Where Past Meets the Future: New Mortar Solutions for Conservation of the Buildings of Medieval Rhodes

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Lede: The interaction between the historical context of the medieval town of Rhodes and contemporary demands shapes the requirements for building strategies and materials, that could support sustainable solutions, particularly those applicable to conservation mortars

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The history of the building is almost as old as humankind. The research will explore the building tradition of Rhodes Island in the Dodecanese Islands complex placed in the southeast Mediterranean area, from the 6th century (Byzantine Empire) until the early XX century (Italian Occupation of Rhodes). The objective is to find out how the societies that inhabited this area throughout history, through their habits and traditions, impacted the building strategies and materials. The specific focus is on mortar as a building material and its technological development.

In the past couple of decades, the emission of CO2 significantly increased, and we have become aware of the consequences this phenomenon carries with it. One of the biggest contaminators is the building industry. Many strategies are currently being developed to reduce CO2 emissions and preserve energy resources. Some studies have shown that the use of built cultural heritage has the potential for a more sustainable building solution. However, the CH buildings require specific treatment, following the principles and guidelines. Also, many of the CH buildings don't fit today's requirements regarding energy consumption levels. The traditional materials have proven durable, standing the test of time, through centuries. Mortars are a good tool for upgrading the energy levels of heritage buildings because their discrete appearance aligns with the conservation philosophy of minimal intervention. Through the analysis of historic mortars, the research strives to find durable solutions used in the past. With the mixing of traditional and innovative materials, we go one step further to satisfy the requirements of today, as the cultures of the past did long before us. It is about what the past can do for the future and what can the future do for the past.

1. Introduction

1.1 Scope and Motivation

The research explores interdisciplinary conservation aspects through the adaptive reuse of the architectural heritage of the medieval town of Rhodes. Rhodes is the largest island that belongs to the Dodecanese Islands, a group of islands in the southeast Mediterranean Sea. This area is characterized by the intertwined building traditions of its inhabitants through the centuries. Throughout its history, Rhodes was a significant territory, initially belonging to the Byzantine Empire, later falling under the governance of the Knights Hospitallers, occupied by the Ottomans, and lastly by the Italians. In the second part of the XX century, it became part of today's Greece. Each of the cultures mentioned above left an imprint on their building tradition that affected the construction of the area. The presence of various architectural styles and types of construction offers an incredible opportunity to explore changes in building strategies and the use of materials.

The focus, however, will be on mortars, their use, and the change of their properties. The research on traditional mortar technologies aims to provide significant insights into the composition and materials used; this knowledge, if applied to contemporary manufacturing, could contribute to sustainability. Mortars have a significant role in masonry structures. The compatibility of the physical, chemical, and mechanical properties of mortars and units is a factor that affects the durability and overall value of a historic structure. By comparing and evaluating mortar's physical and chemical properties, we can track the development of technological solutions.

We admire architectural heritage for its beauty, longevity, and resilience, despite the nature of the surrounding environment. A significant role in the long-lasting service life of historical buildings lies in the choice of materials used as well as in the builders' skills. The durability factor casts light on historic buildings as a solution for new sustainable building strategies. With adaptive reuse and preservation of historic buildings, we preserve the energy already embedded in the building, save energy resources, and avoid significant CO2 emissions. However, we are aware that historic buildings may not meet the requirements of today's needs, facing problems with thermal insulation, level of air infiltration, and significant energy losses. Mortars hold the potential to be a valuable tool regarding the improvement of the properties of historic buildings. According to the principle of the minimal intervention conservation philosophy, mortars present a valuable tool to implement the materials that may contribute to enhancing a building's properties. This research seeks new technologies that could be implemented in traditional mortar recipes that will enhance the performance of the heritage building and lower energy losses.

Therefore, alongside the architectural and construction history and conservation guidelines and principles, the researcher explores aspects of chemistry, biology, material sciences, building sciences, geology, and soils. This range of multidisciplinary approaches stands out for the groundbreaking nature of the techniques and the type of material selected for analysis. These different views are essential to gaining a holistic understanding of the samples since each of the techniques provides only a partial picture of the comprehensive mortar characterization. This research seeks to improve the existing knowledge of materials that could be helpful for our present and greener horizons. Thus, through an analysis of traditional mortar technologies in combination with contemporary solutions, we are one step closer to the successful, sustainable development of buildings and the conservation technology of the future.

1.2 Development of the Medieval Town of Rhodes

The ancient Rhodians established the town of Rhodes in 408 BC. Since then, the city has changed significantly, becoming one of the most alluring medieval towns and examples of military architecture. The town developed rather quickly because of two significant factors: progressive urban planning - a "Hippodamean" urban matrix, where all the streets were organized according to the grid plan, and its strategic location, at the crossroads of the Mediterranean's ancient maritime routes (Manoussou-Ntella, 2017).

The development of the Medieval town of Rhodes started in the 7th century AD when Rhodes became a part of the Byzantine Empire. The walls of the new fortification were built on remains of the ancient city, meant to protect the town from the Arab naval incursion. With the arrival of the Knights of the St John of Jerusalem, known as Knights Hospitallers, in 1309AD, Rhodes became a religious center (Zarifis et al., 1989). During their rule, until 1522 AD, the city expanded, and the fortification was significantly improved (Manoussou-Ntella, 2017).

The most significant building activity during the Hospitallers period was from 1480-1481 after the first, unsuccessful siege of the Ottomans followed by a strong earthquake with continuous shocks that caused significant damage. The Grand Masters' palace was damaged as well as the great towers by the harbor. The churches were leveled with the ground, and buildings that survived needed to be rebuilt due to severe damage. The severe damage required intensive building activity. Under the rule of the grand masters Pierre d'Aubsson, Emery d'Amboise, and Fabrizio del Carreto, radical alterations of the buildings were done, excluding the most important ones that kept their original shape. However, it was not long before the medieval town suffered destruction. In 1522, after their second siege, the Ottomans occupied the city (Zarifis et al., 1989). During these times, there were no significant changes in the appearance of the medieval town, not until 1856, when a vast explosion destroyed the church of St. John and damaged the surrounding. On the remains of the church, a school in neoclassical style was erected. Overall, during the Ottoman rule, many houses were converted to fit the Ottoman way of living, and churches were converted to mosques. In that sense, they practiced what we call today adaptive reuse. The Greek people who previously inhabited the town were exiled. They formed *Marassia* neighborhoods in the "suburbs". The neighborhoods were concentrated around old Orthodox churches.

In 1912, Italians occupied the island of Rhodes. Their rule lasted until the German occupation of Rhodes in 1943. They started intensive restoration of the monuments of Rhodes. Their intervention included reshaping the town including demolition of certain buildings in the area.

The biggest change in the building technology of this region happened throughout this period. They were impressed by the town's architectural styles, dominated by Western European-style buildings that had seen little change during Turkish rule. Influenced by 19th-century romanticism, there was a strong belief in preserving medieval landmarks. They were keen on removing any additions or alterations that didn't belong to the original structure, discounting the preservation of authenticity (Kollias, 2001).

2. Building Tradition in the Medieval Town of Rhodes

In some regions, like the Dodecanese islands, where the island of Rhodes belongs, the cultures from different parts of the Mediterranean intertwined. Here, we face the abundance

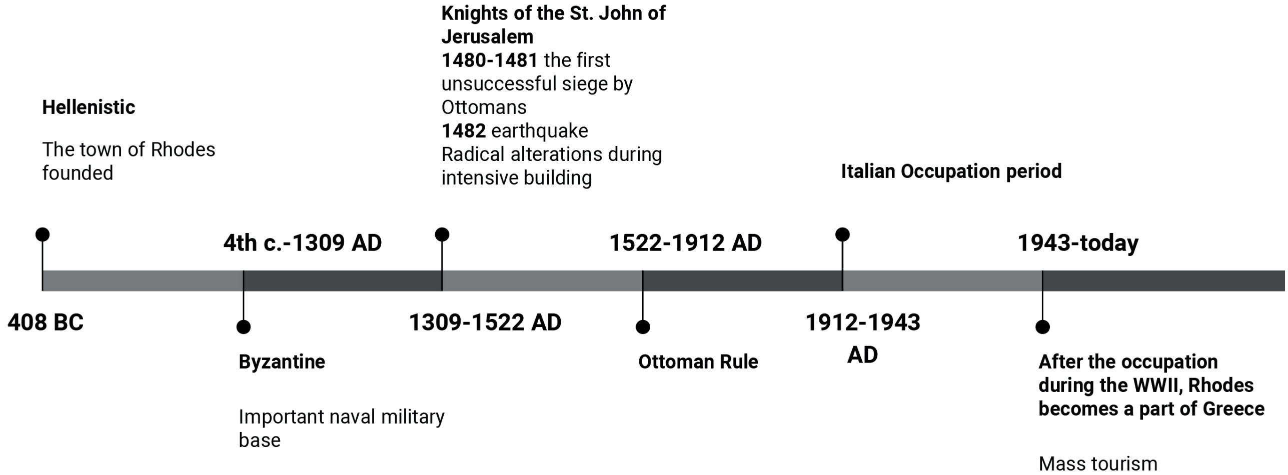

Figure 1: Historical Survey of the Medieval Town of Rhodes

of influences from classical and ancient architecture towards Gothic, Balkan, and Oriental traditional architecture, later adopting the neoclassical elements. The clash of Eastern and Western tradition and innovation made this region a fruitful area to explore the development of building technology through the centuries. Still, these cultural monuments require specific maintenance.

The building activity would be intensive only after major destruction, such as one caused by a siege or an earthquake. Usually, the typical practice was re-using the existing structure, incorporating the whole sections of the old buildings into a new one, or simply acquiring building materials, such as stone units (Zarifis et al., 1989).

In the Early Byzantine and Middle Byzantine periods, with the uprising of Christianity in this area, the building materials extraction was from the structures of the ancient Hellenistic city. The units were processed minimally to fit to improve the joints' quality, usually in thickness 0.05 – 0.1m closed with lime mortar. The skillfully crafted structures appeared as an ashlar masonry structure (Kollias, 1998).

From the early Christian period to the end of Ottoman rule, buildings were typically constructed using ashlar masonry. In the Early Christian period, stone was recycled often and processed to improve joint quality. Plaster became an important adhesive material for wall construction during this time. The joints were filled with lime mortar, with a thickness of 0.05-0.1m. Structural walls were of great thickness, from 0.8m thick reaching 3m to 3.20m in fortifications, consisting of a three-layered structure with two parallel outer walls and an inner layer of clay. The two external walls were ashlar masonry with an internal layer of clay stones and clay. Sometimes, the external walls were connected with a transversal stone block for reinforcement (Kollias, 1998).

Forts and significant buildings in the medieval city of Rhodes, especially those from the period of the Knights, were built using lime mortar, giving them a more rustic appearance. Plaster was a mixture of lime, sand, or other materials. During the time of the Knights Hospitallers (14th century), fortifications were improved and extended with additional features. They continued to reuse materials from the remains of the ancient city, using stone blocks that were initially very large, 1.5 in width and 0.5m in height. In the 15th century, the tone blocks became significantly smaller not exceeding 0.3-0.35m with straight horizontal and vertical joints. The joints were covered with a layer of irregular rendering mortar, about 2-3cm thick. At the end of the 15th century, the structures had precisely cut stone blocks with very thin joins that were very hard to distinguish. This way of building became popular, and it started to appear both in sacral and secular buildings. Kollias points out that this way of building services from the ancient Greek tradition of the Hellenistic period. With the arrival of the Ottoman Empire to this area in 1522, building ashlar masonry structures with Rhodos' sandstone continued (Kollias, 1998)

In the period of the Knights Hospitallers, the stone was quarried from the bedrock of the moat of the town. The other source was the quarries formed in the middle of the town. Across the 15th and 16th centuries, the quarries were opened in the other parts of the island in Kosnikinou and Malona (Kollias, 1998) .

The type of mortar mainly used for building was lime-rich or a mix of lime and pozzolanic material. The limestone for the production of mortar was quarried from the neighborhood islands of Nussyros and Cos, where it can still be found in abundance. The mortar produced was extremely strong and used in the construction of vaults and unflustered stone faces. However, limestone was only used as a building material to build constructive elements in the period of Italian Occupation in 1912. In Rhodes, it was used in the areas

Figure 2: Traditional masonry structure from the Hospitallers' period

where it was abundant (Kollias, 1998). From the sources, we can see that stone was quarried from places in the vicinity of the structure being improved or built. This allows immediate access to the material needed, eliminating the need for transportation, which would require more time and resources. However, with the increase in building materials and more ambitious projects, the immediate resources may be insufficient. That would lead to the opening of new quarries where the building material could be found in abundance. The lime mortar mixed with brick dust – kourassani used for waterproofing the roofs (Kollias, 2001). Even since antiquity, kourassani served as an exceptional water-resistant material for protecting domes, flat roofs, and the inner linings of water tanks.

All up until the arrival of the Italians, the main building materials used were traditional materials such as calcareous sandstone for units and mortars based on lime (reference). During the Italian occupation, much reconstruction and restoration was done in the Medieval town of Rhodes. Italians were the first who bring cement to the island, fully understanding its potential for various building purposes, including the imitation of the stone surfaces or reinforcement of the ancient structures. Nevertheless, their lack of knowledge of the compatibility of materials during restoration works led to long-term problems in the historic structures. In the years after, in the 1980s and later when the conservation works of the Rhodes started, the problems of the previous interventions occurred. However, the choice of material used was incompatible with the original materials (Kollias, 2001).

3. Sustainability and Cultural Heritage

Vitruvius described how the "old men" needed to shelter themselves - it all started with digging caves in the mountain slopes or creating simple structures of mud and branches. By observing others' shelters and with the addition of new elements, their shelters gradually improved. He points out:

Figure 3: Neoclassical school built during the period of Ottoman rule

"And since they were of an imitative and teachable nature, they would daily point out to each other the results of their building, boasting of the novelties in it; and thus, with their natural gifts sharpened by emulation, their standards improved daily" (Pollio, 1914).

Since then many things have changed, but still, we strive to surpass ourselves on a daily level. The building technology level reaches sky-high today, soon to leave Earth's stratosphere and move on to some other, more challenging places. However, at this moment, the Earth is home to more than 8 billion people (World Population Clock, n.d.), and this number continues to grow exponentially, so we have to focus on our future here. With this many inhabitants, the building requirements are high. The production on a massive scale causes significant consumption of natural resources, and the processes of production, usage, and disposal of buildings severely harm the environment.

The intention is to abstain from the well-known figures of annual CO2 emissions and energy losses. Instead, the focus will be on solutions and strategies to safeguard our environment and pave the path for a sustainable future through the use of CH buildings. Current research establishes the environmental benefits of the adaptive reuse of heritage. Studies on individual buildings find significant reductions in energy consumption and released CO2 and other greenhouse gas emissions, fossil fuel consumption, and material use. The main driver of environmental benefits in the literature is "embodied energy" - the energy built in buildings and materials. The durability of the material and the structure overall significantly affects the embodied energy. Heritage buildings have proven more durable, with a lifespan often longer than 100-150 years, when compared to the contemporary ones of 40-60 years. Traditional building materials are long-lasting and possible to repair. With regular and proper maintenance, they will require less reparation, which will also affect the embodied energy of the material and the whole building. (Wong & Sivaraman 2011 as cited in Judson, 2012).

Since the 1990s, life cycle assessment (LCA) approaches have been used in the building and construction industry to evaluate a structure's environmental performance. This performance is measured in terms of material use, energy consumption, and environmental impacts over the building's lifetime. This process is frequently applied to assist with environmental sustainability decision-making. Compared to many other methods, life cycle assessment (LCA) has the significant potential benefits of being able to quantify impacts,

Figure 4: Imitation of the sandstone surface on a building from the Italian Occupation period

including energy embodied in buildings and environmental impacts associated with building life cycle stages. It can also determine when and how to upgrade buildings to optimize the environmental outcome. This includes issues of longevity, obsolescence, use-efficiency, and related concerns in addition to the balance of embodied and operational energy. (Horne, Grant & Verghese 2009 as cited in Judson, 2012).

More attention is paid to the adaptive reuse of buildings in general and heritage buildings in particular. Many buildings have lost their main functionalities and could be adapted to accommodate new functions. Burra Chapter defines adaptation as" changing a place to suit the existing use or a proposed use". The adaptation should only be made with minimal alteration to the original fabric after other options have been discussed (The Burra Charter, 2013). Unfortunately, CH buildings may fall short of today's expected standards in comparison to new buildings. They face problems such as low thermal resistance value, lack of insulation, high level of air infiltration, or maintenance issues that can affect all of the previously mentioned problems.

We are streaming toward the design of net zero carbon emission buildings through the use of innovative materials that lead to lower energy consumption. Nevertheless, the threat of conservation of the built cultural heritage through adaptive reuse is a maladaptation of the CH, due to inappropriate works to upgrade energy efficiency, damaging the original fabric of the structure. Therefore, enhancing the building's performance is essential and achievable with innovative materials produced today. Despite such interventions, to identify and preserve the authenticity of the built heritage and its values we are obliged to follow certain principles and guidelines.

According to ISCARSAH[1], to identify cultural heritage values, a multidisciplinary team of experts including architects, engineers, archeologists, and historians is essential. Authenticity and heritage values play a pivotal role in determining tangible and intangible aspects. In the case of tangible cultural heritage, also known as architectural heritage, key elements that contribute to its heritage value include geometry, materials, overall structural arrangement, construction details, and connections, as well as the environment of the monument. Character-defining elements such as imperfections and alterations of the monuments should be respected in case they don't jeopardize the structure's safety or impact the structure's durability. The intangible values of built heritage structures equally contribute to the character-defining elements of a structure. The construction tradition and techniques, structural concepts, and their original use and function are the sources of evidence of ancient knowledge and technology. Thus, "minimum intervention" is a crucial concept that ISCARSAH guidelines refer to. Minimum intervention combines the best possible protection and enhancement of heritage values while respecting the structure's authenticity (Roca, 2020).

4. Methodology

To achieve successful results, an extensive set of analyses must be completed, from the field survey to laboratory experiments. However, to gain an understanding and knowledge of this specific topic, the relevant literature has to be studied thoroughly.

To complete a successful intervention in the adaptive reuse of the CH buildings, creating a complete architectural survey is a necessary first step. The survey includes a description of the history of the region when the building was built and the geo-political context of the region with insight into the area's inhabitants, traditions, and conflicts. Comprehensive research on construction methods and materials traditions will provide insight into the building parameters, such as the significance of the building in historical, cultural, or architectural terms, structural aspects, and construction methods. It is important to recognize the building's phases of construction - the building's stratigraphy so that the sampled material is representative and relevant to the research. This is especially crucial for research where the diversity of historical material and period is present, as we have in the Medieval town of Rhodes. To obtain the answers we are looking for, laboratory analysis is required, which means the sampling survey has to be conducted prior to the test. The sampling process has to be kept to a minimum. The needed quality and quantity of the sample will depend on the chosen analytical method (Hughes & Callebaut, n.d.).

Based on the results of the analysis, the mortars will be classified according to the building phases, their composition, and condition (Hughes & Callebaut, n.d.). The classification of the historic mortars was done and brought to us by RILEM. The mortars were categorized based on two main aspects - as a function of their technological application and as a function of the nature of their binder. Following this categorization, the historic mortars selected for the analysis will be classified. According to their technological application recognized as mortars for plasters, application of facing (pavement/floors, other architectural elements), mortars for decoration, and masonry mortars (bedding, painting, sealing, stiletto work). The second categorization is according to the nature of the binder: mortars based on lime, based on lime and pozzolanic material, based on the hydraulic binder, based on clay binders, based on organic binders (Groot, n.d.). This categorization will be used to organize the results of the analysis of the historic mortar. Additionally, another categorization will be done, according to the grain size of the aggregate. To obtain the necessary data for the mortars' classification, the selected laboratory analysis had to be performed. It is essential to use a combination of techniques since each technique provides only a partial picture of the comprehensive characterization. An example of the selected analytic techniques is the SEM analysis, which provides a clear view of the microstructure of the mortar sample as well as its chemical composition. The professional background and experience of the researcher are essential in choosing the proper technique (Groot et al., n.d.).

The experimental part of the research will deal with the recreation of the historic fabric for the conservation of the historic structure with the implementation of innovative material in the function of improving the material properties. A sample collected from the structure was selected as a representative case study and analyzed. Following its characterization, it will be recreated in a combination of innovative compatible materials? that will potentially upgrade the performance of the traditional materials.

Besides the material properties, the emphasis will also be on the compatibility of the newly developed material with the original fabric of the historic structure. Today‘s building material market is abundant in eco-friendly building solutions. The new technologies use organic-based materials such as "Hempcrete" or cement-based on bacteria (*Biomason*). The study intends to implement these solutions into the traditional ones and perform a comparative analysis of the newly developed materials and the traditional ones. The material properties that include thermal conductivity, and durability, as well as the energy released during the manufacturing of the mortar, will be observed.

5. Conclusions

The exploration of Rhodes' architectural and construction legacy, spanning from the city's founding in 408 BC to its diverse cultural periods, offers a thorough basis for comprehending the development of building technologies within this area. The Dodecanese islands present a singular opportunity to investigate the evolution of building techniques over centuries, given the collision of Eastern and Western traditions.

Rhodes Island's built environment has an indelible mark of a rich history shaped by a diversity of cultural influences. This research reveals the powerful role mortars play in the longevity and resilience of historic structures through a thorough investigation of mortars and their characteristics.

The study aims to incorporate modern solutions while also providing insight into conventional mortar technologies, which could completely transform sustainable building methods. The endeavor holds importance as it has the potential to improve heritage building performance, which in turn minimizes environmental impact and energy losses. This strategy adheres to the minimal intervention conservation philosophy, which emphasizes maintaining authenticity while improving a building's attributes.

Also, emphasizes how crucial authenticity and heritage values are to conservation efforts. The application of life cycle assessment (LCA) techniques points out the environmental advantages of adaptive reuse by showing that heritage buildings offer significant reductions in energy consumption and environmental impact in addition to their historical and cultural significance. With the application of more sustainable approaches in the field of conservation technology, on the representative buildings in the Medieval town of Rhodes, the research explores different ways to close the gap between cutting-edge materials and conventional building methods. In summary, we take a big step towards a future where heritage buildings are not only preserved but also act as models of sustainable development by fusing the knowledge of the past with the innovation of the present.

Endnotes

1. The International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage (ISCARSAH) is a technical committee of the International Council on Monuments and Sites (ICOMOS)(ISCARSAH, n.d.)

Author

Milica has obtained her BA and MA degrees in Architecture at the University of Belgrade. In 2022, she finished her Advanced Master's studies in the field of Structural Analysis of Monuments and Historical Structures.
Currently, Milica is PhD candidate, holding an MSCA-ITN ESR fellowship (https://place-itn.cyi.ac.cy). Her research targets the technological changes of mortars in the south-eastern Mediterranean area, focusing on the Dodecanese islands and Crete. It is anticipated that the detailed study of traditional mortar technologies can provide valuable knowledge of the design and materials used, which if adopted in modern production, may contribute towards sustainability. Therefore, the overall objective of her research is to understand the main cultural interactions and their impact on architecture, especially on the technological development of mortars. Through comparative studies and assessment, it will be possible to trace the evolution of building techniques and technological solutions expressed in the mortars' composition and physicochemical properties. The systematic study of mortars will provide a deeper insight into how the change of civilizations in this territory altered mortar composition, the modification of their performance properties, and the motivation behind it.

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