sandstone. It demonstrates better performance on sorptivity due to the absence of cement substrates but lower compressive strength(Figure 99).

Although both mortars are suitable according to the regulations they present some drawbacks. For example, although weaker than sandstones, their water permeability is more complex and strongly depends on the properties of the stone(Figure 100).

Further on-site testing is required for a thorough understanding of how repair materials perform and their macro-scale problems, and especially the ones related to vapour permeability and moisture entrapment.[48]

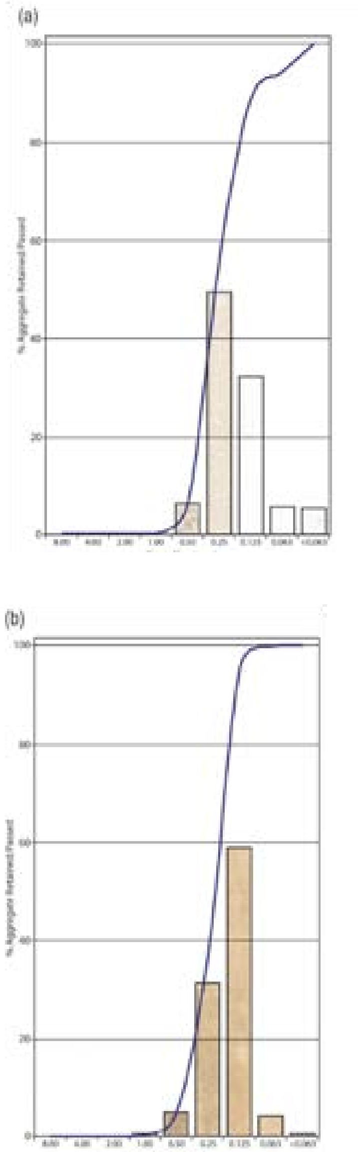


Figure 99: Particle size distributions of materials with (a) Lithomex and (b) Conserv

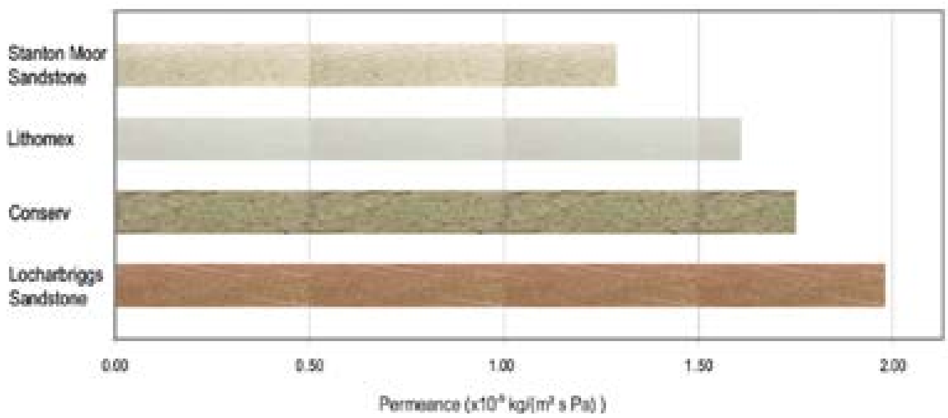


Figure 100: Permeance of restoration mortars and sandstones

Innovative stone consolidation treatments

Where traditional techniques prove inadequate, the consolidation of a monument can be achieved by the use of any modern technique for conservation and construction, the efficacy of which has been shown by scientific data and proved by experience.[4] When traditional building materials cannot provide the necessary protection from deterioration then new measures should be taken. A detailed and thorough analysis of the level of deterioration is needed through applying non-destructive techniques in situ. Following that, it is advised the use of fiber optics microscopy, infra red thermography and ultra sonic measurement to assess the environmental impact of the damp climate and to provide data regarding the physicochemical characteristics of the porous stone that is mostly affected.[54] Therefore, in order to guarantee the durability of original materials and long lasting effect of the consolidants over the distant future, innovative consolidating products have been studied thoroughly and improved over the last 50 years. As the main destructive factor of the performance of building materials is the appearance of condensed water, more actions should be taken to overcome this problem. Nowadays, a new way for protecting the outdoor materials from natural weathering is the application of water-repellent polymer coating.[35]

The development of new techniques for the study of surfaces with nanotechnology add new possibilities for the conservation of cultural heritage. In the last decade nanotechnology [54,55,56] has been developed to produce new surface consolidating agents to resolve the aesthetical problems and to improve the conservation of building stones over time.[19] The competitive features of nanomaterials to conventional materials are their enhanced durability, efficacy, compatibility, lower cost and easy application process. However the potentiality of these materials has not been tested extensively in outdoor environment and many experiments have to evaluate their durability.[20]

Silicone technology has been on the conservation field for decades now presenting efficient results. It is based on polymers with outstanding water repellency that do not block the surface's micro-porosity allowing the building materials to breathe. They provide a better transmission of moisture levels within the layers of the material without being affected by temperature fluctuations and climatic conditions. Although the visual aspect do not play a significant role for its treatment, these products implement very low water absorption levels over time keeping that way the original aesthetic appearance. Some of the main advantages of using this type of consolidation treatment are:

- Maximum reduction of water uptake
- Permeability and breathability
- Resistance to salt efflorescence
- No alteration in surface appearance
- Durability and long lasting efficacy
- Reduced maintenance costs
- Thermal conductivity stability
- Environmental compatibility

The main disadvantage is the fact that the application of such coating is irreversible and a wrong selection of silicone can damage inevitbly the building materials.[35]

Consolidation effectiveness is influenced by a variety of parameters and above all by the phisico-chemical compatibility of the consolidant, the severity of the climate,[58] the environment where it will be applied together with on site application procedure.[59]

Previous attempts for consolidation of Rhodian sandstone applied organic materials but the results were not desirable due to low performance. Although inorganic materials seem to have some advantages such as good durability and high compatibility with the carbonate matrices, they suffer from low solubility and usually give insufficient penetration further hampered by a scarcely cohesive effect.[60]

Figure 101: Lecce stone

Figure 102: Use of Lecce stone for Baroque ornamental monuments

The following is extended only to give a brief indication of the effect of three different treatments in porous stones with similar properties.

The first case study is the conservation treatment with ethyl silicate on Lecce stone(Figure 101) in southern Italy. Historic buildings from the 1900's found to deteriorate in great depth due to the low-durability of the stone. The heavy recession on the surface and the typical alveolisation were treated with TEOS and it proved effective and harmless. The high porosity accessible to water and a low degree of cementation are similar to the physical properties of the Rhodian sandstone and the experience gained from this consolidation can be considered as e reference model for the soft porous Rhodian sandstone.

TEOS(tetra-ethyl-ortho-silicate) acts as a strengthener on silicate building materials as Lecce porous stone(Figure 102) and presented good compatibility behaviour on it. Applied by brushing thought to make the stone more resistant to degradation caused by salt crystallisation. The higher effectiveness of this product is ascribed to the deep penetration of the particles' dispersion 10 and the formation of Si-O-Si bonds in the stone pores providing the necessary stability and durability towards alveolar weathering.[59] In order to guarantee the sufficient depth penetration into the pores structure an alkyl-alkoxy silane was also added improving the water capillary absorption and vapour permeability of the stone.

Thanks to the similarity between the Baroque decorated monuments in Lecce town centre(Figure 95) and the ornamented architectural features of the Hospitallier period in Rhodes, the stone itself and the state of decay, the approach applied here could be served as a role model for conservation practices in Rhodes.

Figure 103: Globigerina Limestone

Figure 104: Deterioration of Globigerina Limestone

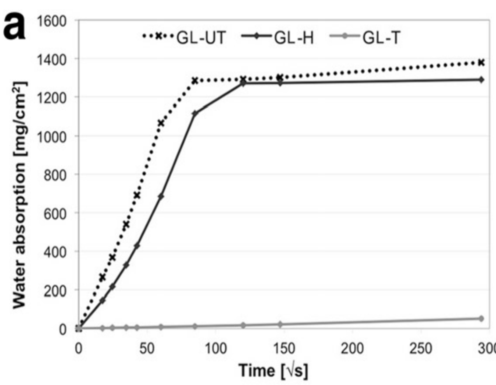


Figure 105: Sorptivity and total water absorption of Globigerina Limestone before and after treatment, HAP treated and TEOS

Another marine environment with considerable damage on its historic fabric is the Maltese Islands with a variety of monuments made by the local Globigerina Limestone(Figure 103,104). The alveolar weathering observed on the building stone along with salt crystallisation are the primary deterioration causes of the building materials. More specifically about the Globigerina Limestone, it is a soft and malleable with a pale cream – yellow colour. This type of stone is fine grained, very porous with a relatively low tensile strength and high water absorption levels.[61]

The selected consolidation treatment for this stone is an inorganic consolidant designed to form hydroxyapatite (HAP) in the substrate.[59] The HAP approach manages to improve the mechanical strength in less than 48 hours while increasing significantly the tensile strength to 22% of its initial strength. The efficient consolidating effect is more appealing thanks to the better bonding seen between the grains. The HAP efficacy can be also contributed to the fact that there is no actually alteration in total open porosity and a temporary hydrophobicity is enhanced in the stone core(Figure 105).

The final case study is focused on applying nanoparticicles on Carrara marble, a carbonate stone and in particular on a comparison between the Ca-alkoxide consolidants of NANOMATCH project to the commercial CaLOSiL. This stone presents same deterioration patterns due to urban built environment, the vehicular traffic and air pollution and it was suffice to analyse the effect of the two different products. Both products aim to the consolidation of calcite-based matrices by deposition of calcium carbonate as it is seen on the Figure .

NANOMATCH can be described as a surface homogeneous microcrystalline layer depending every time on each stones' properties but less compact whereas, on the other hand, CaLoSiL appears a standard thick layer on the surface of the stones. Another disadvantage of the typical manufactured CaLoSil product it the alteration of the aesthetic aspect of the stone adding a discontinuous brownish colour on the outmost surface mostly seen in the Carrara marble. On the other hand, NANOMATCH is confirmed not to modify the visual appearance of the stones when appropriately applied and also to be distributed randomly on the pores' structure.[62]

Concerning NANOMATCH performance, we have to mention that after this treatment it was occurred increase in cohesion in deeper layers and decrease in the amount of material peeled from the surface. On the contrary, CaLoSiL product demonstrated ineffective cohesive effect on the surface of the stone leading to detachment of the surface layers.

After discussed all these case studies to construct a coherent opinion on suitable conservation treatments, some general conclusions have been shaped and presented now regarding the Rhodian stone:

- TEOS product, a widespread consolidant all over the world has proven its high efficacy thanks to the presence of quartzitic fractions and could be safe solution for the enhancement of the mechanical properties of the Rhodian sandstone. Although it is observed a slight alteration on water transport due to the temporary hydrophobic effect of ethoxy groups, it seems a valuable and comprehensive product.
- the new innovative approach with HAP treatment presents comparable and even desirable results than TEOS in a much shorter time thanks to the higher compatibility with the substrate. However, it has not been tested enough to guarantee the preferred results for the Rhodian sandstone.
- both NANOMATCH and CaLoSiL could be considered efficient consolidants for Rhodian stone as it is seen for the application on the similar Carrara stone without changing the visual characteristics of the stone.

Therefore, having in mind all the advantages and disadvantages of such approaches, the consolidation effectiveness of two inorganic nanoparticles dispersions was evaluated for Rhodian sandstone(Figure 106,107). Non-destructive techniques employed on selected representative locations in the Medieval Town of Rhodes showed the performance of two consolidants (Rhodorsil RC70 and Bluesil). The consolidation treatment aims at conserving the coherence of the grains and improving the compressive strength. As the Rhodian sandstone presents high porosity and water absorbency leading to alveolar weathering and hard carbonate crust formation, the use of an ethyl silicate consolidant (Rhodorsil RC70) that is already widely a conservation treatment in Rhodes, seems to be an acceptable solution.

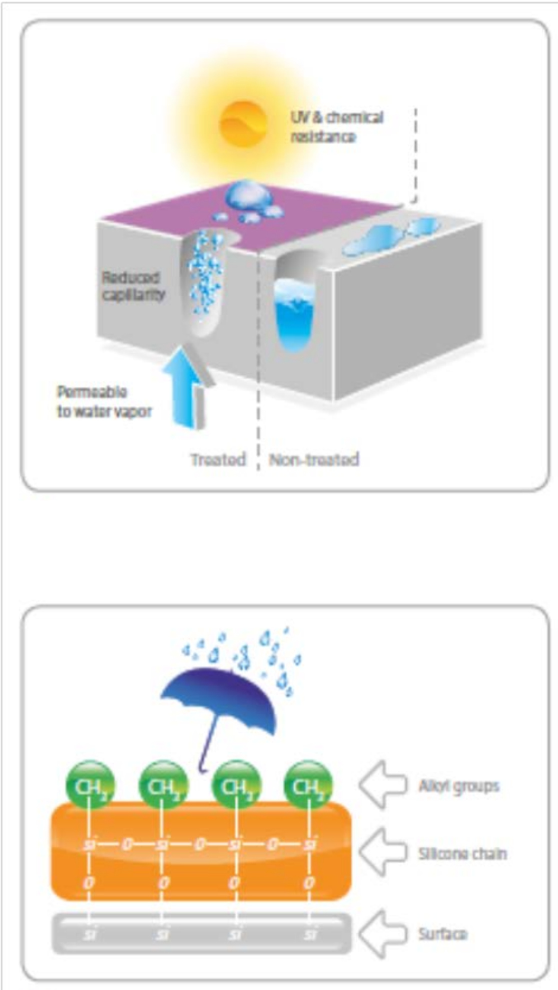


Figure 106: Water repellency of silicone products

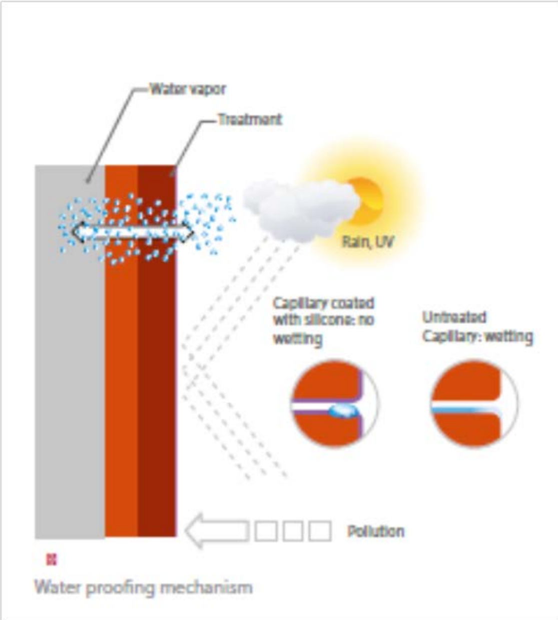


Figure 107: Water proofing mechanism of inorganic nanoparticles

RHODORSIL™ SILICONES

Rhodorsil consolidant is a solution of organic silicates diluted in white spirit suitable for porous inorganic materials. It is a colourless liquid with silicone content 70% and consumption 0.2-2.2 I /m2 and it does not contain any hydrophobing additives.[63] Application over years has shown great compatibility with the Rhodian sandstone while preventing discoloration and radiation absorption. Moreover, it achieves the desirable water vapour permeability as it is creates an amorphous coating of the stones that covers uniformly the porous grains without sealing them. It can be applied either with a flat brush or a roller for small surface areas or by an air spray gun for extended surfaces.

BLUESIL™ SILICONES

The second silicate product is Bluesil and its main concept is to form a water-proof barrier while maintaining the surface's breathability(Figure 108). In particular, the silicone bond creates a monomolecular layer inside the capillaries providing the necessary water-proof protection that covers uniformly the porous grains without sealing them and altering the composition of the materials. It present excellent water repellency of silicone resins and high vapour permeability allowing the material to breathe and let water vapour escape without creating any damage.

Bluesil™ can guarantee long lasting protection and offer significant benefits as:

- Resistance to weathering
- Prevent water absorption
- Beading effect
- Outstanding resistance to ageing agents
- Very good resistance to acid rains
- High protection against efflorescence and algal growth
- High durability and breathability
- Reduced restoration and maintenance costs
- Energy cost saving

The application process is easy and simple choosing from three options, with a brush, dipping or by spraying. The water repellent is diluted before application to provide accurate results and its performance depends on the quantity of material applied to the surface, the absorption capacity of the material and its porosity.[35]

Figure 108: Component of Bluesil product

Recommendations

General guidelines of the conservation programme in the Medieval Town of Rhodes

Greek Ephorate of Monuments in the Medieval Town of Rhodes is an executive agency of the Greek Government and is charged with safeguarding its remarkable historic environment. However, given the current economic situation in Greece a new conservation plan is needed and requires multi criteria analysis method of prioritizing interventions. It should concentrate on cost-effective and feasible proposals, a creation of a consistent framework for any future interventions and specification of the authorship of the conservation actions.

The objectives of the conservation plan are:

- coordinate action to conserve and enhance the built fabric of Rhodes and promote balanced adaptations to the current needs through a programme of financial assistance
- preserve and reveal the aesthetic and historic value of buildings:
- assess the damages on the built fabric and the identify coordinated system of proper solutions to preserve it
- develop a set of coordinated and approved policies and consultation with the local planning authority
- maximise stakeholder engagement in the planning and implementation process
- support economic diversity and growth
- increase public awareness in the conservation and restoration process by developing learning and outreach programmes
- engender a sense of custodianship and secure long term support from individuals and organisations
- revitalize the entire residential complex with new households, either by restoring the ruined ones or rebuilding them according to their original architectural style
- setting specific conditions, building restrictions and specific land uses
- monitor constantly the effectiveness of the implementation of the conservation plan[64,65]

The creation of a strategic management plan needs the specialist technical and scientific advice from all related fields including architects, structural engineers, craftsmen, archaeologists to identify and assess the level of urgent repair to conserve its functional, structural and cultural significance. The proposed conservation plan needs to be effectively maintained and efficiently managed to provide the desirable results without altering the architectural and historical character of the Medieval Town of Rhodes.

Conservation strategy

When choosing the appropriate conservation strategy we must consider the impact of the selected intervention on the visual image of a historical centre. Bearing in mind the ''ethics of conservation'', it is essential to understand how the buildings developed over the years, their current condition, materiality and construction process. Then, in order to propose conservation measures, the repair strategy should be reversible, focused on retaining the maximum amount of original building material and respect the character of buildings by prohibiting unwanted modifications.[18]

Therefore, the proposed repair strategy for the historic building in the Medieval Town of Rhodes is based on using materials compatible with the original fabric in order to preserve the existing state, consolidate it with the innovative products that was mentioned on section 6 to prevent any unexpected deterioration. The use of local materials and building techniques together with maintenance of masonry and repair of the damaged members secures the stability and future development of buildings.

More specifically about Rhodian sandstone which is the most vulnerable building material in the conservation area, extensive actions are required. The most important conservation needs of the sandstone are consolidation treatment, surface water protection and the replacement of weathering and structural stones with new suitable ones. The selection of new stones should be made according to geological maps and taken preferably from the same quarry not only for the aesthetical conservation treatment of the masonry but also for the structural function of the building. In that framework, the stone blocks will perform the same thermal expansion and moisture efficiency, water permeability, resilience to salt while having similar mechanical and physical characteristics to the older ones. Other possible stone treatments include indentation or cutting out damaged areas of stone susceptible to salt efflorescence and plastic repairs. Plastic repair as we saw at Section 6 about restoration mortars is complex process that needs extensive experience to determine the aggregate mix and it is only applied on very small areas indentation will cause major loss of adjoining stone.[18]

Active management plan

Rhodes presents a rare uniform historic image, similar to very few places like Malta and Lecce that needs to be preserved intact at all costs. An innovative and interdisciplinary approach for monitoring the built cultural heritage is recommended to target feasible solutions and to provide local authorities with comprehensive and integrated policies.[54] In particular, Authorities need to move Towards a comprehensive conservation management of the monumental complex of the Medieval Town of Rhodes, starting from an integrated information and decision plan similar to ''HERMES" project but more focused on the deterioration patterns and causes of building materials. This will produce a strategic decision making tool based on a database and a novel computational algorithm that will capture the general condition of a building, document the distribution pattern of weathering and interpret them automatically to that will demonstrate the general condition of the building, document the distribution pattern of the weathering forms and interpret them automatically to recommend compatible conservation interventions, as it is now requested by the Greek Ephorate. This digitised mapping method can minimise the rate of decay within the conservation area by defining the criteria: vicinity to the sea, location within the conservation area, physical condition of the building (poor, moderate, good), vacancy, ownership, type of use, type of decay pattern (salt efflorescence, living organisms etc), environmental factors (humidity, moisture, wind, temperature, previous interventions and social impact. This platform will be open and ready-to-use information for the local stakeholders and everyone interested in the protection of the built fabric of Rhodes.

An outline of this project deliverables is being defined now:

- identify the damage and its causes
- describe and map the deterioration patterns
- interpret the collected information according to the classification table
- define the appropriate conservation treatments and classify the expected the conservation actions.[66]

Selection of this data will lead to a scientific interpretation of the information suggesting the necessary interventions as:

- use of new compatible stones with the same mechanical properties like the old ones
- integration of stone cavities
- redressing joints with compatible restoration mortars
- selection of appropriate consolidants to protect disaggregated stoned from extensive alveolar weathering

The combination of this two-dimensioned approach will monitor the behaviour of the consolidant, its interaction with the original material and its substrate and at last evaluate the general resulting performance

Social involvement- Economy scale

The historic environment of Rhodes is a simultaneously an alive urban space with an outstanding architectural and cultural significance which today faces many changes and damages. Managing change within the historic environment can be difficult enough for an individual owner to choose wisely the necessary conservation treatment and to get repairs organised.[67] The existence of a multi-disciplinary manual for conservation inside the conservation area will be not only beneficial and educational but also a stimulus for all owners to do things correctly.

It is recommended that the Greek Ephorate of the Medieval Town of Rhodes and the Municipality of Rhodes cooperate to create a constructive conservation programme that everybody should be advised about before taking any actual remedies. The creation of such strategic management plan needs the professional guidance of architects specialists in conservation of historic building and all the technical and scientific advice from related fields such as structural engineers, craftsmen, archaeologists to identify and assess the level of disintegration. It is based on efficient communication across a wide spectrum of stakeholders to establish effective partnerships so no organisation or individual will be left with no resources.[68]

Together with the Conservation Management Plan it should be administered a Conservation Funding Programme to ensure the continuity of the historic fabric of Rhodes and to help owners conserve their historic building. This successful example is seen in Edinburgh World Heritage Site where funds were provided to property owners either in the form of Repayable Grants for private residential and commercial owners or as Project Funding for public organisations.[69,70] The same attempt could also be delivered in Rhodes to target funds and enhance the city's heritage.

If centrally coordinated and even procured, all these efforts can lead to economies of scale that will reduce the cost of treatments thanks to mass orders in implementing specified consolidants , materials or even contracting stone masons. [71] We must keep also in mind that by using the same materials all over the area, like stone from the same quarry with the same texture, will achieve the same visual appearance and the aesthetic impact on a historic city. In conclusion, as part of the social involvement in the conservation process it is encouraged for individual owners to attend traditional technique workshops. A wide range of educational and professional courses could provide advice, guidance and the adequate traditional skills through seminars and practical working sessions for every building owner. For example, homeowners will be handed all the necessary tools to assess their building 's condition and learn how to carry out correct repairs to maintain successfully their historic buildings.[72]

By that way, they can promote the correct traditional consolidation techniques and how effective they are in improving the aesthetical and functional performance of buildings in such a historic surrounding. This will raise awareness that anyone can gain expertise in local materials and traditional skills, as also realise their meaning.

Strategic planning of conservation

Building

Environment

Documentation of decay

Evaluation of environmental conditions

Maintenance strategy

Repair interventions

Selection of compatible restoration materials

Management of cultural significance

Strategic management of conservation plan

Conclusion

The Medieval Town of Rhodes hosts a variety of historical buildings constructed by several civilisations through years. Nowadays all these significant heritage buildings and their cultural and visual features face serious deterioration due to various effects as it is mentioned in Section 4.

Understanding traditional materials and building techniques, recording and indexing of the historic buildings pathology will lead naturally to appropriate restoration materials compatible with the structure as a whole. The identification of the deterioration patterns of the Rhodian sandstone is fundamental to design retrofitting and restoration procedures. In a major historic building stock like Rhodes, the preservation of the historic fabric is a major research goal that needs a rational and quantitative evaluation.

The proposed conservation management plan focuses on enhancing the architectural and cultural value of the this impeccable surrounding with the development of novel protective techniques and a multi-criteria model that will document the architectural features and pathology of buildings and propose suiltable consolidation treatments. This hollistic conservation plan refers to information acquisition, data processing, numerical modeling, hierarch of interventions and decision-making conservation plan.

Examining some comprehensive and effective conservation management plans together with specified consolidation treatments in other countries it was enlightening on developing the know-how in Rhodes. Comparing international examples of conservation treatments and understanding what other countries perceive as the best conservation strategy, how they implement it and finally its impact on the historic environment, it was considered valuable and decisive from the beginning of this paper.

However, we have to keep in mind that the administrative and technical culture in Greece differs from the conservation guidelines in other places and attention to the Greek regulatory framework should be drawn. In particular, in Rhodes the general conservation principle is the preservation of the historic buildings as they were originally constructed, allowing for any necessary reinforcements and consolidation but prohibiting modifications to its structure that alter the visual aspect of the buildings.

The prevention of deterioration of building materials and damages on the historic fabric will certainly offer significant economic and cultural benefits to society. The implementantion of this conservation plan will serve as catalyst or even trigger economic development in the area able to save funds for future conservation actions. By involving a wide cros-section of the community, many people are going be aware of the problem and its solution, support this effort and therefore ensure the protection and conservation of heritage in Rhodes. The local community input can significantly change the perspective of conservation in this area and create the desirable effect on the city.

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Appendix