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THE CHALLENGE OF A SUCCESSFUL MORTAR INTERVENTION IN HISTORICAL BUILDINGS

ABSTRACT

Modern societies can understand the value of preserving their cultural heritage in order to safeguard their history but also to ensure the future of generations to come. Nowadays, scientists and conservators can exploit the accumulated experience from many case studies performed to learn from the past and improve this knowledge. New challenges can be incorporated into the consideration of successful intervention in historical structures, such as sustainability issues and circular economy. The methodology applied to the analysis and application of compatible mortars should be based on scientific criteria, while norms and nomographs should be formed to ensure the precision of the works. Cooperation between different disciplines remains the key factor in the success of these efforts.

KEYWORDS: HISTORIC STRUCTURES, MORTARS, SUSTAINABILITY, COMPATIBILITY, METHODOLOGY.

INTRODUCTION

Historical buildings comprise a great number of different structures, which include many values, and their protection is essential for our civilization. They are structures listed individually in the national registers of historical monuments, sites or places and manifests of significant value (i.e., historical, artistic, cultural, social or economic). These structures can inspire and teach new generations while they connect the past and the future of humanity. They constitute a countless number of different types of constructions dated from prehistory to present, making them a real treasury of human civilization. According to Burman (Burman 2001), their survival is essential to the spiritual, emotional and economic well-being of humans. Preservation of such buildings is a global challenge as these remaining structures highlight our past (culture, religion, civilization) but they also teach morals for the generations to come. Today, in modern societies they are artistic, cultural as well as economic poles. During their lifespan, many of them require maintenance as the materials age, but they also suffer the effects of different events such as earthquakes, floods or even fires. The problem has grown bigger during the last decades, with climatic changes becoming more severe.

Old structures built under different social and technological status should be protected so that they can be adapted to new requirements. The principles under which any interventions should be done in these buildings are described in Charts and Declarations (Venice Chapter in 1964 - ICOMOS 1964; Nara Document on Authenticity in 1994 - ICOMOS 1994), which recommend the use of compatible to the authentic materials. The increasing awareness of society about safeguarding heritage buildings and at the same time protecting the environment promotes strategies of combining principles of restoration with environmentally friendly materials and techniques.

Society's awareness about heritage structure preservation has increased globally because of the higher recognition of the "values" associated with social changes and the economic value of cultural tourism. The value of a monumental structure or area is increased after its preservation. Therefore, strategic policies of preserving built heritage have been promoted, including the development of seismic strengthening measures, and the establishment of regulatory frameworks and management systems. Technological advances in this field have fuelled the market with many innovative materials and techniques or even new concepts of confronting seismic risk. The preservation of these structures concerns both life expectancy and protection from collapse as a result of earthquakes in seismic regions, or from other natural or anthropogenic disasters (Lourenço 2006). The former is closely related to the conservation/consolidation from decay phenomena due to the ageing effects of the environmental impact on buildings. Collapses are most often attributed to the inherent inadequacy of historical masonry structural systems when required to bear horizontal loads.

The great diversity in the typology of the masonry of historical structures due to the various components, techniques of construction, morphology, type of reinforcement and functionality makes their study, in terms of time and cost, challenging. The approach to preserving a structure of high value needs to follow guidelines defined by the Charts and regulations and should aim to retain the authentic parts of the structures. These structures need appropriate high-quality interventions to ensure satisfactory long-term performance and aesthetic continuity. The demanding sustainability is mainly driven by environmental and economic reasons. In parallel, many of these structures can change their use and continue to serve in a society with an active role.

CONSERVATION UNDER THE PRISM OF SUSTAINABILITY

Historical structures were usually load bearing masonries made of brick, stone, wood and mortar. These materials were usually locally sourced and were combined in a variety of different ways. These buildings have proved their sustainability as a result of the principles used for their construction and their long-lasting performance.

Figure 1. Historical structure of Hagia Sophia (Greece), Thessaloniki, 6th century AD (photo by the author).

During the second half of the 20th century, a lot of research was performed in order to propose solutions for the restoration and rehabilitation of historical structures.

Figure 1 shows some typical Byzantine masonry with thick mortar joints (the thickness of the joints is almost equal to that of the bricks). The pathology of this masonry is restricted to small cracks (in the joints but also in the bricks) while loss of material can be seen at the edges of the mortar. The dawn of the 21st century brought an acute climatic problem. In light of this, research into compatible restoration mortars incorporated new ideas based on recycling principles and circular economy. One of the problems arising is that of the repair materials that have to fulfil the criterion of compatibility with those already existing in the structure, the old building materials. Many studies have been made concerning the parameters that can be tested to produce strong, durable and compatible new repair materials.

Figure 2 shows an example of a worksite at a Roman site in Dion. The application of compatible mortars based on lime and natural pozzolan

Figure 2. Restored masonry of a Roman site (Dion- Greece) (photos by the author).

(Figure 2 - top) as well as lime-based grouts to strengthen the masonry (Figure 2 - bottom) is indicated.

To understand the behaviour of the structure it is essential to find the role of the materials used, such as the mortars, or to characterise their type according to their use. It is also required to investigate the mechanisms of the decay and determine the grade of deterioration. The possibility of producing repair mortars incorporating secondary materials was tested by different scholars in previous years. The alternative material tested was recycled fine aggregate originating from mixed construction and demolition waste, bio-fibres, artificial pozzolans, plastics etc. (Stefanidou *et al.* 2014; Stefanidou *et al.* 2021; Safi *et al.* 2013). The results, despite restrictions, have had a positive outcome in most cases. In this way, a new era of utilising waste in repair mortars is in line with the new demand for sustainable construction, without jeopardising the integrity and authenticity of historical buildings (Taglieri *et al.* 2017). In the case of mortars, traditional binders such as air lime, natural pozzolans, brick dust and clay have been been combined successfully for the above-mentioned reason (Papayianni and Stefanidou 2007; Schafer and Hilsdorf 1993).

RESEARCH OF HISTORICAL MORTARS AS A BASIS FOR THE DESIGN OF REPAIR MORTARS

Knowledge about old techniques, materials and their performance, represents a solid foundation for conservation decisions (Álvarez 2020: 944; Talib *et al.* 2023; Schueremans *et al.* 2011: 4338-4339). Maintenance works include a series of complex actions and methods, the suitability of which is checked in the laboratory, but also with on-site test applications, which lead to an understanding of the problems and the design of the solutions required in each case.

Restoration respects the authentic character of the monuments, in all their historical transformations and is based on scientific studies. The character of the monument includes the matter, which is inherent in its image and its aesthetic character. The materials incorporated represent the technology of a different era. The restoration materials must be of high quality, compatible with the construction material of the monument and distinguishable from the original historical materials. The term anastylosis refers to the complex work of restoring structures, which consist of independent architectural members and mainly includes the integration, in their original position, of existing members. The completeness of the operation is determined by the completeness of the documentation, the experience of the involved specialties and the quantity and quality of the new materials that are added to the construction.

A triple helix can be considered for any intervention works and includes the design and use of repair mortars: suitable materials selected, the environment under which the structure serves and the techniques used for the material application (**Figure 3**).

During previous decades, research on historical materials and structures has been focused on:

- An understanding of the performance of the components (binding materials, aggregates and additives).
- The elucidation of the old recipes and the methods of application to broaden the historical background on these previous cultures and to support the decision making for preservation.
- The technological characteristics of the mortars (the ratios and quality of the different raw materials, the application procedures, the characteristics of the substrates, and the specific climatic conditions), for ancient materials as well as for the repair ones.
- The durability of the materials under different surroundings (environmental factors, pollution and weather conditions).
- The incorporation of by-products in the mortars' composition without altering the basic properties and retaining the compatibility qualities.
- The methods of testing the different properties, their reliability and practical implementation (in situ and in lab conditions).
- The design and choice of the most suitable repair materials and the monitoring of their effectiveness.

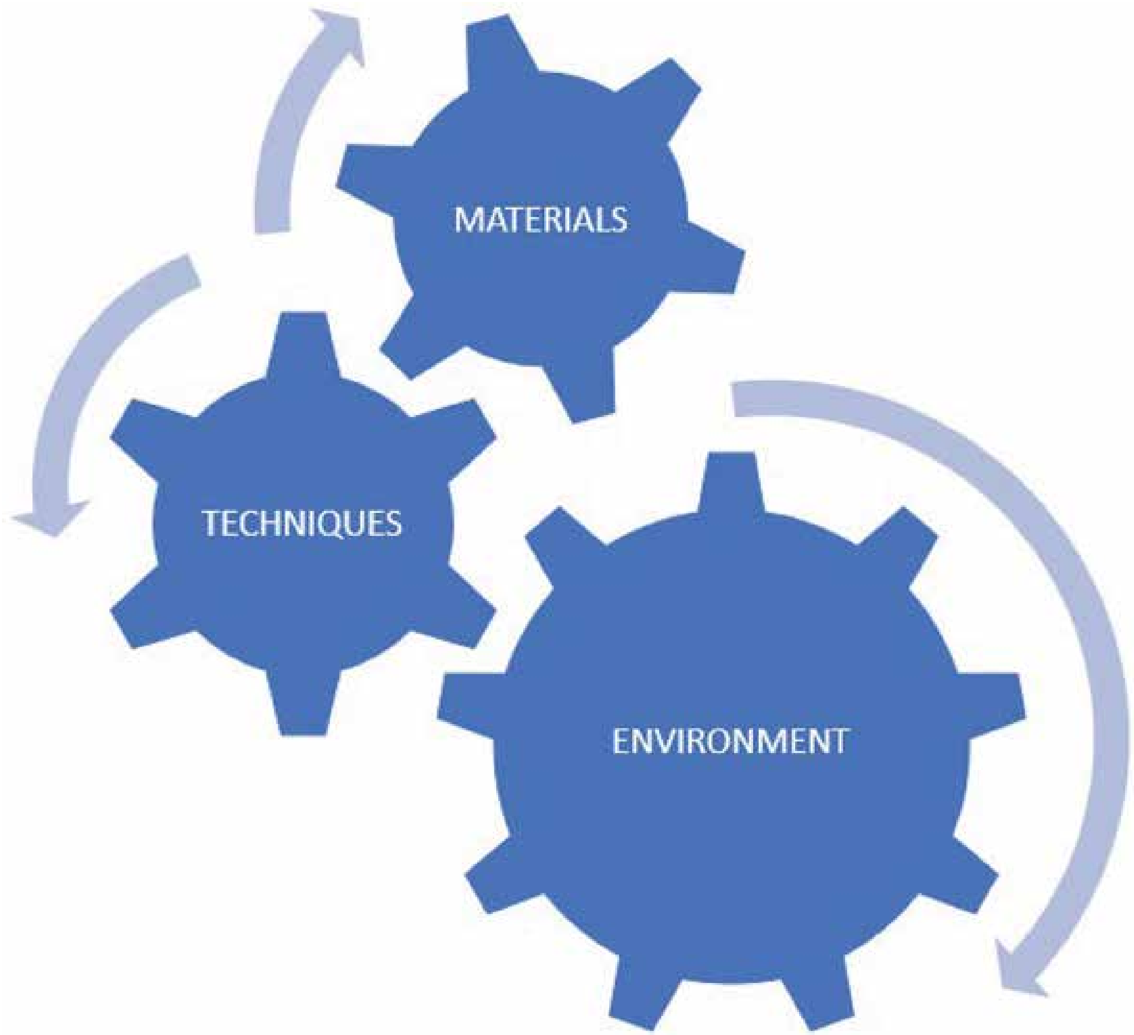

Figure 3. Parameters under consideration for mortar intervention (scheme made by the author).

The most common building material pathology symptoms are cracks, efflorescence, spalling, deformations, de-colorization, flaking, and depositions. Health monitoring of historical structures by integrating technologies can assist the understanding of the existing situation in synergy with optical observations in order to map the existing situation during restoration operations.

COMPATIBILITY ISSUES

The widely accepted concept of compatibility between an existing structure and new repair materials has not been clarified in technical terms up to now. The criteria for the suitability of the raw materials used for manufacturing these materials are not adequate or well defined. There are no constitutional laws or basic relationships concerning the parameters that influence their performance. A manual of practice, including recommendations, instructions and simplified methods of checking, in situ, the manufacture and application of these mortars is necessary in restoration works. The lack of such a manual has a direct impact on the quality and cost of restoration work. Inappropriate repair mortar (not well designed and applied) results in additional loss of the original structure or aggravation of its pathology, which will require an additional repair intervention. In **Figure 4** a problematic intervention on masonry using cement-based materials is indicated. The result, beyond the aesthetic incompatibility, is also problematic in terms of functionality. It seems that

Figure 4. Problematic interventions with cement-based materials (photo by the author).

the decay of the authentic material is accelerated, while the impermeable cement remains.

In general, the cost of repairing monuments and historical buildings is much more than that of modern structures. Specific materials are not often available in the market (they are manufactured to order) and specialised technicians are needed for these works. In most cases of restoration projects, a study of the existing materials is not foreseen in the budget, or the cost allocation is very limited. Additionally, there are not many laboratories or research institutes that are able to undertake studies of this type. With regard to designing repair mortars, each laboratory or research centre follows its own methodology based on its previous experience. There are no protocols of repairing historical buildings and the situation is becoming increasingly urgent as each of these structures is unique. Monitoring systems by which the behaviour of repair mortars could be recorded do not exist in the field of restoration.

Almost in all preventive interventions, repair mortars are used. Despite the wide-ranging research and case studies that have been performed, there is still a gap between knowledge and practice in the conservation of monumental heritage. The design of lime-based repair mortar could be based on a scientific footing if a set of nomographs, regulations and a manual of practice were to be developed for users. There is also a need for the establishment of appropriate infrastructure in laboratories of the private and public sector for testing repair mortars. By following this policy, a direct impact could be made on both the cost and quality of repair works.

Some of the characteristics that distinguish the to-date resistant old lime-based mortars from the modern cement-based mortars (Papayianni and Stefanidou 2007: 356; Stefanidou and Papayianni 2005: 915; Papayianni *et al.* 2013: 89) are:

- Low apparent specific density (1.5 – 1.8);
- High porosity (20-40%);
- Low water retentivity and quick drying;
- High degree of compaction;
- Very good bond with substrate;
- Well crystallised matrix;
- Low compressive strength (<3MPa).

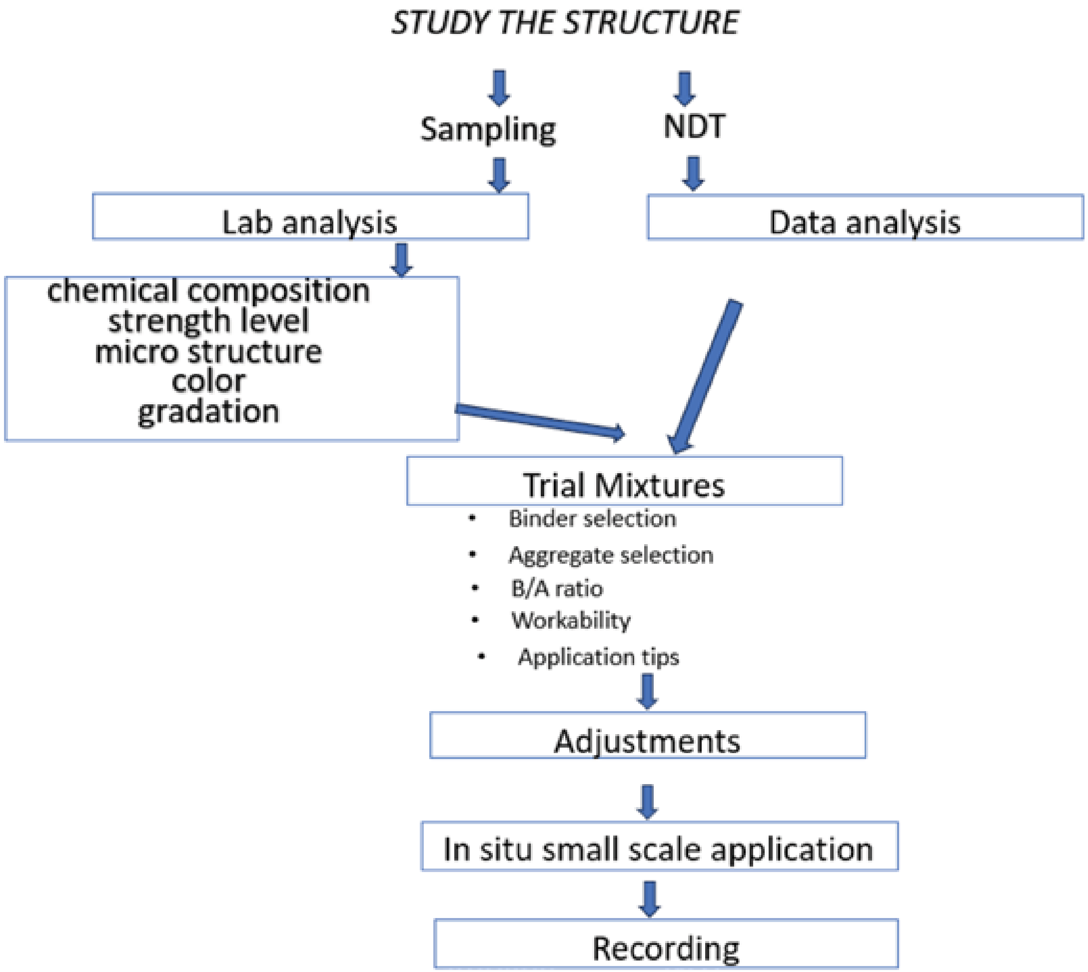

Figure 5. Schematic representation of the workflow (scheme devised by the author).

The pieces of information taken from the analysis of existing mortar (**Figure 5**) are: The type of binder; more than 40% content of CaO indicates lime mortar. An adequate quantity of reactive silica content usually implies a hydraulic component. For repair mortars, the quality of existing air lime is a significant topic that should also be taken into account (Veiga 2017: 133-136). The mineralogical origin of aggregates; their gradation and max aggregate size are parameters taken into account for the design of repair mortars. An estimation of strength level, based on site or laboratory measurements, is also a factor under consideration. Decisions are taken based on:

- the binding system. Here, among other things such as the fineness and the colour, we consider the environmental background (resource availability) and the reactivity of available raw materials.
- the aggregates retaining the characteristics of origin, such as max size and granulometry. An improvement of gradation is possible to be made.
- the water quantity (determined according to the workability desired).
- the additives used for improving fresh/hardened properties (plasticity, porosity and strength).

The suitability of raw materials is tested in terms of physical chemical and, recently, on criteria based on sustainability. Afterwards, trial mixtures are made in the laboratory and the specimens are tested. Colour, strength and porosity are measured and some durability tests are carried out if necessary (exposition in different ageing environments) (**Figure 5**). Sometimes, a pilot application on site is suggested for in situ adaptations.

During this procedure, a compatible material is defined based on the aesthetic harmonisation with the old structure without disturbing the behaviour of the original structure (in terms of hygroscopic, mechanical, structural, thermal and physical behaviour). At the same time, it should be effective (adequate early strength is developed for the work to progress) under the specific environmental conditions and it should be as resistant as possible to the mechanisms of deterioration.

The addition of a hydraulic component (pozzolan or a small amount of white cement) increases the strength and decreases the porosity. The quality (pozzolanicity) and the fineness of the pozzolan may increase the early and final strength considerably. The addition of up to 20% of white cement does not significantly decrease the porosity while increasing early strength (Papayianni *et al.* 2013: 88-92). Regarding the role of aggregates, care should be taken to synthesise an even aggregate gradation. The influence of aggregate content and of the binder/aggregate ratio on strength development of soft lime mortars is greater than that of lime-pozzolan mortars. This has been attributed to the weak transition zone created by large granules. The most important role of aggregates seems to be the decrease of creep and shrinkage deformation and the blocking of crack propagation which results in the stability of mortar volume. Compaction during application could significantly improve the strength and related properties of mortar. In field works, compacted mortar shows three times higher values of strength than that without compactness. Finally, the curing regime and period constitute a problem, especially for mixed type binding systems (Stefanidou and Papayianni 2005; Papayianni and Stefanidou 2007).

CONCLUSION

Intervention in historical structures is often a necessary procedure aimed at maintaining the structure and the mortars included in it. External factors (environmental issues) as well as inherent weakness (material issues) can act synergistically (or not) resulting in the urgent need for measures to ensure the safety of the structures. During previous decades, a lot of experience has been accumulated through different case studies where a variety of challenges had to be overcome. Many relevant papers have been published, and cooperation among researchers has assisted with the process of finding solutions. New challenges (such as the climatic crisis) should also be taken into consideration when developing intervention policies. Best practices have already been applied and cooperation among different disciplines, as well as among research teams, can provide effective solutions in the face of the many challenges that have arisen globally regarding these complicated issues of intervention regarding historical mortars and structures in general. Successful interventions are of benefit to both the buildings and modern societies.

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REZIME

IZAZOV USPEŠNE PRIMENE MALTERA U ISTORIJSKIM GRAĐEVINAMA

KLJUČNE REČI: ISTORIJSKE STRUKTURE, MALTERI, ODRŽIVOST, KOMPATIBILNOST, METODOLOGIJA.

Sprovođenje tehničkih intervencija nad istorijskim građenim strukturama je često neophodno i podrazumeva različite postupke koji imaju za cilj da se ove strukture sačuvaju. Među njima se nalaze i oni vezani za pripremu i primenu maltera za konzervaciju.

Metodologija istraživanja istorijskih maltera i primene kompatibilnih maltera za konzervaciju bi trebalo da se zasniva na naučnim kriterijumima, a od izuzetne važnosti je i postojanje normativa u izvođenju samih radova na istorijskim strukturama. U planiranje uspešne intervencije u ovim strukturama danas su uključeni i novi izazovi, kao što su pitanja održivosti i cirkularna ekonomija.

Istraživači i konzervatori danas imaju mogućnost da iskoriste akumulirano iskustvo iz mnogobrojnih sprovedenih studija o istorijskim građevinama, kako bi učili iz prošlosti. Saradnja između pripadnika različitih naučnih i stručnih disciplina je ključni faktor uspeha u procesima očuvanja istorijskih građevina. Ova saradnja, uz vezu među istraživačkim timovima, može biti jedno od bezbednih rešenja za suočavanje sa svim izazovima koji se javljaju u složenim pitanjima intervencija vezanih za istorijske građevine, među kojima su i one koje podrazumevaju izradu maltera za konzervaciju, kako bi građevine bile sačuvane za buduće generacije.

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